A TELEVISION/COMPUTER SYSTEM FOR HUMAN LOCOMOTION ANALYSIS

Thesis presented for the degree of Doctor of Philosophy

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To my Parents and Mary

Summary

The literature review, Chapter One, is in three parts. The first part concerns the development of locomotion analysis, placing particular emphasis on the methods of measurement used. The second part is a review of kinematic measurement systems in which the attributes and limitations of each method are fully discussed. The final part of the review describes other television/computer systems that have been used or developed for locomotion measurement and discusses the limitations of these systems.

Chapter Two discusses methods of detecting the spatial position of body segments using a television camera and justifies the use of a passive marker system to indicate anatomical landmarks. A suitable material for markers and its response is described. Methods of identifying the signals produced by the markers in the camera video output are suggested, and the circuits for the marker detectors used are presented.

The principles of operation of a television/computer interface designed to generate the spatial co-ordinates of markers are described in Chapter Three. A simple scheme to obtain these co-ordinates is first of all presented and the limitations of this method are shown and used to justify the development of a more complex digital system. A description is presented of the functional elements of this system, which generates the co-ordinates of markers detected in the video signals from up to six television cameras. The basic principles of television referred to in this chapter will be found in Appendix Al; similarly those aspects of the PDP 12 computer system which directly concern the interface are described in Appendix A2.

Chapter Four presents the logic of the interface in the form of a description and a set of logic drawings. The nomenclature used to describe the logic is first of all discussed and then a detailed description with the aid of timing diagrams and tables is presented for each drawing.

Computer programming of the interface is described in Chapter Five The instruction set created to control the interface is listed, and two programming examples are provided to show how the instruction set may be used. A method of decoding the interface data, to relate the co-ordinates to the camera

which generated them, is also presented. A summary of the computer software written and listed in Appendix A3 is given.

Chapter Six describes how the system was tested in all aspects of its design and in its suitability for human locomotion measurement. Errors and methods of calibrating the data are discussed. The co-ordinates generated by the interface for the trajectories of markers placed on a walking subject are presented and a means of identifying markers from co-ordinate data is described. Some modifications to the basic design are suggested to give improved performance. The performance of the system is summarised and comparisons are made with other methods. Clinical and other applications of the system are discussed and recommendations for future work are given.

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CONTENTS

CHAPTER I

REVIEW OF THE LITERATURE

1.1 Introduction

It is the purpose of this chapter to review the literature concerning the development of locomotion analysis, the different types of kinematic measurement systems and television/computer systems.

1.2 Development of Locomotion Analysis

Scientific enquiry into the nature of human locomotion has a history extending back to the time of Ancient Greece. Aristotle (384-322 BC) described the actions of muscles and subjected them to a geometrical analysis. Leonardo da Vinci (1452-1519) described the mechanics of the body in standing, walking up and down hill, rising from sitting, and jumping. William Harvey, in his notes "De Motu Locali Animalium" (Harvey (1627)), frequently refers to the work of Aristotle when discussing the relative motions of body segments. In these notes Harvey also stresses the function of the antagonistic action of muscles in modulating movement. Typical of these philosophers was the great range of their studies. Harvey was no exception, and his reference to the kinds of gait in man resembling that of a duck, a crane, a crow etc. were not facetious comments but typical of the way in which he drew his illustrations from every kind of animal life which he had studied. Borelli (1680) described forward motion as the projection of the centre of gravity of the body and consequent loss of stability which was regained by swinging the limb through. Borelli considered the skeleton as a system of levers and again did not confine his studies to humans, as Figure 1.1 shows.

The Weber brothers (1836) were perhaps the first to attempt some quantitative measurement of locomotion. They used measuring lines and evolved a theory which considered the swing phase of gait as a pure pendulum. This theory was later repudiated by Fischer (1895-1904). Carlet (1872) investigated human walking using a pneumatic system of recording displacements of parts of the body, foot pressure and periods of muscular activity. The test subjects were constrained to walk in a circle around the recording equipment.

It was not until the advent of photography that significant advances in quantifying locomotion were made. Muybridge (1882), in America, demonstrated

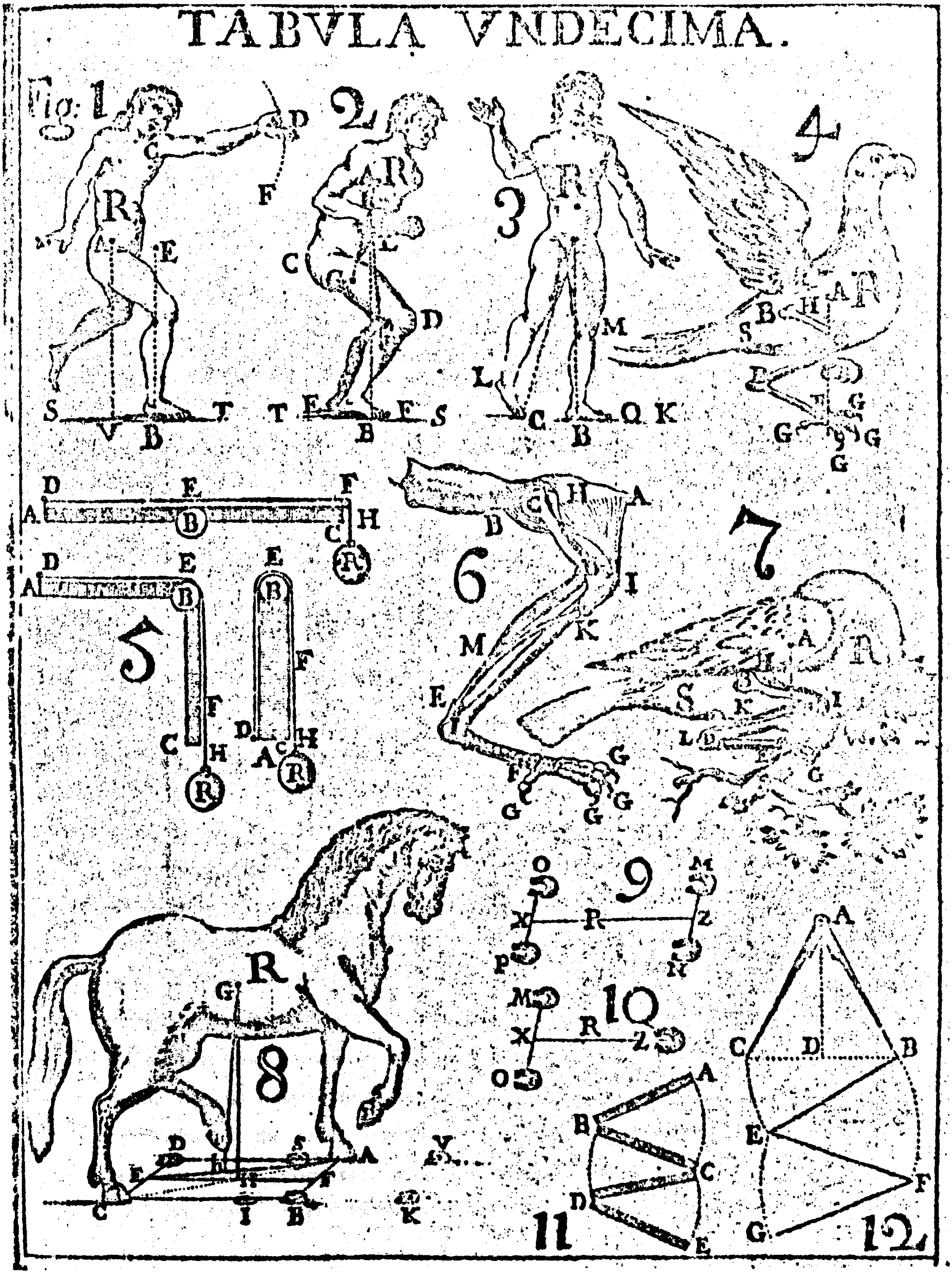


Figure 1.1. Plate from Borelli (1680).

the ability of the photographic system to arrest motion. He used 24 fixed cameras and two portable batteries of 12 cameras each to photograph animals and people in action. Investigations were performed on human subjects walking, running, rising from the sitting position and various other activities. The serial photographs were combined and used to show a slow motion moving picture of the recorded event. In some of the studies the background was divided into squares to allow a quantitative estimation to be made of the displacements of various parts of the body. The photographic technique was further adapted and improved by Marey (1895). His technique was to use a single plate camera which had a rotating disc with slits mounted in front of the lens. The subject was dressed in black and the limbs and joints were marked with shiny strips and bright buttons. The tests were carried out in bright sunlight and a "stick" diagram of the subjects motion was recorded on the plate, Figures 1.2 and 1.3. This technique, known as chronophotography, is still in use in various forms today.

Fischer (1895-1904) was the first to perform a comprehensive analysis of three dimensional movements of parts of the human body. In these investigations the subject was dressed in black and carried incandescent light tubes strapped to the various segments of the body. The subject walked in a darkened room in the view of four plate cameras; the plates being exposed at a constant cyclic rate. The exposed images of the tubes on the plate gave stick diagrams representing the successive positions of body segments. Measurements from these plates were corrected to eliminate errors due to perspective, which was complicated by the layout of the cameras. Two of the cameras were perpendicular to the axis of progression (one on each side) and the other two were positioned obliquely at 30° to the line of progression to obtain the frontal view. The information was analysed to obtain displacement, velocity and acceleration curves against time in three dimensions. This data together with data collected by Fischer on the mass properties of the body segments was used to calculate resultant forces acting on the centres of gravity of the segments. Fischer's work has been referred to by all subsequent investigators and his findings largely conditioned the mechanical design of external prostheses for the first half of this century.

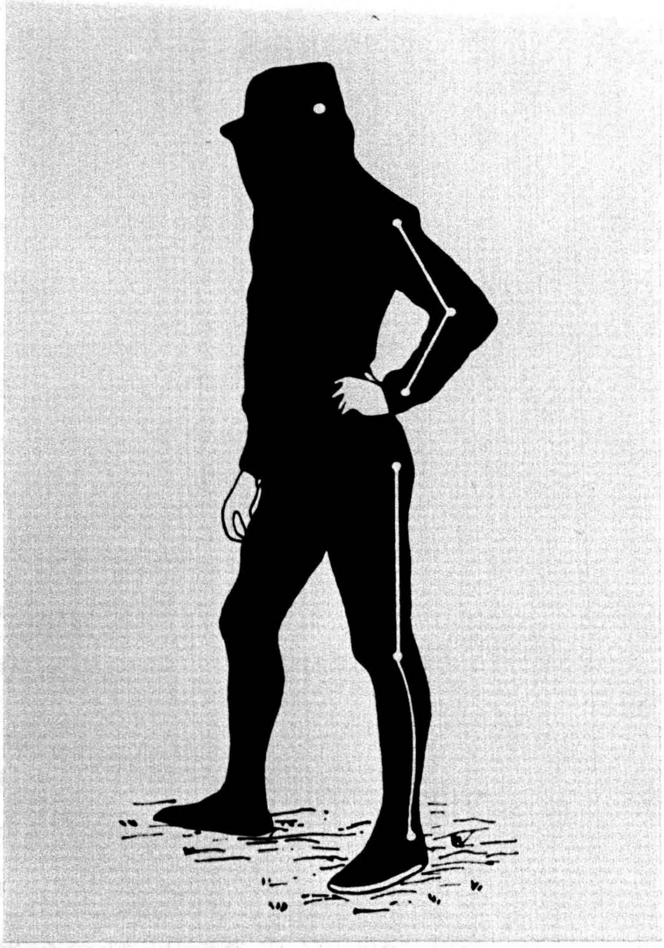


Figure 1.2. One of Marey's subjects dressed for photography (From Bernstein (1967)).

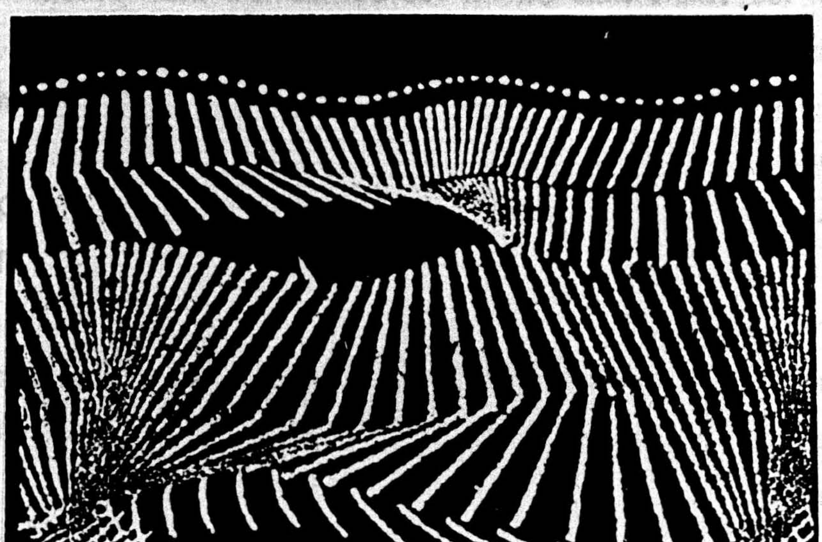


Figure 1.3. Stick diagram produced by Marey's technique (From Bernstein (1967)).

Amar (1916) extended Fischer's work by developing an instrument which measured three components of ground to foot force. This "force plate" was of purely mechanical design, spring deflections indicating the applied forces. Investigations into the gait of subjects wearing external prostheses were made, and the results were used to suggest improvements in prosthetic design. Elftman (1938) also designed a mechanical force plate, in which the spring deflections were recorded by a high speed cine camera, which also recorded the position of the foot in one plane. Elftman (1939) extended his work to study the planar kinetics of the leg, using the force plate to measure stance phase forces and cine photography to measure displacements. As recording techniques improved investigators attempted to look for finer details in the recorded patterns of locomotion. Bernstein (1940) used chronophotography with repeated exposure rates from 60 to 190/sec and claimed that small details in the patterns of motion, in the derived curves of force etc., were common to all normals in locomotion. In the waveforms of the horizontal component of force acting on the centre of gravity of the thigh he claimed to observe, consistently, 10 distinct features in one cycle - Figure 1.4. Studies were made of the development of running technique in children using chronophotography, as well as many other types of movement. Data on the segment mass parameters of the body was also collected by Bernstein (1934) from studies of 150 live subjects. Most of Bernstein's work was carried out in two dimensions, but he did some tests in 3 dimensions by means of stereo photography (using a mirror to provide the second image).

A major landmark in locomotion analysis was the research carried out by the College of Engineering and the Medical School of the University of California, Berkeley. Their report, University of California (1947), covers a wide range of work, and provides much original information about the characteristics of human locomotion in the normal and in the amputee. Their studies provided data on the rotations of the lower limb segments about their long axes, Levens (1948). This data was obtained by making measurements of the spatial position of stainless steel pins which were inserted into bony prominences of the limb, from the recordings of three 35 mm cine cameras. Two dimensional

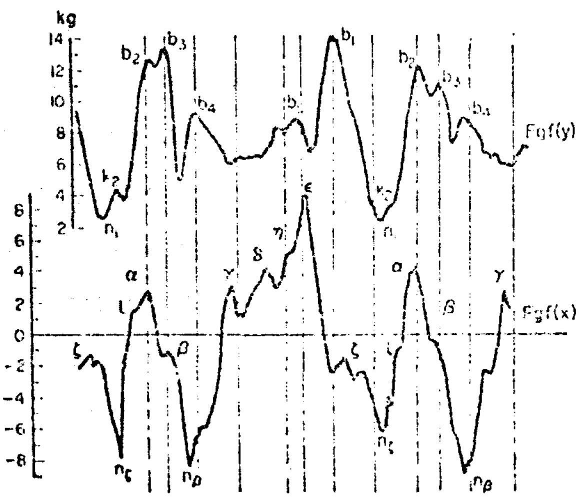


Figure 1.4. Force curves at the centre of gravity of the thigh in normal walking used by Bernstein to illustrate distinctive features during the walking cycle. Above: vertical components. Below: horizontal components. (From Bernstein (1967)).

studies of motion were made using interrupted light techniques, and three dimensional measurements were made with cine cameras. One of the principal advances made by the California group was the development of a force plate which could measure the six quantities necessary to define the resultant force actions transmitted between ground and foot during walking. The objectives of these studies were "l) to gain an accurate knowledge of the functions of components (of the body), so that repair techniques could be improved, 2) to form the basis of physiotherapy treatment, 3) to provide design parameters for external support devices and limb replacements". Figure 1.5 shows a part of the experimental set up.

Details of the labour involved in the University of California studies are contained in Bresler and Frankel (1950). In this paper it is revealed that to calculate the external forces and moments in the leg during normal level walking some 14,000 numerical calculations were made, 72 curves were plotted, and 24 curves were subjected to graphical differentiation for only one stride. The calculations were performed on desk calculators and the data processing for the first subject took 500 man hours, this was reduced to 250 man hours for the fourth (last) subject.

In a historical review of gait analysis Steindler (1953) claimed that "kinetic analysis of gait reveals and enlightens many situations concerning the practising physician....", also that it had "....become apparent that the kinetic analysis of gait has developed into a guide for clinical practice and an effective adviser in difficult and controversial situations....". The colossal manual effort involved in a proper kinetic analysis of gait certainly precluded its use in a clinical situation, and restricted the number of tests that could be made for research studies; hence the results of such studies needed to be treated with caution if they were to be applied to other subjects.

Saunders et al (1953) proposed, on the basis of the University of California's research, that locomotion is fundamentally the translation of the centre of gravity of the body through space along a pathway requiring the least expenditure of energy. Six factors which had a major influence on this motion were identified:- rotation, tilt and lateral displacement of the pelvis together with knee and hip flexion and knee/ankle interaction. Loss of any of these motions lead to

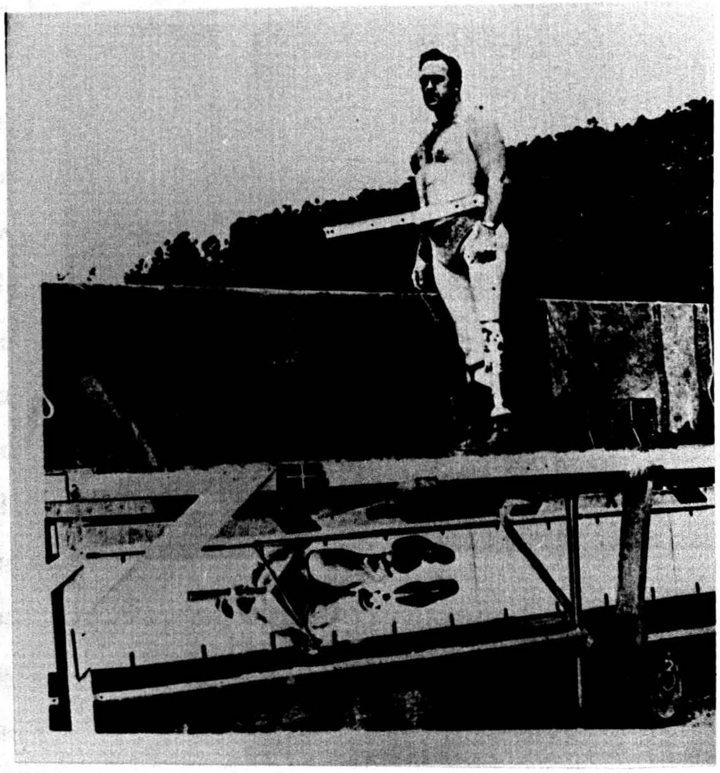


Figure 1.5. Part of the University of California's experimental set up – the glass walkway. (From University of California (1947)).

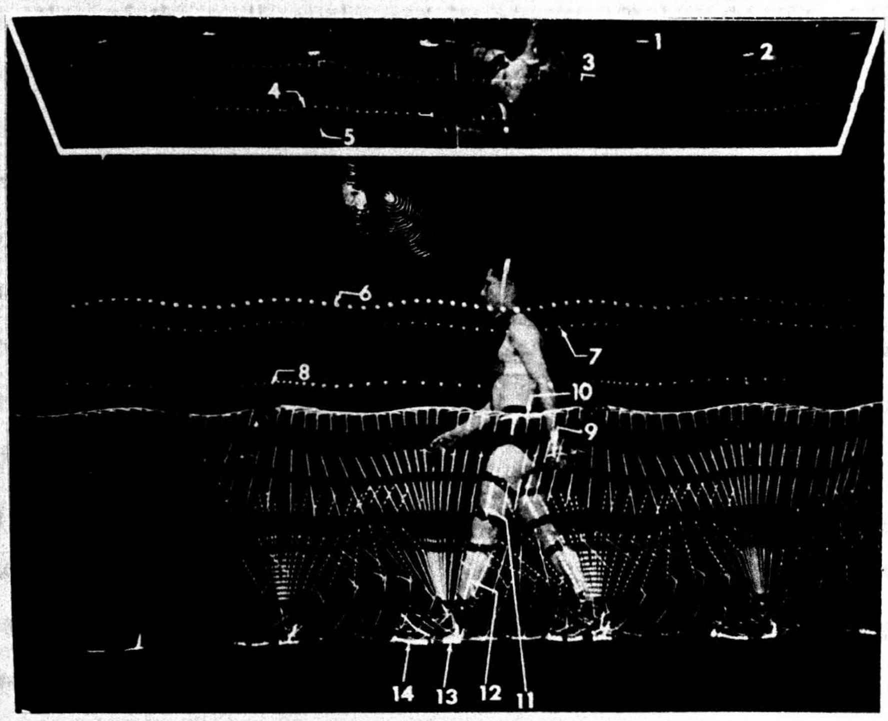


Figure 1.6. Photographic recording of locomotion as used by Murray (1964).

compensation by the others, which was reasonably effective if only one determinant was lost but the loss of two determinants lead to an increase in energy requirements of three times. The force plate and interrupted light photography were used in these particular studies, and the energies referred to were the mechanical energy requirements not the physiological energy requirements. The cadence of normal gait was compared with that of various pathological gaits by Drillis (1958). The cadence for normals was found from a sample of 936 pedestrians on a New York city street. Measurements of pathological gait were made in the laboratory using foot contact switches to record the times of the various phases of gait, and a tachograph was used to record the horizontal velocity of the trunk. More detailed studies were made using interrupted light photography at frequencies from 25 exposures/sec to 100 exposures/sec. Mention is also made in this paper of the use of 3 accelerometers to determine the acceleration of the subjects' centre of gravity, but no results are quoted.

Use was made of a stroboscope to obtain interrupted light stick diagrams by Murray (1964). 60 male subjects were analysed, measurements being made of 1) duration of the walk cycle and its phases, 2) length and width of steps and strides and foot angles, 3) saggital rotations of pelvis, hip, knee and ankle, 4) vertical, forward and lateral excursions of the head and neck, 5) transverse rotation of the pelvis and thorax, and 6) saggital excursions of the upper extremities. 14 markers were used and the subject was filmed in semi-darkness in one plane, but with an overhead mirror to provide the view of lateral movements. Figure 1.6 shows one of the photographs from which measurements were made, obviously a considerable amount of manual effort was required. Murray suggested that the results of these investigations showed the walking patterns of normal men, however although a fairly large sample was taken compared with other work the size of sample was still relatively small. The 60 subjects were split into 5 age groups, and the sample for each age group was split into three further groups by height.

The resultant force action at the human hip joint was studied by Hunt (1965) using cine cameras and a force plate similar in design to that at the University of California. During this work accelerometers were used, mounted on the shank, to check the differentiation procedures used to obtain acceleration from the cine displacement/time data. The results showed that, generally, the differentiation procedure was satisfactory and that the use of accelerometers available at that time would involve excessive complications and constriction of the test subject. Paul (1967) determined the forces transmitted by the hip joint using cine photography, force plate and EMG recordings, during normal level walking. The displacement data was obtained in three dimensions by using two cine cameras, and measurements were made over a complete gait cycle. The manual measurement of the film and force plate records, and preparation for input to a digital computer took 23 man hours. A considerable improvement over the time required for the University of California studies but still a major obstacle for this sort of study. Paul was able to compare his results with an in vivo test made by Rydell (1966) who used an instrumented femoral head prosthesis. Paul's results showed some agreement with those of Rydell, when compared on a basis of body weight and stride length. Morrison (1967) used the same experimental techniques as Paul to evaluate the forces transmitted by the knee joint. The reasons for these studies were similar to those given by the University of California group.

Grieve (1968) introduced the concept of angle/angle diagrams, in which the angles of rotation about one joint were plotted against those of another joint. This method produced closed loops which Grieve suggested provided consistent and recognisable patterns, illustrating this by showing the changes produced by different walking speeds. Data for these studies was obtained using cine film and because of this time consuming method only 13 subjects were studied. Pelzer (1969) used a variety of the available techniques to measure locomotion and also measured oxygen consumption and CO_2 production to assess the physiological energy cost of particular activities. An instrumented pylon, similar to that first used by the University of California (1947), was developed to measure directly the axial load, knee moment, anterior-posterior shear, medial-lateral shear and torque.

A study of hip joint motion in three planes was made by Johnston and Smidt (1969) using electro-goniometers. They measured extension and flexion, abduction and adduction, and internal and external rotation. Patterns of hip movement for normal subjects were presented and qualitative observations of departure from the "normal" patterns were noted in certain pathological cases. Measurements from the recordings were made manually. Kettelkamp et al (1970) followed up Johnston's work with a similar study of the knee using the same goniometer apparatus. In both studies errors arose due to the geometrical offset of the goniometer with respect to the joint centre, and due to the mobility of the soft tissues to which the goniometer was strapped.

Wirta (1970) uses a variety of techniques for his analysis – electro-goniometers, foot switches, myoelectric detectors and twin force plates, together with specialist instrumentation to measure the spatial displacement of the hips. The significant aspect of Wirta's system is his data collection method. The system records the data on magnetic tape which is then processed automatically to provide data in punched card form, suitable for input to a digital computer. However this system still involves many physical attachments to the subject and hence constrains completely free movement, as Figure 1.7 shows. Extensive use is made of a computer, as the key to a data handling system, by Lamoreux (1971). In this system an exoskeleton, Figure 1.8, is used to measure skeletal motion. This apparatus is instrumented with potentiometers as in the more normal electrogoniometer. Information from instrumentation which measured pelvic displacement and heel contact was also recorded. The collected data was digitised and stored by a computer system and the data was subsequently processed to produce parameters such as flexion-extension at the joints, relative rotation etc. which were presented graphically. All the experiments reported in this paper were based on one test subject.

Assessment of locomotion performance after total joint replacement has been made using a quantitative measuring system by Charnley (1968) and Murray (1972). The system used by Charnley is discussed in a paper by Jacobs et al (1972) in which the waveforms of the vertical components of force, as measured by force plates, are subjected to further analysis. Comparisons are made between normal and pathological gait, and waveforms are classified according to shape. It was claimed that certain mathematical parameters help distinguish one wave from another and also bear a distinct correlation to the diagnostic state of the hip joint. Murray (1972) carried out an analysis on 30 patients

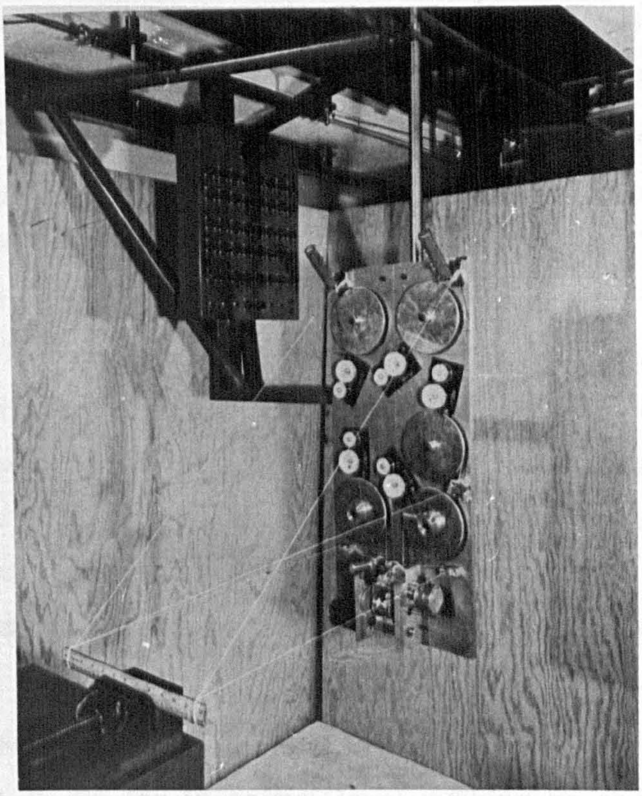


Figure 1.7. Wirta's apparatus to measure hip position during walking. (From Wirta (1970)).

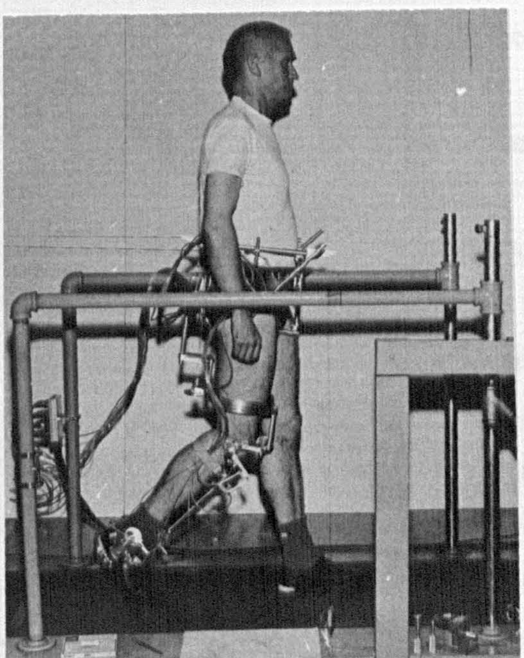


Figure 1.8. Lamoreux's "exoskeleton" in use. (From Lamoreux (1971)).

before and after hip joint replacement. The same measuring system was used as in Murray (1964) for the locomotion studies. The paper concludes by saying "The quantitative values presented in this study provide a basis for comparing the functional performance following major reconstructive procedures on the hip". However it is difficult to see how true comparisons can be made because of the number of variables - the ages of the subjects ranged from 36 to 85, there were large variations in the extent of the pathology, the degree to which other joints were affected, a lack of information about weight and height etc. The improved performance was clearly shown in the results, but a large amount of manual effort was required to obtain the data.

A strain gauged force plate and cine cameras were used by Poulson (1973) to perform a biomechanical analysis of the leg during fast and slow walking, walking up and down a ramp, and up and down stairs. In his studies on the biomechanics of the leg in normal level walking he considered 1) muscle force, 2) internal joint force, 3) muscle tension versus length, 4) segment energy levels, 5) joint power and 6) muscle power. The cine film and force plate record were transcribed into a form suitable for input to a digital computer by using an X-Y analyser. This device produces coordinates in punched tape form of the position of a pointer which is placed over the point on the recording to be measured. Even using this labour saving device 1½ to 2 hours were still required to transcribe the data for one stride.

A statistical study of the kinematics of normal locomotion was presented in a paper by Winter et al (1974). The data for this two dimensional analysis was collected by a television-computer system. Three walking speeds were analysed over at least 3 strides for each test. Ranges of linear and angular measurements of displacements, velocities and accelerations are shown, and comparisons are made with the studies of Murray (1964) and Lamoreux (1971). These comparisons show agreement between the studies where comparable measurements were made; except in the case of the angular accelerations of the ankle reported by Lamoreux. Winter et al suggest that this difference might be attributed to the different types of footwear used, the instrumentation worn by Lamoreux' subject and the fact that a treadmill was used. However the last two factors would certainly have affected the other parameters also. Lamoreux used a sampling rate of 200/sec compared with Winters 60/sec; this could also account for the difference in the accelerations measured because Winters' results would have been subjected to a much higher degree of smoothing and hence loss of the high frequency components which would produce the higher accelerations.

1.3 Kinematic Measuring Systems

For the purpose of this review these systems will be grouped under the following general titles:- Photographic, Non-Photographic Optical, Contacting, and Other Techniques.

1.3.1 Photographic Systems

Interrupted Light. This method was introduced by Marey (1895) and is still in use today. The use made of the technique by Marey and Fischer has already been discussed. Bernstein (1934) made refinements to the technique and used the system extensively, he referred to it as cyclography. Tiny gas filled electric light bulbs were used to mark positions on the test subject, the light from these bulbs to the camera was interrupted by means of a rotating shutter. Bernstein claimed that he could achieve exposure rates of up to 600/sec, although to avoid the recorded light dots from merging with one another, such high exposure rates could only be used when observing purely fast movements. Most of his experiments were made at exposure rates of between 60 and 190/sec., the measurement of shutter speed being accomplished by the determination of a tone emitted by a siren located on the shutter and rotating with it. Later an electromagnetic tuning-fork was used to switch a neon bulb and the speed of the shutter was adjusted until a circle of astericks marked on the shutter appeared motionless when illuminated by the neon. Enlargements were made of the exposed film and during this process a grid of ½ or 1 mm squares was superimposed on the recording. Measurements of the displacements of the recorded points were then taken and used for the analysis. Cyclography is not suitable for the recording of overlapping movements, and to overcome this deficiency Bernstein introduced kymocyclography i.e. cyclographical exposures on slowly and evenly moving photographic film. A further extension of the technique was the three dimensional recording of movement by placing a mirror at 45° to the main optical axis of the objective and so effectively making a stereoscopic recording. The manual labour involved in obtaining quantitative data from these methods must have been colossal, although Bernstein refers to this part of the procedure as being "easy".

The University of California used the interrupted light technique in their fundamental studies of locomotion as reported by Bresler (1950) and Eberhart (1951). Opthalmic electric bulbs were attached to the subject at estimated joint centres of the leg, on the iliac crest, and on the heel and toe of the shoe. The lights were continuously lit and the subject walked in a darkened room, the field of view of the open camera lens being interrupted 30 times/sec by a rotating disc with an 18° opening. The speed of the disc was made uniform by using a mains synchronised motor to drive it. A Kodatron speed lamp was synchronised with the shutter and fired to catch the subject in mid-field for identification. The data was measured from the resulting photograph using a toolmakers' microscope (30X magnification) and a scale factor. Only data in one plane was obtained using this method and Eberhart stated that the interrupted light technique was "not particularly useful in evaluation of gait".

More recent use of the method has been reported, by Murray (1964, 1967, 1972). Instead of using light sources as markers and a rotating shutter Murray uses reflective markers and a stroboscope flashing at 20 times/sec. Fourteen markers are used to identify various anatomical landmarks on the subject, and an overhead mirror in the field of view of the camera provides a view of lateral displacements of markers on the head, neck, thorax and pelvis. Although only sampling the positions of the points every 0.05 sec Murray frequently quotes intervals between events such as 1.06 ± 0.09 sec (Murray (1964), p.294).

All interrupted light measurement systems suffer from the problem of manual data reduction. The technique can be quite accurate for movements in one plane, but there are identification problems if movements overlap, and if a point remains more or less stationary (as in the foot during stance phase). Also if the subject moves out of the defined plane of motion then parallax will occur. The recording of movement in 3 dimensions is not impossible, as Bernstein demonstrated, but it is difficult. Another disadvantage is that subjects are generally required to walk in a darkened room.

Cine. Muybridge's serial photographs of human and animal movement can be said to have pioneered cine photography. Elftman (1939) was one of the earliest users of cine photography to obtain displacement-time data of locomotion, although he only made two-dimensional measurements. The University of California made extensive use of the method and an evaluation of its use is given in Eberhart (1951). In these studies two cameras were used, set up to provide front and side views of a glass walkway (Figure 1.5). The side view camera was also used to provide a bottom view by means of a mirror placed at 45° to the vertical underneath the glass walkway; by this means it was possible to obtain an estimation of the transverse rotation of the leg. An adjustable contact brace was strapped to the pelvis locating on the posterior and anterior iliac spines; anterior and posterior projections were attached to this brace to magnify angular displacements and allow the transverse rotations of the pelvis to be measured. To measure transverse rotations at the ankle, targets were fixed to a "U" shaped bracket holding two small pins. The pins entered the cortices of the bone of the medial and lateral malleoli, after a local anaesthetic had been administered. These projections on the ankle and the pelvis could be seen via the mirror and hence it was possible to measure the transverse rotations. Saggital and lateral displacements were measured from 1" diameter black dots on a white background placed over the joint centres of the limb. To minimise errors due to parallax the cameras were placed forty feet away. Measurements of the target displacements, to an accuracy of ½", were taken from each frame of the exposed film; as the cameras were running at a film speed of 48 frames/sec. the manual measurement process took a considerable time. High speed cine, with film speeds of up to 700 frames/sec., was also used during these studies. Filming had to be done outdoors in bright sunlight. No quantitative results are quoted from the high speed cine tests and it appears that only qualitative use was made of the technique.

A much higher degree of accuracy was obtained by Paul (1967) who used cine photography in his studies of the forces at the hip joint. Two Paillard Bolex H16 reflex 16 mm cameras were used running at a film speed of 50 frames/sec. Synchronous electric motors provided the drive to the cameras and the frame speed was shown to be constant within 0.4% by filming a crystal controlled timing unit. After a test run the film was re-wound and than re-exposed to a grid of 5" squares placed in a known position in the field of view. Subsequent measurements were taken from the film using the grid as a reference, optical errors thereby being restricted to those occurring within a 5" square. A high level of illumination was required (8 KW total giving an illumination of 260 foot candles over the measurement area) as the markers used to identify the anatomical landmarks were small ($\frac{1}{4}$" diameter) white paper spots, and exposure times were relatively short for indoor high speed filming (1/125 sec). The camera records were synchronised by firing a flash bulb which was in the field of view of both cameras. Firing of the flash bulb also triggered an event marker which was recorded on a U.V. recorder along with ground reaction forces provided by a force plate. A worst possible phasing error of 18 m S was quoted, and the measurement accuracy of the displacements of the markers was stated to be 0.05" ($\sim$ 1 mm). The measurement of film and force plate records for one test on one subject occupied two operators for approximately 9 hours; preparation and checking of the data for input to a computer took a further 5 hours. Corrections for parallax were made in the subsequent analysis.

In an attempt to remove the manual effort required to analyse cine film Kasvand (1971 & 1972) developed a computer-based system to do the processing. A flying spotscanner under computer control was used to interrogate each frame of the test film. Two digital to analogue converters provided the deflection voltages, from digital x, y coordinates, to position the scanner beam. Once the deflection voltages had been set up the scanner beam was turned on and the output of the photomultiplier was read with an analogue to digital converter to provide a measurement of the transparency of the film at the point x, y. It was stated that a 35 mm frame can be resolved into 4,000 x 3,000 elements with this system. During filming the camera was moved along parallel to the subject and to provide the necessary spatial reference 5 parallel digital encoded bars contained between two continuous bars were visible in the background. Anatomical landmarks were indicated by 1" diameter black spots on a white background, the spatial reference bars being 1" wide and also black on a white background, as seen in Figure 1.9. The computer programs used to obtain the displacements from the film provided for operator intervention at any stage. Initially a coarse scan of the first frame was done and the results displayed, the operator then marked off the area of the spatial reference code and selected the spots to be analysed, defining a neighbourhood for each spot, Figure 1.10. Having set up the initial conditions the computer program then reads the reference code and locates the specified spots from frame to frame, providing a continuous on-line display as shown in Figure 1.11. Processing speed for 5 spots in one frame was about 15 sec if no operator interaction was required. EMG signals from 4 major muscle masses were recorded simultaneously on a FM tape recorder together with signals from foot switches which were used to synchronise EMG data and displacement data. No details of the measurement accuracy of this system were given and the difficulties of expanding the system to three dimensional measurement were not discussed. Synchronisation of EMG records and displacement data, by using the foot switch signals, could not be particularly accurate because of difficulties in estimating the corresponding times of heel contact etc. from the displacement data.

An automatic system for transcribing data from cine film has also been developed in the Biomechanics Facility of the Childrens Hospital in Iowa City, U.S.A. (Pepoe (1970)). This system utilises fibre optics to provide a line scan of cine film, and is interfaced to a PDP 12 computer. Three sheets of fibres are used, with 1024 fibres in each sheet. The fibres are arranged in bundles in such a way as to digitally encode the position of a light spot falling on the fibre ends by illuminating an array of phototransistors. The sheets are clamped together and cine film is projected onto the fibre ends. The illuminated phototransistors provide a digital x co-ordinate (to 1 part in 1024) of any light

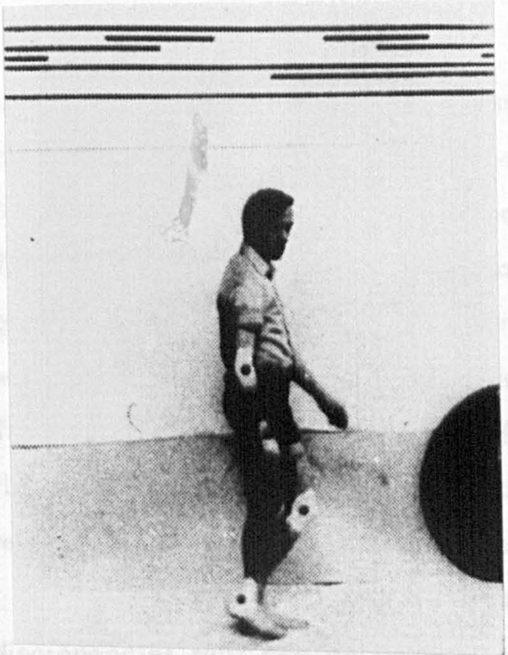


Figure 1.9. Marker and spatial reference system used by Kasvand (1971).

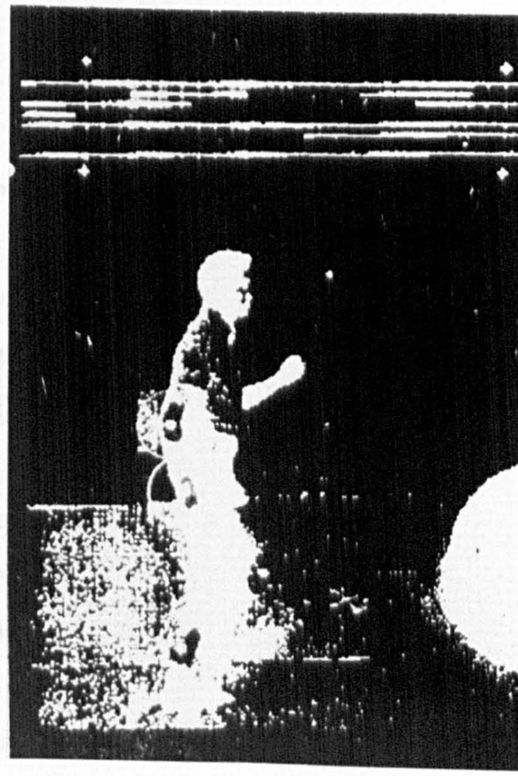


Figure 1.10. Coarse computer scan with local search areas marked. (Kasvand (1971)).

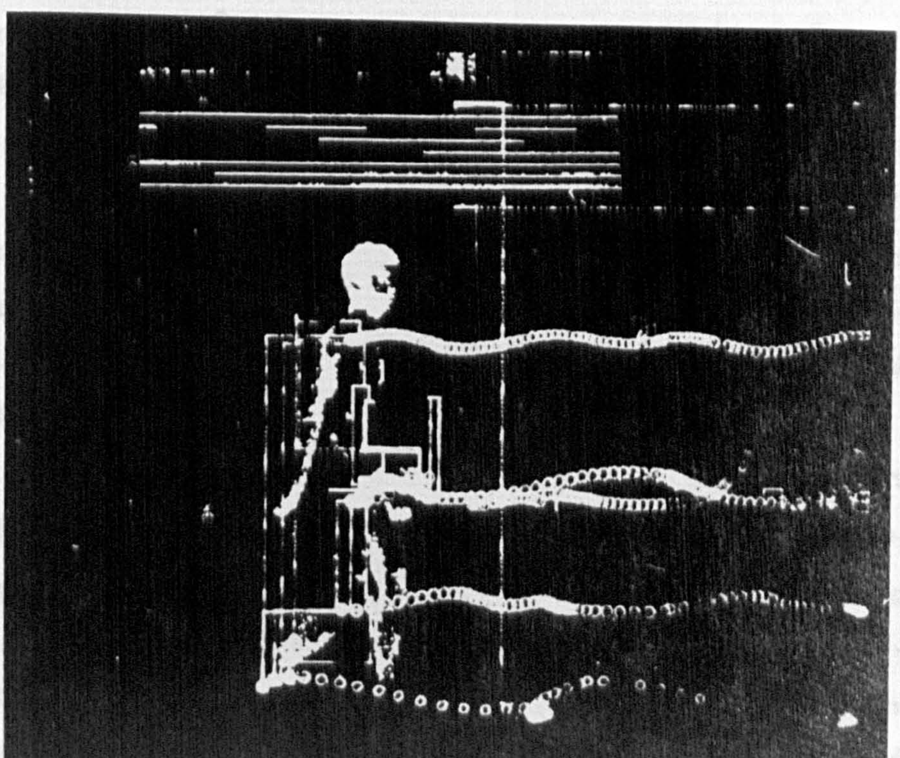


Figure 1.11. On line computer display of marker trajectories produced by Kasvand's system (Kasvand (1971)).

spots in the film. The y co-ordinate is provided by a shaft encoder which is rotated by the moving film. The shaft encoder increments a counter in the PDP 12 which is reset at the beginning of each cine film frame, providing 750 counts/frame. If two light spots fall in line then the co-ordinates generated by the system will be erroneous. This would prove to be a limitation when markers are placed close together, such as on the foot, or at the pelvis. The film is processed at the rate of 2 frames/sec., which is faster than the flying spot scanner method of Kasvand (1971), but further processing would be required to identify co-ordinates belonging to particular markers.

In a more conventional cine system Sutherland (1972) discusses the discrepancies that can be made in manual measurements of cine film. Comparisons were made of the differences in values computed from measurements, made by two observers, of the same piece of film. The parameters compared were rotation of the pelvis, femur and foot; flexion-extension of the knee; and plantar flexion and dorsiflexion of the ankle. The discrepancies in values were most serious where the total range in the value of the parameter was small. The worst case was pelvic rotation in which there was an average discrepancy of 2.6° (20% of total range) and a maximum discrepancy of 6.3° (48% of total range). The best agreement obtained by two observers was in the measurement of flexion-extension of the knee. Here the average discrepancy was only 5% of the total range and the maximum was 13%. Repeatability of measurements by a single observer was found to be better and resulted in variations of computed parameters of 0° to 2.5°. Sutherland used a Vanguard motion analyser to obtain the displacement measurements from the film; even so it took 2 hours to digitise the data.

Cine systems have played a major part in the most important locomotion studies. However the manual effort required to obtain data from film has been a great obstacle. The number of subjects studied and the number of tests carried out for each subject has been severely limited by this constraint. Semi-automatic systems of film analysis have reduced the data collection time substantially, fully automatic systems are still in the development stage and present problems of synchronisation of film data and other data. If a fully automated system were developed to the point where three dimensional studies of movement together with data from other sources could be achieved there would still be disadvantages in using cine. Firstly the recorded movement is not immediately available, the film must be developed; secondly in addition to the cost of computer processing time (which will be required for any comprehensive analysis) there will be an appreciable cost in film and film processing; thirdly flying spot scanners for this purpose are not commercially available; and lastly an appreciable amount of computer time would be required for data collection.

Photogrammetry. The technique of obtaining three dimensional measurements from two planar recordings of an object has been used extensively in surveying (Halbert (1960)). The method requires that two simultaneous recordings are made of the spatial position of the object. Providing the distance (base) separating the recording devices is known and the focal length (principal distance) of the optical system is also known then the third dimension (usually called depth) can be derived from the two planar measurements. Bernstein (1934) made the first use of the method for studies of human movement; no details of the accuracy obtained were given and his general method has already been discussed. More recently Ayoub (1970) has developed a stereometric system for measuring human motion. A measurement accuracy of 2% was claimed, although to obtain this it was stated that it was necessary to measure the differences in the spatial positions of common points in stereo-pairs (the two planar recordings) to within 0.0004 inch. Stereocomparators can certainly measure to very high accuracies, but it must be remembered that when photographing movements, because of the relatively long exposure times used, there is certain to be a degree of blurring of the image. To use the limits of accuracy of a stereocomparator sharp edges are required. The other measurements involved, base and principal distance, must also be known to a high degree of accuracy, as any errors in these measurements will affect the overall accuracy considerably. Ayoub studied hand and arm movements using stereo-photography and the interrupted light technique to produce multiple exposure stereo-pairs. The type of movement studied is limited for the same reasons as with interrupted light photography and again manual measurement of the results is necessary.

Lippert (1973) used a photogrammetric system to study the mobility of fracture fragments of the tibia. Lippert rejected conventional methods of movement measurement, such as cine photography, because of the "artificial restrictions imposed on the subjects' movement by the measuring apparatus". In Lippert's tests targets were attached above and below the fracture site by stainless steel pins inserted into the bone (through both cortices). A Zeis SMK-40 stereocamera was used and a measurement resolution of 1.0 - 1.5 mm was claimed. The patient was photographed, on the same film, in four positions - one "no load" and three other positions which put various loads on the limb. The tests had to be carried out in a darkened room which, with patients whose movements were restricted by their plaster casts, was inconvenient and occasionally led to targets being knocked. Measurements from the exposures were made manually and 6 personnel were required to run the tests.

Photogrammetric methods can be used to obtain three dimensional displacement-time data for human movement, but very precise alignment of the photographic system is required. Measurements must be made manually using a stereocomparator, which is very costly and could not be justified for exclusive use in these sort of studies. The clinical use suggested by Lippert is not acceptable in terms of the effort required, and the insertion of pins into the bones of patients.

1.3.2 Non Photographic Optical Methods

Methods of this type did not become available until the late 1960's. Obviously television/computer systems could be included under this heading but discussion of such systems will be deferred. Limited studies using non photographic optical systems have been carried out, but so far the studies have been restricted to kinematics (and kinetics where no external forces are involved) and no comprehensive analysis of locomotion has yet been presented. In some cases the systems have only been available for a short time and no doubt the inclusion of other measurements will soon be attempted; in other cases the additional facilities required for measuring other aspects of locomotion have not been available.

Systems using polarised light have been developed by Reed and Reynolds (1969), Grieve (1969) and the University of Loughborough (1973 and Mitchelson (1975)). The techniques used are essentially identical and so a description will be limited to that of the University of Loughborough system. A schematic diagram of the system is shown in Figure 1.12. Light from a D.C. powered light source is polarised by a linearly polarised filter which is rotated. This has the effect of rotating the plane of polarisation through 180°, which happens twice for every revolution of the polarising filter. The polarised light is received by a matched pair of photodiodes connected in opposition to each other. A window of polarising filter is placed over each photodiode with the planes of polarisation at right angles to each other. The effect of this arrangement is that any non-polarised light incident on the photodiode pair is received in equal amounts by each and thus the resulting signals cancel each other. On the other hand polarised light incident to the photocells is first transmitted to one cell and extinguished at the other, and then vice versa as the plane of polarisation of the light source rotates. A sinusoidal voltage is thus produced by this receiver. A reference mark on the rotating filter of the light source is detected by a photocell, a reference pulse being produced every time the mark passes the photocell. The logic of the electronic circuitry is arranged so that a linear voltage ramp is initiated on receipt of the reference pulse, and the ramp is stopped when the sinusoidal signal from the receiver passes through its zero reference voltage in a negative going sense. The final value reached by the voltage ramp is stored in a sample and hold circuit. This voltage represents the angular displacement of the receiver with respect to the light source. Any orientation of the receiver to the light source can be chosen as zero angular displacement by delaying the reference pulse by an appropriate time. The output voltage is updated once for every revolution of the light source filter, in the case described 150 times a second. The measured noise level of the angular displacement output was stated to be in the region of 0.3 degrees (in a total range of 180°), and the linearity of the system was quoted as ± 0.1° over the total range. Measurement errors can arise when the receivers undergo two rotations with respect to the plane of polarisation of the

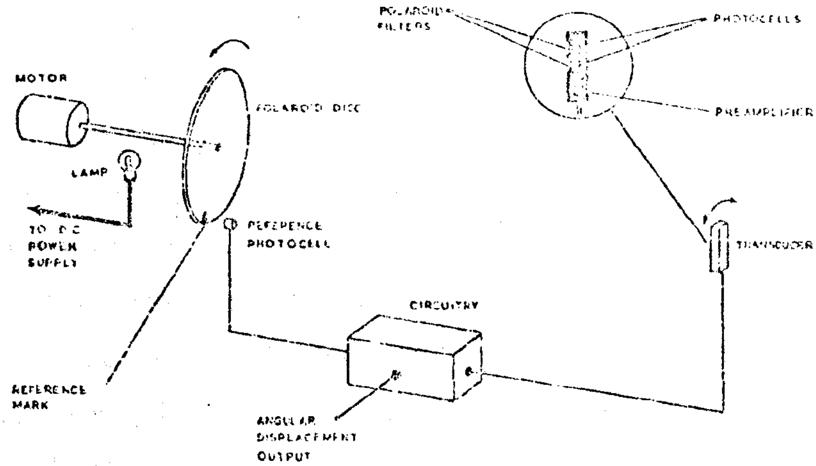


Figure 1.12. Schematic diagram of the Polarised Light Goniometer. (From Mitchelson (1975)).

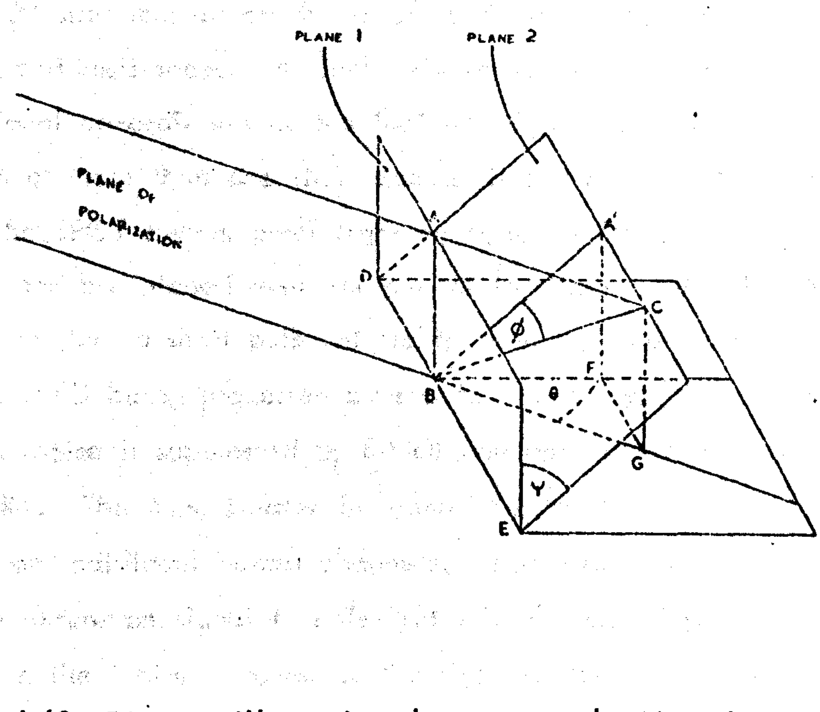


Figure 1.13. Diagram illustrating the error angle ϕ , due to the two rotations of the transducer ψ and θ .

light source, in addition to the rotation which is being measured. Mitchelson shows that this can amount to a measurement error of 7° for two additional rotations of 20° in planes mutually perpendicular to the plane in which the measured rotation is taking place. Obviously careful positioning of the receivers can keep such errors low for locomotion studies. Analogue outputs of angular velocity can be obtained by appropriate analogue processing of the angular displacement voltage; although the effects of noise must be carefully considered, and preclude the derivation of acceleration in this way.

This technique provides a relatively inexpensive means of obtaining angular displacement data. The disadvantage of the technique is the need to attach the receivers to the body and provide a power source and connecting leads to them. Also only relative measurements are made, the technique does not provide absolute measurements.

A continuous light spot position sensor forms the basis of the commercial SELSPOT system, Lindholm (1974), Selcom (1975). The sensor is basically a large area silicon photo-diode of the Schottky barrier type manufactured by United Detector Technology Inc.. An equivalent circuit of a single axis sensor of this type is shown in Figure 1.14 (from Woltring (1973)). The average position of a light spot imaged on the sensor surface at any instant varies the current in the load resistances. A dual axis version of the sensor provides the two dimensional co-ordinates of the incident light spot. In order to monitor the position of more than one light source time division multiplexing must be used. In the SELSPOT system small light emitting diodes (LED's) are used as the light sources and are placed over anatomical landmarks. The LED's are switched on in turn to give a short pulse of light; the x, y co-ordinates from the detector for each LED being processed by special noise suppressing and linearizing circuits (noise is suppressed by 60 dB and non-linearity is decreased from 60% to 0.5%). The co-ordinates for each LED are then made available as analogue signals on individual output channels. The resolution of the system depends to a large extent on signal to noise ratio in the signal processor and detector, and hence on the incident power of the light source on the detector. For sufficiently large incident power ($\sim$ 1 mW) a resolution of 10^{-4} (1 in 10,000) is quoted

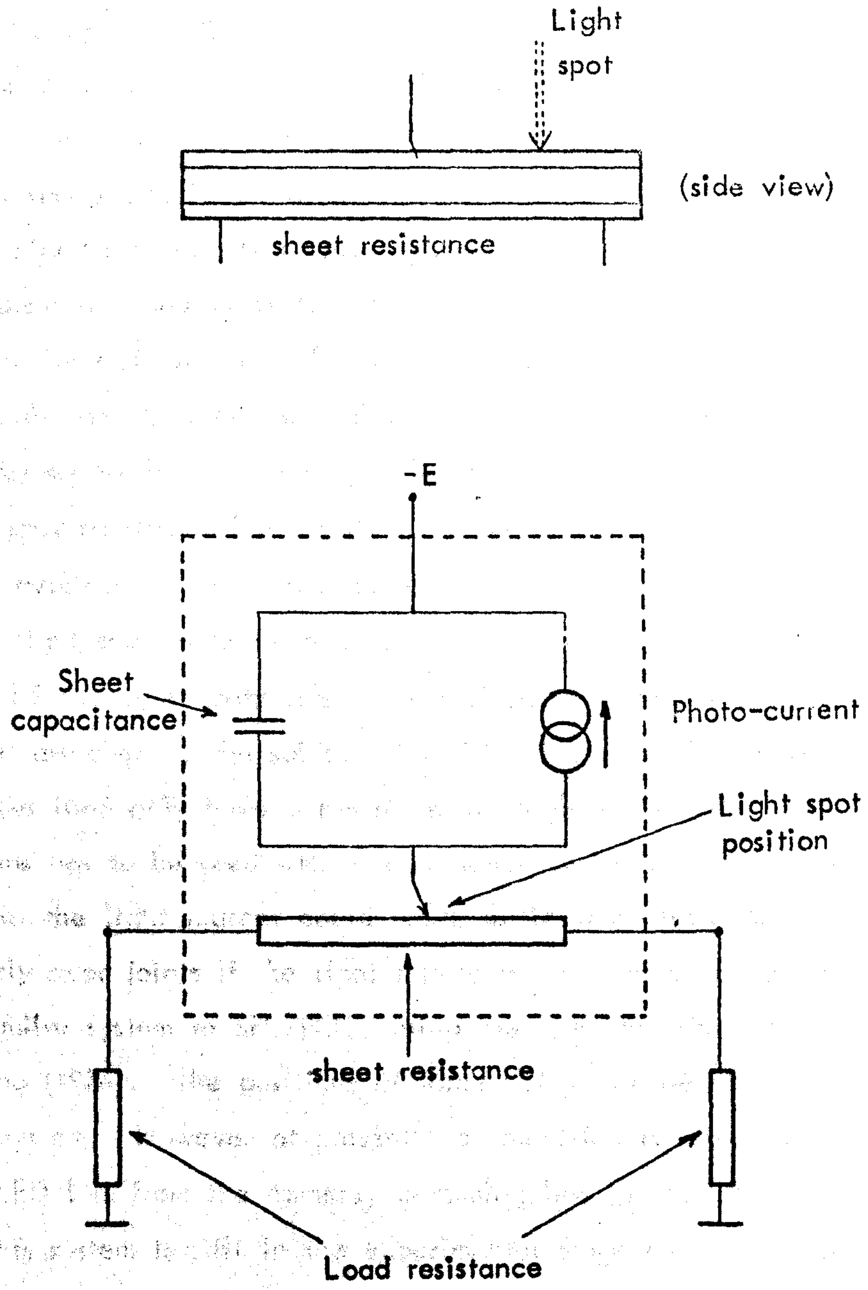


Figure 1.14. Equivalent electrical circuit for a single axis continuous light spot position sensor (From Woltring (1973)).

(Woltring (1973)), however currently available LED's cannot produce this sort of incident power at the ranges of interest in locomotion studies. The duration of the incident light pulse also affects the signal to noise ratio due to the time constant of the sensor, so that Laser LED's of high power but rather short duration (200 nS - 1 μS) are not particularly suitable. However a resolution of better than 10^{-3} is claimed with currently available LED's over a range of 6 m within a cube of 3 m sides, at a sampling frequency of over 200 Hz for up to 30 LED's (Selcom (1975)). Three dimensional measurements can be obtained by using two sensors, and there is also the possibility of using extra sensors positioned so as to pick up light sources that may occasionally be obscured to the main sensor. The SELSPOT system has the advantage that output signals are obtained for individual markers and there are therefore no co-ordinate/marker identification problems; also the resolution and sampling frequency specifications of the system are good, provided LED's of sufficient power are available. The disadvantages of this type of system are the necessity for active light sources to be mounted on the body, the need for switching circuits, and the consequent requirement of power supply all of which would have to be attached to the subject if trailing leads are to be avoided. The light sources used only have a narrow solid angle of radiation and hence some kind of lens has to be used with a consequent reduction in radiant power. The mounting of the light sources could prove difficult on some anatomical landmarks (particularly over joints if the light source is strapped onto the subject).

A similar system to SELSPOT, using the same detector, has been reported by Woltring (1974). The positions of three LED's can be sampled at 300 Hz with this system. However at present the resolution is rather poor - 1 in 400 with the LED 1 m from the camera, becoming less as the LED is moved further away. This system is still in the experimental stage and it is hoped to improve the resolution by a factor of four for distances up to 3 m.

Another opto-electronic measurement system is being developed by Mitchelson (1974, 1975). This system, called CODA (Cartesian Optoelectronic Dynamic Anthropometer) uses an array of silicon photodetectors in front of which is placed an encoded optical mask, Figure 1.15. Cylindrical optics are used to focus point sources of light into a line image onto this array. The component

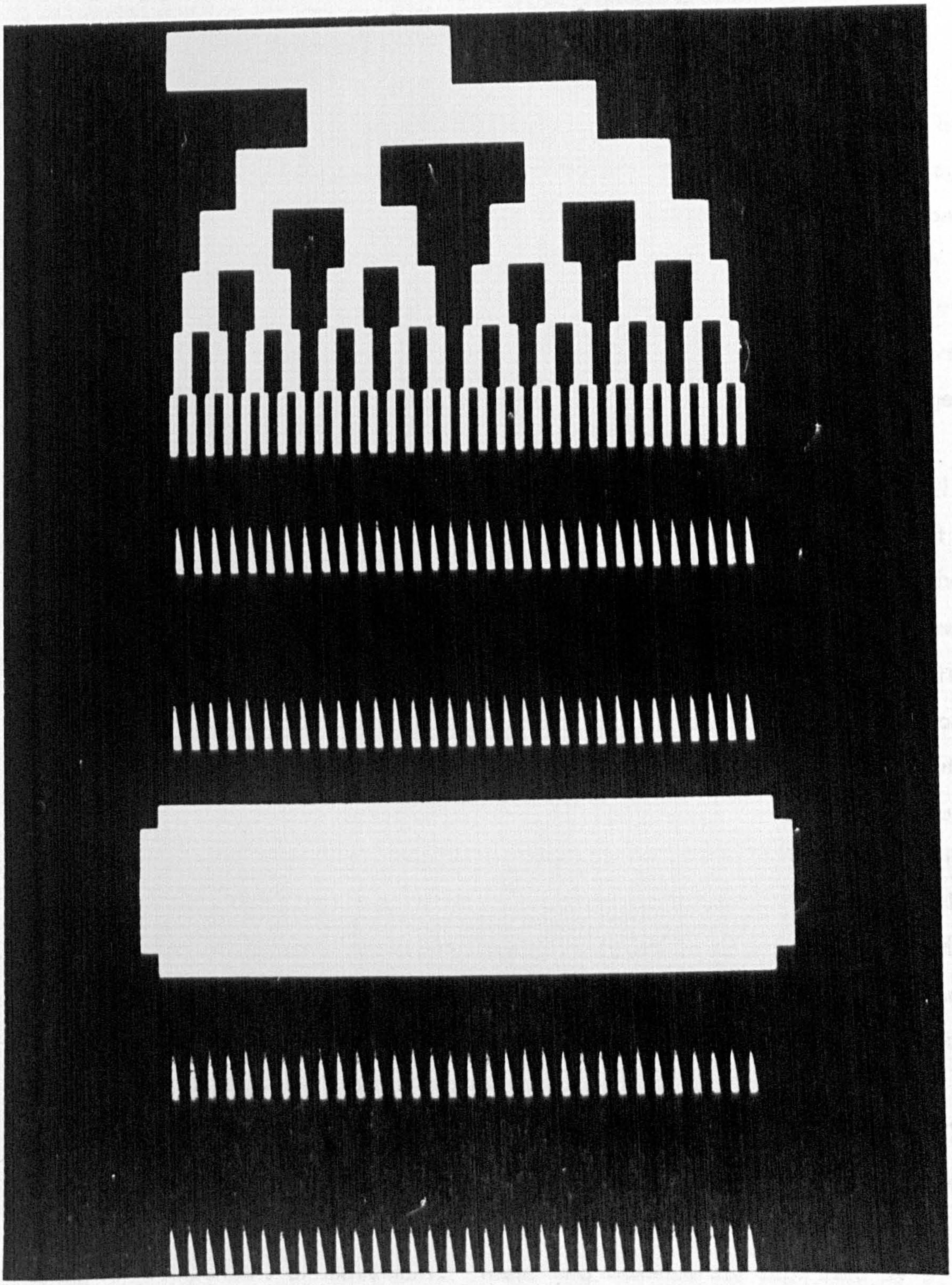


Figure 1.15. Optical mask used in "CODA" system. (From Mitchelson (1975)).

of movement of the point source that is at right angles to the orientation of the line image causes a corresponding shift of the line image across the focal plane. The first seven rows of detectors are behind the digitally encoded portion of the optical mask, and a direct digital readout of the position of the line image is thus obtained (7 bits). Further resolution of the position is obtained by using the analogue vernier part of the optical mask. The analogue vernier consists of 4 rows of 64 transparent wedges, the pattern of wedges being advanced by 1/4 of the interval between wedges for each row. As the line image moves across the wedge the amount of light falling onto the photodetectors is linearly proportionate to the position of the image on the wedge. However, the width of the line image may be as much as ½ the base width of a wedge so the linear relationship only holds good in the central half of the wedge. Due to the staggered arrangement of the 4 rows the line image can only fall in the linear part of a wedge on one row at a time. The system can select the row in which there is a linear response, which therefore provides 2 further bits of resolution (1 out of 4 rows). The analogue output of the selected row is then digitised and a further 6 bits of resolution is claimed. The seven bits from the digitally encoded portion of the mask together with the two bits from the row selection and the remaining 6 bits obtained from the analogue output gives a total of 15 bits resolution. One bit is lost in order to avoid ambiguous or erroneous matching of the outputs from the digital and analogue parts of the system. Two more bits are lost in the arithmetic processing necessary to derive parallax free three dimensional co-ordinates. A final output resolution for the instrument of 12 bits or 1 part in 4096 is the design specification. The broad transparent portion of the optical mask provides a reference signal which allows corrections to be made for fluctuations in the intensity of the light sources.

Three dimensional co-ordinates are obtained by using three cameras. One of the cameras is oriented so that it is sensitive only to the vertical components of displacement; the other two cameras are both oriented to be sensitive to the horizontal components of movement. These two cameras are separated by a known base length and therefore stereo-photography principles can be applied to derive the "depth" component of position. Corrections for the effects of parallax can also be made. As in the SELSPOT system LED's are used to provide the light source, but due to the faster response of the sensors used it has been possible to use the higher power Laser LED's. Each light source is switched on in turn to give a light flash of approximately 200 nS duration, 90 μS is then required to derive the co-ordinates of the light source; and so with a total of 10 light sources (markers) a sampling frequency or repetition rate of 1 KHz can be attained (although Mitchelson appears to be limiting the system to 8 sources).

Mitchelson states that the resolution of the system is limited by the signal to noise ratio at the sensors. With the laser light source 2 m from the camera this is stated to be 33 to 1; which gives an overall resolution of better than 1 in 4,000 (when the resolution of the digital part of the system is also considered). The signal level from the LED at the sensor follows the inverse square law so there is a corresponding decrease in resolution with increasing distance from the camera. Table 1.1 shows the effect of this on the resolving power of the system. The "width of overlap" columns give the amount by which the fields of view of the outside cameras overlap and hence the working dimensions of the system. With this system the subject would walk towards the cameras, so the minimum overlap required to ensure that lateral movements would be observed would be 0.75 m. If the recording of motion is started when the subject is 7 m from the camera then two and possibly three strides would be accommodated, and the resolution would vary from 10 mm to 0.5 mm. At the present stage of development of this system there is a systematic error of 1 part in 400 due to the imprecision of the vernier (wedge) part of the optical mask. This error is compounded when calculating the parallax free co-ordinates of the light source and Mitchelson (1974) quotes errors in horizontal and vertical co-ordinates of 1 part in 130, and of 1 part in 200 for the depth co-ordinate.

The overall accuracy of this system must also depend on the accuracy with which the constants of 1) base length between the outside cameras, 2) focal length and 3) width of the focal plane can be set up. These constants are used in the analogue computation of the parallax free co-ordinates and are represented by preset constant voltages or currents. Any inaccuracy in

Distance from camera	Resolution	Field of view of 1 camera	Overlap for base = .5 m	Overlap for base = 1 m	Resolving power
m		m	m	m	mm
2.0	1:4000	1	0.5	0	0.25
2.5	1:2500	1.25	0.75	0.25	0.5
3.0	1:1800	1.5	1.0	0.5	0.85
3.5	1:1300	1.75	1.25	0.75	1.3
4.0	1:1000	2.0	1.5	1.0	2.0
5.0	1:640	2.5	2.0	1.5	4.0
6.0	1:450	3.0	2.5	2.0	7.0
7.0	1:330	3.5	3.0	2.5	10.0

Table 1.1.

setting up these constants will affect the overall accuracy. Precise alignment of the sensor with the optical system is required, and also the camera must be oriented precisely to the external measurement axis. Mitchelson suggests that improvements in the precision of the optical mask and more efficient diffusion of the light from the laser landmarks will allow the design specification of a resolution of 1 part in 4,000 to be reached.

These optoelectronic methods are mostly still at the development stage. If the design specification of some of them are attained then they will provide powerful measuring systems. However it seems most likely that the range over which movement can be monitored will be restricted by the power and angle of radiation of available light sources. To monitor the movement of more than one light source it is necessary to use active light sources which will obviously require a power supply. Switching of the light sources will require control cables to be attached to the subject, or a telemetry link.

1.3.3 Contacting Methods

Goniometers. The electrogoniometer as used by Karpovich (1959) is a very simple and cheap instrument; basically it consists of a precision potentiometer fixed to a support bracket with the spindle of the potentiometer fixed to another support bracket. Relative motion between the support brackets rotates the potentiometer spindle and hence varies the resistance in direct proportion to the angle between the brackets. By suitably attaching the brackets on either side of a joint relative motion can be measured. Johnston (1969) used goniometers to measure saggital, coronal and transverse rotations about the hip joint; the same device was used by Kettelkamp (1970) to obtain similar measurements about the knee joint. The device consisted simply of a linkage in which the three rotations were individually transmitted to three goniometers; obviously, the measurements obtained were of the rotations of the linkage which is not the exact centre of the joint. Corrections were made for this but errors arising from movement of the goniometer assembly due to relative motion of the soft tissues with respect to the skeleton could not be accounted for.

Lamoreux (1971) designed an exoskeleton which was attached to the lower limb, Figure 1.16. The exoskeleton at the hip provided an external analogue

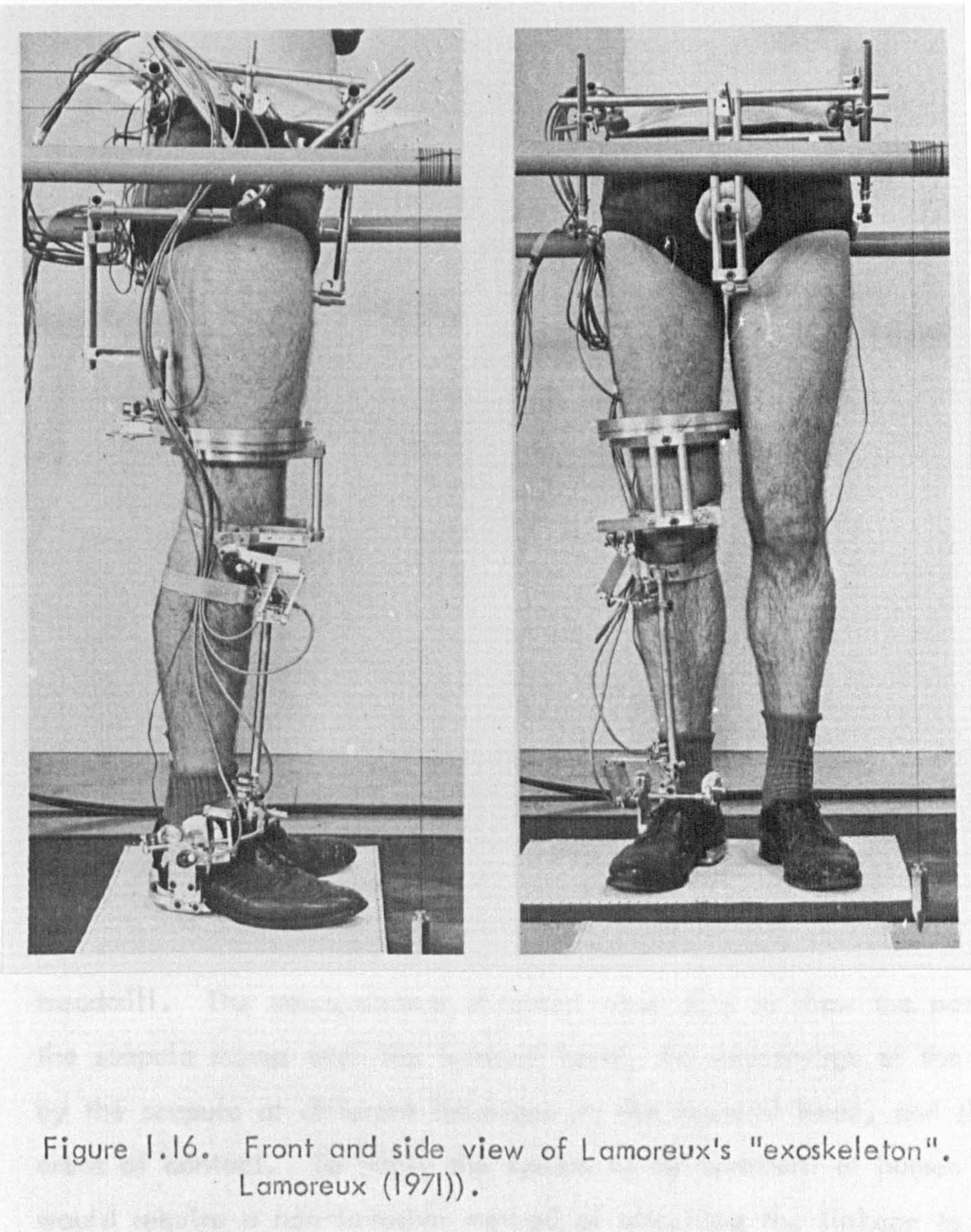


Figure 1.16. Front and side view of Lamoreux's "exoskeleton". (From Lamoreux (1971)).

of the hip joint which, after careful alignment, could have its effective centre at the centre of the hip joint. The three joints of this analogue were instrumented with potentiometers to measure the relative rotations. Parallelogram linkages were used to measure the relative rotations at the knee and ankle. These linkages will transmit two of the three components of an arbitrary rotation in three dimensions and absorb the third. Lamoreux states that precise alignment of these linkages is not necessary and that the axes of measurement are the axes of the exoskeletal joint between which the parallelogram linkages are attached. To measure the three components of rotation two linkages are required; with Lamoreux's system simultaneous measurement of the three components can be made at the ankle but not at the knee. Measurements obtained via the exoskeleton were made while the subject walked on a treadmill. The physical attachment of the exoskeleton (total weight approx. 6 lbs) and the use of the treadmill, must condition the subject's gait.

A potentiometer instrumented linkage system was used by Kinzel (1972a, 1972b) to measure the total motion between two body segments. His linkage had six degrees of freedom and he could therefore measure the three rotations and three translations which completely describe the motion at a joint. By making separate measurements of the joint surfaces Kinzel was able to study the relative motion between the joint surfaces. The end points of the linkage system were securely mounted on pins which had been inserted into the bone. This system was used to study the scapula-humerus joint in Alsatian dogs, walking on a treadmill. The measurements obtained were able to show the path by which the scapula moves over the humeral head, the percentage of the time spent by the scapula at different locations on the humeral head, and the apparent areas of contact. To apply the system to measurement of human joint motion would require a non-invasive method of attaching the linkage to the subject, and a non-invasive method of measuring the joint surfaces. Both of these requirements would limit the accuracy of measurement considerably.

Tachograph. This is another inexpensive form of instrumentation, which, in its simplest form, consists of a D.C. generator which is driven by a string attached to the subject. The output voltage of the generator varies with the velocity of the attachment point of the string on the body. Drillis (1958) used the method to record the horizontal velocity of the trunk. Ganguli (1973) claimed that the system was suitable for use in a clinical situation. With his system the string was located in horizontal pulleys which were mounted on shafts extending between floor and ceiling, a bearing being provided at each end of the shaft. Four such pulleys were arranged at the corners of a rectangle with the string in a loop around them. The drive to the D.C. generator was taken from another pulley on one of the shafts. The string was attached to the side of the subject in the region of the iliac crest of the pelvis; the height of the string being adjusted by the position of the pulleys on the shafts. This arrangement would mean that the recorded velocities would be affected by transverse rotations of the pelvis, and would therefore not be a true measure of the motion of the centre of gravity of the subject. Ganguli evaluated the data by taking the ratio of the first period to the second period of the "centre of gravity" curve (the fundamental frequency of this curve being twice that of the gait cycle frequency). He claimed that this ratio would be independent of all factors except the symmetry of gait.

Molen (1972) used similar principles to measure the instantaneous velocity of the centre of gravity of the body. Magnetic tape prerecorded with pulses at a fixed frequency and constant tape speed was attached to the subject at front and rear at the level of the centre of gravity. The tape was then looped round guides and passed over a tape read head; vibration damping was incorporated into this path and the height of the tape read head was adjustable to suit the subject. As the subject moved the output frequency of the pre-recorded pulses was proportional to the instantaneous velocity of the tape passing over the read head. A frequency to D.C. converter was used to give a proportional output voltage.

These methods are inexpensive, but the information that they give is very limited. They may show, for instance, an assymmetry in the gait, but it is most unlikely that they will indicate the cause of the assymmetry.

Accelerometers. The technique of measuring acceleration directly with accelerometers was used during the University of California's fundamental studies of locomotion. (University of California (1947)). In the report by Eberhart (1951) on the experimental procedures used in these studies, the data provided by accelerometers was stated to be "inferior" to that obtained by using cine film techniques, but this was most likely due to the type of device available at the time. The vertical and fore- and - aft accelerations of the trunk together with the angular accelerations of the shank were measured directly using accelerometers by Gage (1964). Harmonic analyses were made of the resulting data and comparisons were made between normal and amputee gait. The degree of symmetry of gait in the normal was clearly shown by the dominance of the even harmonics; the odd harmonic values in the amputee gait being consistently higher, showing the more pronounced assymmetry of their gait. Gage stated that certain gait defects showed up as specific abnormalities in the harmonic analysis, although combinations of defects were difficult to interpret from the frequency spectra. No attempts to derive velocity and displacement data from the accelerometer recordings were reported by Gage. Accelerometers were used to verify the procedures by which accelerations were derived from displacement/time data by Hunt (1965). Measurements were made from accelerometers mounted on the shank of the subject and the results obtained showed general agreement with data derived from cine film recording.

Smidt (1971) followed up suggestions made by Gage (1964) and studied the effect of "induced" abnormalities - by immobilizing certain joints. He used three orthogonally mounted accelerometers placed on the body close to the centre of gravity. Data was recorded over 4-6 strides and foot switches were used to determine heel strike, foot flat, and toe off. Again, a Fourier analysis was performed on the acceleration curves of the fore-aft and vertical - the lateral accelerations were not particularly cyclic and hence not suitable for Fourier analysis. Smidt quantified the "smoothness" of the gait by taking the ratio of the sum of the even harmonic coefficients to the sum of the odd harmonic coefficients. A high harmonic ratio indicating a smooth acceleration curve. Smidt stated that the harmonic ratio could discriminate between the "induced" abnormal gaits.

The total movement of the shank (with the one exception of the transverse rotation) was studied by Morris (1973) using five accelerometers mounted on a perspex platform. Morris suggests that the inferior results obtained by earlier investigations using accelerometers was due to the use of unsuitable transducers. Strain-gauge accelerometers which deform elastically due to inertial force were used by Morris and stated to be the most suitable type. The signals from the accelerometers were recorded on a portable tape recorder carried by the subject or passed by a lightweight cable to a fixed recorder. The recorded data was processed on a small digital computer which allowed the use of interactive programmes. The operator selected one cycle of the data by setting cursors on a visual display of the data to mark the beginning and end points. This portion of data was then filtered to remove drift and to set a lower frequency limit to the signal pass band. Further processing obtained angular velocity, direction cosine, translational acceleration, velocity and position data. The system developed by Morris has the advantage that it can be used outside of a specialist laboratory, with little discomfort to the subject who may wear normal clothing. However, the system has so far only been developed for use on the shank. Attaching accelerometers to the thigh, for instance, will be difficult because of tissue movement; the site chosen on the shank was relatively free of such problems.

The use of accelerometers always requires some kind of physical attachment to the subject, and some kind of link to a recording device. Studies have been limited to one or two segments, and no investigator has attempted to incorporate ground reaction into the analysis, as far as is known.

1.3.4 Other Techniques

Cine radiographic techniques have been suggested as a method of gait analysis (Eberhart (1951)). The equipment necessary is not only costly but it is also limited in its scope. The depth of field is restricted, and the width of the field of view is somewhat narrow. The only recorded use of such equipment for locomotion analysis is by Jenkins (1972); however, this study was of the gait of chimpanzees. Recordings of the gait were made at 50 frames per second while the animal walked on a treadmill. The field of view was only 25.4 cm, which meant that the separate sequences had to be recorded for each joint. The data was quantified by measuring joint angles from the film, and the results were compared with the gait of man. The use of cine radiographic equipment is probably not worthwhile, because of the above mentioned restrictions and because manual reduction of the data is still required. It may, however, be useful to obtain data of the movement of marked positions on the skin with respect to anatomical skeletal landmarks.

A novel technique to measure the velocity of a point on the body was developed by Nadler (1958). A sound source (at 20 KHz) was attached to the point on the body to be measured and three microphones with their directional axes orthogonal were set up to receive the sound. Because of the Doppler effect the frequency of the sound received by the stationary microphones varied proportionally to the velocity of the sound source. This frequency variation was measured and hence the instantaneous velocity of the source would be described in three-dimensions by the signals from the microphones. More than one sound source could be used by choosing different source frequencies. The method has been used to study hand motion (Kattan (1969)), but has, so far, not been used for locomotion analysis. There are problems in using the technique because of reflections of the sound from the surroundings, and shielding of the sound by the body.

1.4 Television Systems

Several systems based on television, for the measurement of movement, have been independently developed. All of the systems use the same basic principle to obtain the spatial co-ordinates in one plane of a detectable point or area within the field of view of the camera. This principle is that one co-ordinate may be obtained by reference to the television rastor line on which the point is detected and the other co-ordinate may be obtained from its position on this line. Sampling of the position of a detectable point in time is obtained by the sequential scanning action of the television camera.

Furnee (1967) reported the development of a television-computer system to measure arm movements. A detailed description of the method may be found in Steilberg (1968), a review will be given here. The television standards used were the 625 line, 50 fields/sec British system (for more information on television standards see appendix A1). A 3.995 MHz crystal controlled clock was used to count intervals along a line giving, in 64 μS, 256 intervals. 8 μS of this was taken up by the line flyback period which meant that the active line time was divided into 226 intervals (the x-co-ordinate counter). For the y-co-ordinate an 8 bit counter was used which allowed 256 scanning lines to be counted, the remaining scanning lines were blanked off. Small electric lamps were used to pinpoint landmarks on the arm, the normal scene illumination and the camera settings were adjusted so that the light from the lamps gave the highest level in the video signal. A simple threshold detector was used which was set to give a constant duration output pulse whenever the video signal reached the level caused by the lamps. On receipt of this pulse the contents of the x and y counters were instantaneously stored in a buffer register. As the light from the lamp covered more than one TV line it was arranged that only the detector pulse received on the first line would cause readout of the counter contents. In the version of the system reported by Steilberg (1968) the co-ordinates contained in the buffer register were immediately transferred to the computer memory on a cycle stealing basis, during this transfer period no further marker co-ordinates could be registered. However as the system used a direct memory access method to transfer the data this period would have been of the order of microseconds (i.e. very much less than the duration of one line - probably about 4 μS). Later versions of the system incorporated a 16 word buffer memory for each co-ordinate, and the contents of this memory were transferred to the computer or to a digital tape recorder during the field blanking period (Ingen Schenau (1973)). The sequential scanning action of a television camera means that the positions of the lamps are not all sampled at the same instant. To provide simultaneous sampling of the lamp positions the Dutch group introduced a synchronous shutter into the system, Ingen Schenau (1973) and Stokrom (1973).

This shutter rotated 50 times/sec and a window in the shutter exposed the field of view to the television camera for 2 mS; synchronising circuits ensured that the exposure was made during the field blanking period. The light pattern stored on the camera signal plate was then scanned in the normal way.

Methods for identifying the lamps from the co-ordinates are discussed in Ingen Schenau (1973); also various computer programs to filter the resulting data are presented. Non-linearities due to the camera are corrected by formula, found experimentally - the linearity of y was shown to be independent of the linearity of x. Scaling of the data was done by reference to the co-ordinates (corrected for non-linearity) of 3 points arranged in a triangle. The number of lamps that could be used to mark anatomical landmarks was limited to 5 (in the buffer memory version some locations must be reserved for pick up of spurious signals). So far only one camera has been used, so only movements in two dimensions have been studied. Most of the work done by the Dutch group has been in the study of arm movements, Stokrom (1973), Ingen Schenau (1973). Some locomotion studies have been made, but the results have not been reported, other than on the locomotion of cats, Furnee (1974). No attempt has so far been made to incorporate measurements of external forces.

A television system to measure three dimensional co-ordinates was developed by Waas (1969). Two television cameras were used to provide two planar views of electric lamps placed on anatomical landmarks of the subject. Up to 4 lamps could be used and it was necessary to place them in positions where they would always be in view of the two orthogonally positioned cameras. Digital counters were used to provide the co-ordinates, similar to the Dutch system. On detection of a lamp signal in the video the contents of the co-ordinate counters were read out and stored on magnetic tape. This transfer operation lasted for 9 full scan lines (570 μS) and no further detection of marker signals could take place during this time. The system was designed so that the second camera only gave one co-ordinate, the Z co-ordinate. Obviously the time required to transfer co-ordinates to magnetic tape placed a severe restriction on the system. Markers had to be arranged so that at no time in the gait cycle did they come within 9 scan lines of each other. It is understood that this system is no longer in use.

A computer interface for television has been developed by Dinn (1970). This is a general purpose digital system which performs an analogue to digital conversion of the television video signal. The standard American television system is used (525 lines, 60 fields/sec.) and the sampled area of each field can be varied from a single point up to a 256 x 256 window, with the height and width of the window independently variable. The system could be set to sample every television line or every 2nd, 3rd, 5th, 8th or 12th line, with corresponding sampling intervals along the line. The amplitude quantisation of the video signal conversion could be set to 1, 2, 3, 4 or 5 bits (i.e. 2-32 levels of brightness). The interface could also be set up to sample every television field, every second field etc. up to every 64th field. The word length of the resulting digital data was also variable and could be set to 12, 16, 20, 24 or 32 bits, which gives a wide range of compatibility for different computers. The object of this system was to provide a general purpose facility which could convert television images into a digital equivalent which could then be processed by a digital computer.

Extensive use of this interface has been made in studies of human locomotion at Shriners Hospital for crippled children in Winnipeg. The experimental set up is described in Winter (1972), and shown in Figure 1.17. The interface is set to give one bit amplitude resolution (i.e. either bright or dark) and a sampling matrix of 96 points by 96 points for each field. Comparatively large reflective markers are used to indicate various landmarks on the limb. Winter shows that by using such large markers a more accurate estimation of the spatial co-ordinates of the centre of the marker can be made - a minimum of 10 sample points lie within the marker area of the video signal, and a spatial resolution of 1 mm is quoted. In order to use the comparatively coarse sample matrix it is necessary that the field of view of the camera only covers a small area. This restriction in turn makes it necessary to "track" the subject with the camera. An operator pushes the trolley mounted camera along a rail keeping the walking subject in view of the camera at all times. The spatial reference of the

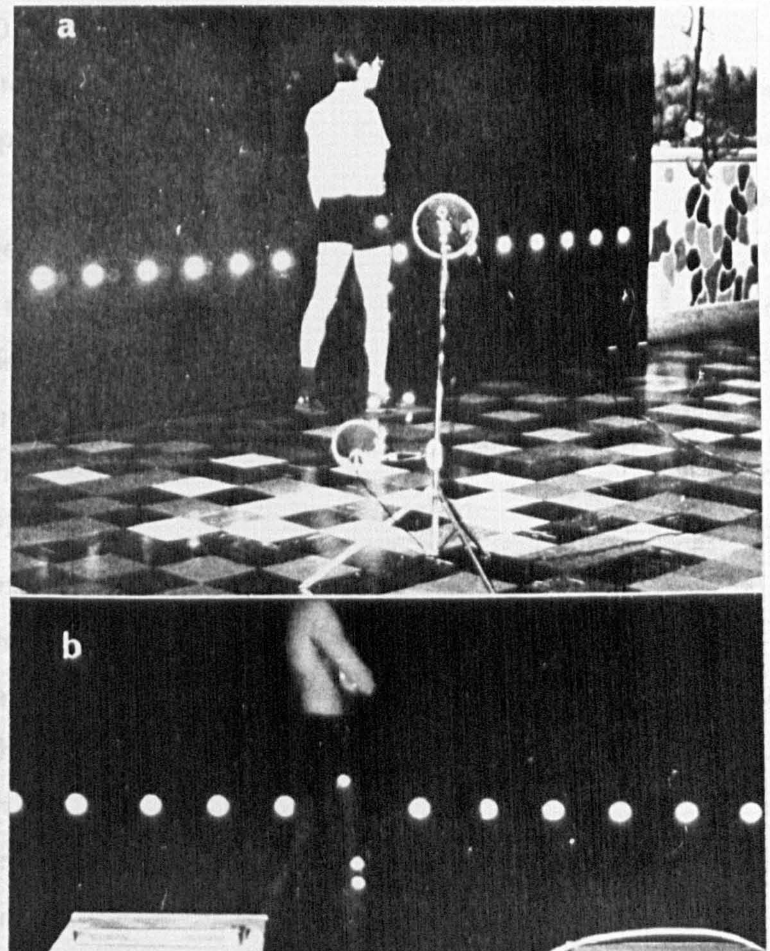


Figure 1.17. Experimental set up of the television system in use in Winnipeg. (From Winter (1972)).

instantaneous camera position is obtained from large markers placed at known intervals in the background, one such marker always being within sight of the camera. These background markers are larger than the body markers and so can be identified in the resulting digital data. Even the restricted sample matrix of 96 x 96 for each television field results in a very high data rate of over 20,000 words/sec (assuming that the one bit analogue conversion is packed into 24 bit words for transfer to the computer). Consequently fairly large computers have to be used, in the Winnipeg case a CDC 1700. The television signal is recorded on a video tape recorder for later digital conversion, after conversion computer programs calculate the absolute co-ordinates of the centre of the body markers with reference to the background markers. Corrections being made for the parallax error introduced by the position of the background markers being some distance behind the plane of walking.

A kinematic study of normal locomotion using this system is presented in Winter (1974). From co-ordinate data for 3 to 4 strides fundamental kinematic information was calculated including - x, y trajectory plots, plots of vertical co-ordinate against time, velocities of markers, acceleration, joint angles and angular velocities and accelerations. The comparative ease with which the data for these calculations was collected demonstrates the power of the Winnipeg system. However at this stage only two-dimensional measurements can be made and the problems of introducing an additional camera to the system have yet to be overcome. No rotating shutter is used in the system. The reason for this being that in normal locomotion the vertical position of the markers only varies over a small part of the television scan and therefore the time between samples is virtually constant. Of course there is a lag between the sample instant for a marker at the top of the scan and a marker at the bottom of the scan; but this could be corrected as the time relationship between the two positions is fixed by the scanning rate, which is known.

On line use of a PDP 11/10 mini-computer was made by Cheng (1974) to obtain co-ordinates of markers from a television camera. This system is quite similar, in some ways, to the Dutch system. 8 bit counters are used for the horizontal and vertical co-ordinates. The horizontal counter is clocked at a frequency of 4.55 MHz, and reset by the line blanking pulses (using the American standard television system), which gives 241 horizontal intervals. The vertical counter is clocked by the line blanking pulses and reset by field blanking pulses, giving a count of up to 246. A simple threshold circuit is used to detect the presence of a marker signal in the video (either reflective markers or light sources are used), and on receipt of a marker pulse the contents of the horizontal and vertical counter are stored in a buffer register. At the same time a program detectable flag is set so that the contents of the buffer may be transferred under program control to the computer memory. On transfer the computer checks the data to see if it is "noise" (caused by the interface at the beginning of each field). If the data is not "noise" then it is compared with previous data to see if it is caused by a marker being detected on several lines. If the data is a new set of co-ordinates then it is stored for later output onto paper tape. Another program detectable flag indicates the end of a television field. During this programmed transfer and evaluation the interface is prevented from detecting further markers. The computer program written to process the interface data would, in the worst case, inhibit further co-ordinate generation for 117 μS (best case time would be 74 μS). This limits the system to detecting a maximum of one marker on any line, which effectively prevents markers being placed at the same vertical position on the body (such as markers on the pelvis for the frontal view). This could be improved, by resetting the "ready" flag immediately after the interface data has been stored, to a worst case time of 34 μS (best case 25 μS). However this is still an unacceptable limitation (greater than half of the television line would have been scanned in this time). No corrections are made for non linearity of the camera system and, because the system only operates in two-dimensions, corrections cannot be made for parallax errors.

All of the systems reported, and still in use, can collect data for two-dimensional movements. At present none of the systems are operating in three-dimensions, and only the Winnipeg system incorporates other measuring facilities (EMG data). The Winnipeg system requires that the camera is moved with the subject, but this does give fairly high resolution. However a fairly large computer is required to derive the basic data, and it is unlikely that results could be viewed in the laboratory within a short time of the test. The results from Winnipeg have indicated the feasibility of using television to obtain useful displacement/time data. The Dutch system and that of Cheng have very much lower data rates but they do not make full use of the available resolution of a television camera; and the methods of data transfer to bulk storage limit the marker configuration that can be used.

CHAPTER 2

POSITION DETECTION OF THE BODY SEGMENTS IN SPACE USING TELEVISION

2.1 Introduction

The television camera is a sequential scanning device which converts a light pattern focussed onto a target plate into an analogue electrical signal the amplitude of which is proportional to the amount of light falling on the target. The time co-ordinate of this waveform is related to position on the target. With the British 625 line system the target is scanned from top to bottom by 292 lines every 20 mS; as a line is scanned the charge pattern on the target, corresponding to the light pattern, is substantially removed and a fresh charge pattern may be built up. The charge pattern will be retained on the target for some time until it is scanned. Unless some means of controlling the exposure of the camera target is used the trajectory, between samples, of a movement will be stored on the target (smear effect). This exposure may be controlled by using a rotating synchronous shutter (Ingen Schenau (1973)); although it is quite possible to compute the average position of a moving point between sample instants from the trajectory and dispense with the need for exposure control. The resolution of the television camera is 1 part in 292 in the vertical scan and 1 part in 1000 in the horizontal scan. The spatial resolution is, therefore, 0.34% and 0.1%. The sampling frequency of British television systems is 50 Hz; which, according to Winter's studies (Winter (1974)), should be sufficient for locomotion studies. The basic principles and parameters of television are further discussed in Appendix A1.

2.2 Detection of the Segment

For the purposes of locomotion analysis it is necessary to find the spatial co-ordinates of defined points on the skeleton. This requirement precludes the possibility of detecting the outline of a limb and then deriving the co-ordinates of that part of the skeleton. The outline of the limb has a certain degree of mobility with respect to the skeleton; also it would have to be assumed that the bone was placed centrally in the limb tissues so that rotation of the limb had no effect on the relative position of the bone and outline as the television camera is a two dimensional detector. A further objection to this method is the high data rate that would be required to define the outline. With the television camera field of view concentrated on, say, one lower limb a data rate in excess of 30,000 words/sec. would be required. It would not be possible to measure rotations of the limb and there would be problems in detecting the outline when other body parts formed the background. Although the method is attractive in that it would require no attachments of any sort on the subject, it is impractical for the reasons outlined above. Methods of marking anatomical landmarks were, therefore, considered.

2.3 Markers

Anatomical landmarks may be indicated with active or passive light sources. Light emitting diodes (LED's) have been used as light sources in various opto-electronic systems (Selcom (1975), Mitchelson (1974), Cheng (1974)). With this type of source it is necessary to use a diffuser over the source in order to obtain radiation of light in as wide a solid angle as possible, because the LED normally has its maximum intensity of radiation in one main direction. Without a diffuser it would be necessary for the source to be always pointing at the camera, clearly this condition could not be met when marking a point on the limb, due to rotations. Using a diffuser reduces the already restricted optical power of the LED. Peak power can only be obtained when the LED is pulsed - up to a point the shorter the duration of the pulse, and the lower the repetition rate (duty cycle), the higher the optical power that can be obtained. To be able to detect short duration light pulses a camera target having a fast response would have to be used, which is costly. The highest power, currently available, LED's emit light in the infrared region; this has the advantage that the light is not visible and will, therefore, not distract the subject. Also ambient illumination which does not emit in the infrared region can be arranged (Fluorescent lighting for example,) and optical filters may be used to ensure that peak signals from the camera target are only caused by infrared sources.

Incandescent light bulbs can provide much higher intensity levels, with a much greater solid angle of radiation than LED's; but they tend to be bulkier and, of course, the light is visible and may distract the subject. All active light sources require a power supply. This may be provided by small individual batteries for each source, or a central power supply carried by the subject. If the higher power of LED's, obtained by pulsing them, is to be used then a pulsing circuit and a means of synchronisation with the television scan would be required. Inevitably, with active light sources, there will be connecting leads and also some reasonably firm method of fixing the source to the skin would be required.

Passive markers require no power supply or connecting leads, and are easily attached to the skin, with no restriction of the subject's movements. Several materials were considered from which to form markers, these included polished metallic surfaces, white paper, retro-reflective tape and coloured versions of these. The materials were compared by placing 5 mm diameter samples of each onto a plywood board (which effectively simulated skin tones) and observing the level of the video signal caused by each under the same lighting conditions. Retro-reflective tape gave by far the best response and was selected as the most suitable marker material.

2.3.1 Response of Retro-Reflective Tape

The retro-reflective tape used was 3 M's "Scotchlite" (see Appendix A4 for characteristics). This material is a plastic sheeting containing extremely small spherical glass lenses which are uniformly bonded at their equators. The optical glass lenses function as microscopic spherical mirrors which focus and return (retro-reflect) incoming light rays directly back to the light source. The sheeting has a pressure sensitive adhesive on the reverse side which is covered with a removable paper liner. To obtain the maximum response from this material, in the television video signal, the lighting must be positioned as close as possible to the camera lens.

With two Malham SE 23 lamps fitted with tungsten halogen 500W bulbs, one on each side of the camera lens, and a camera field of view of 2.5 m the following results were obtained:- 1) the video level of the marker was 90% higher than the level of skin tones 2) the level of signal was within 5% of its peak over the entire field of view 3) rotations of the marker of up to 30° resulted in a change of video level of no more than 5%. These results were obtained using a marker of 5 mm diameter and a television camera with a plumbicon tube. Normal room lighting was left on during these tests as it was considered undesirable to use markers which would require low levels of background illumination.

On the basis of these results it was decided that passive markers of retro-reflective tape would be used instead of active light sources, thereby eliminating the need for power supplies and connecting wires on the subject.

2.3.2 Size of Marker

The size of marker will depend on the type of system evolved. However the minimum size of marker is defined by the television camera parameters and the dimensions of the field of view. To be sure that the marker is detected in the video signal it must be large enough to cover at least two scan lines sufficiently to provide a detectable signal on each. The diameter, D, of a marker to meet these requirements is given by:-

$$D = \sqrt{(W.Hr)^2 + (H.Vr)^2}$$

where Hr = horizontal resolution of camera

Vr = vertical resolution of camera

W = width of field of view covered by horizontal scan

H = height of field of view covered by vertical scan.

For a television camera with a horizontal resolution of 1 in 1,000, and a vertical resolution of 1 in 292 covering a field of view of 2.5 m x 1.8 m a marker diameter of 7 mm would be required. A smaller marker could still be detected, although it would not give as high a signal level.

2.3.3 Marker Shape

The basic shape of a marker which is used to indicate a point on the body should be circular, so that permitted changes in orientation of the marker with respect to the camera axes do not change its effective shape. If it is desired to detect the same marker at two cameras whose axes are at right angles to each other (as in the case for 3-dimensional measurements) then the marker should be spherical.

2.3.4 Marker Discrimination

The response obtained from retro-reflective tape is so good that all that is required to detect a marker signal in the video is a simple threshold detector. However an alternative method was considered which could be worth using in a "noisy" situation. This method uses patterned markers and a hardware pattern recognition system (Jarrett (1973)). A very simple pattern recognition system for the marker of Figure 2.1a is shown in Figure 2.1c. When the video waveform, shown in Figure 2.1b, reaches a lower threshold level an enabling pulse of duration T sec is triggered off, if at any time during this period the upper threshold limit is crossed the "marker detected" pulse is generated, as shown in the timing diagram of Figure 2.1d. This idea can be extended to more complicated patterns, which would reduce the risk of a pattern being generated by noise and also would eliminate the "smearing" effect of the television camera. An example of this is shown in Figure 2.2. This design of marker would eliminate the smear effect because the pattern would only be picked up at the end of the marker trajectory during each sample period.

In the laboratory conditions used it was not found necessary to resort to pattern recognition techniques for marker discrimination. A simple threshold detector as shown in Figure 2.3 was used and found to be reliable. A more sophisticated threshold detector which automatically adjusted its comparison threshold to be a certain proportion of the peak signal received was developed from a basic design by Texas Instruments (1974) by B. Andrews. The basic principle of operation for this detector is shown in Figure 2.4. The advantage of this type of threshold detector is that any variation in signal level from the marker is automatically compensated for. The circuit for this detector is shown in Figure 2.5.

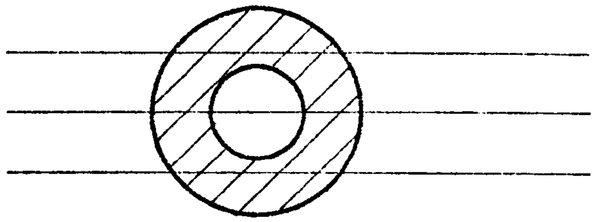


Figure 2.1a Patterned marker.

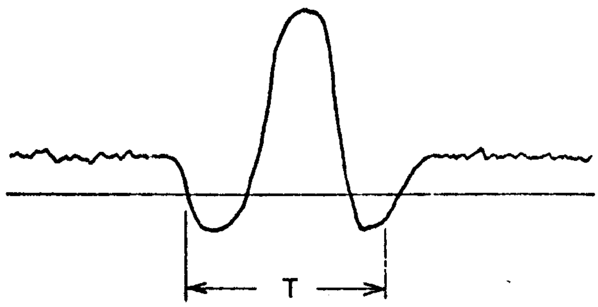


Figure 2.1b. Video signal produced by marker.

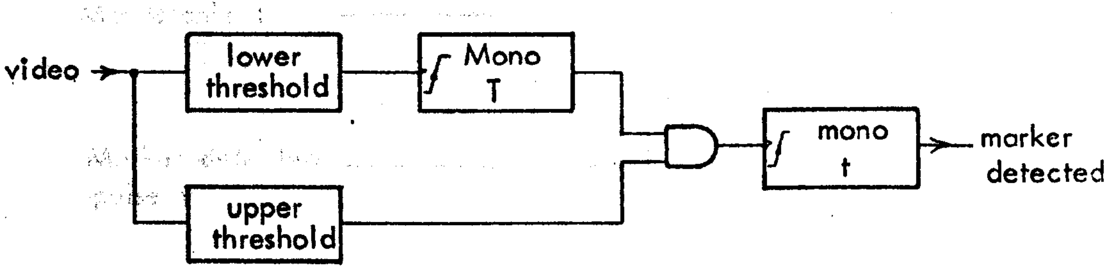


Figure 2.1c. Hardware pattern recognition system for the marker shown above.

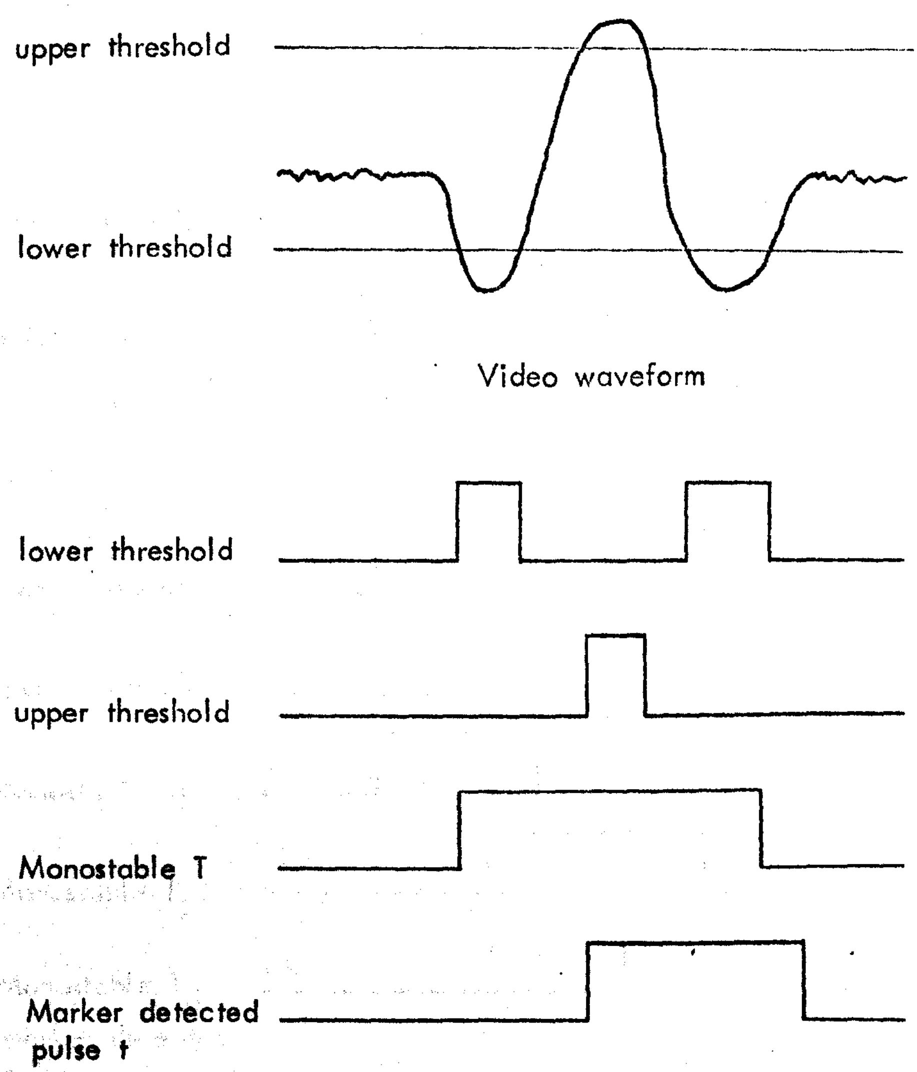


Figure 2.1d Video waveform of patterned marker and timing diagram for the logic of Figure 2.1c.

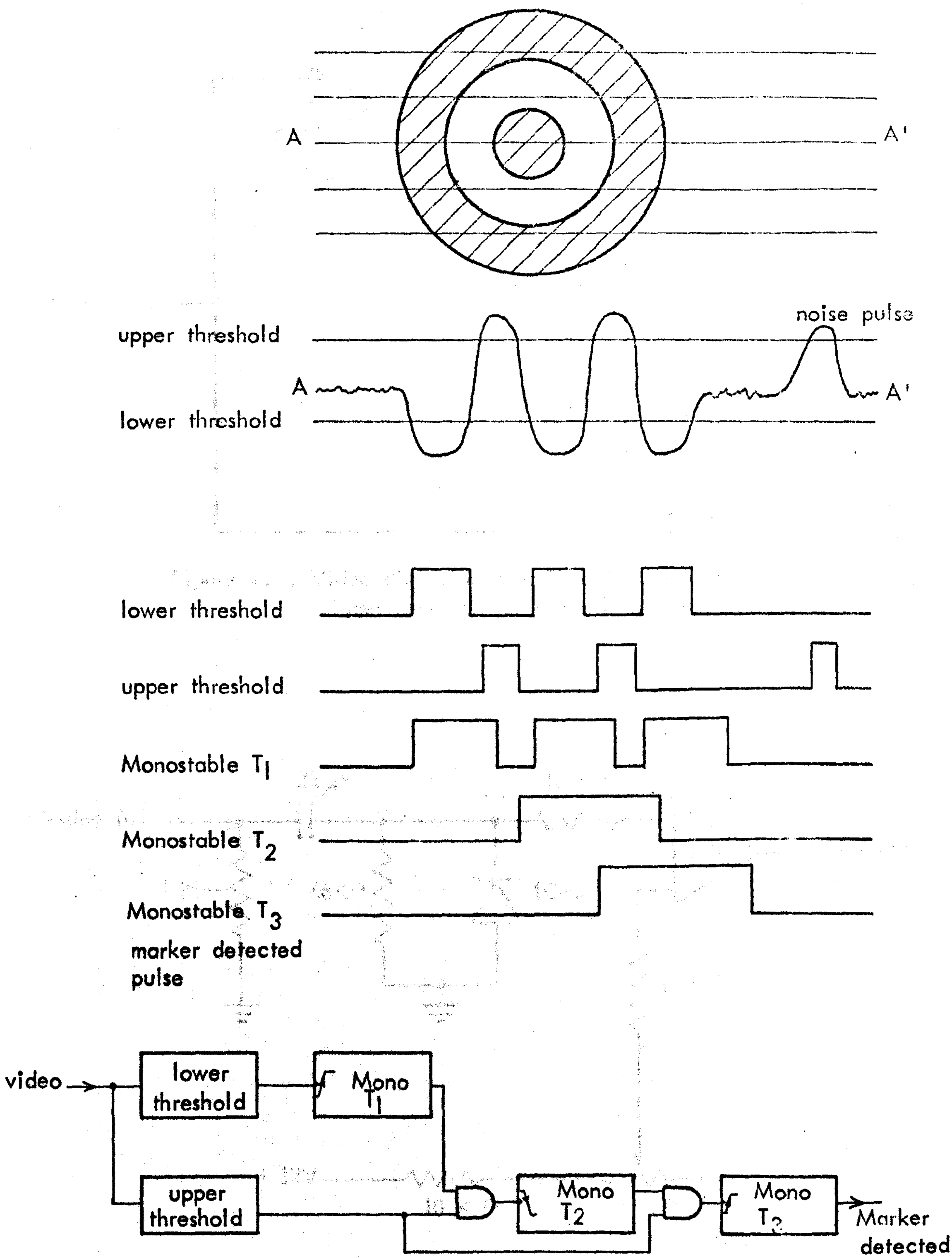


Figure 2.2. Pattern recognition system to eliminate "smear effect" of the television camera. The patterned marker and its video waveform are shown together with the decoding logic and a timing diagram.

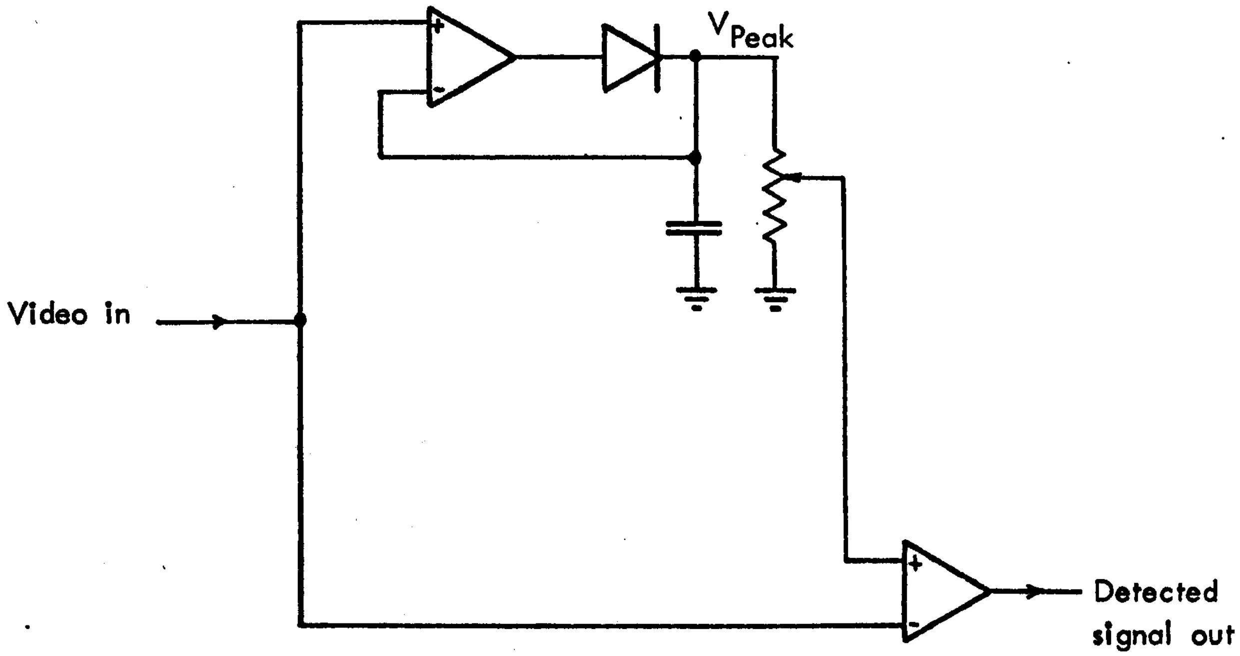


Figure 2.4. Video digitising circuit with automatic trigger level (From Texas Instruments (1974)).

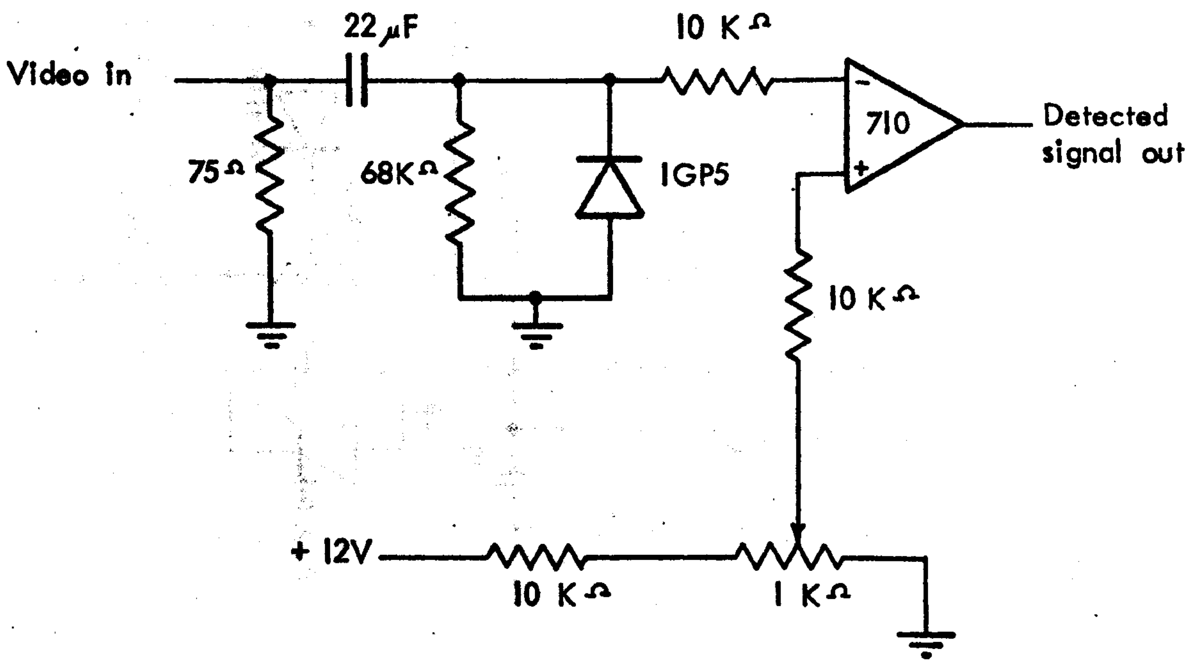


Figure 2.3. Threshold detector circuit used for marker detection.

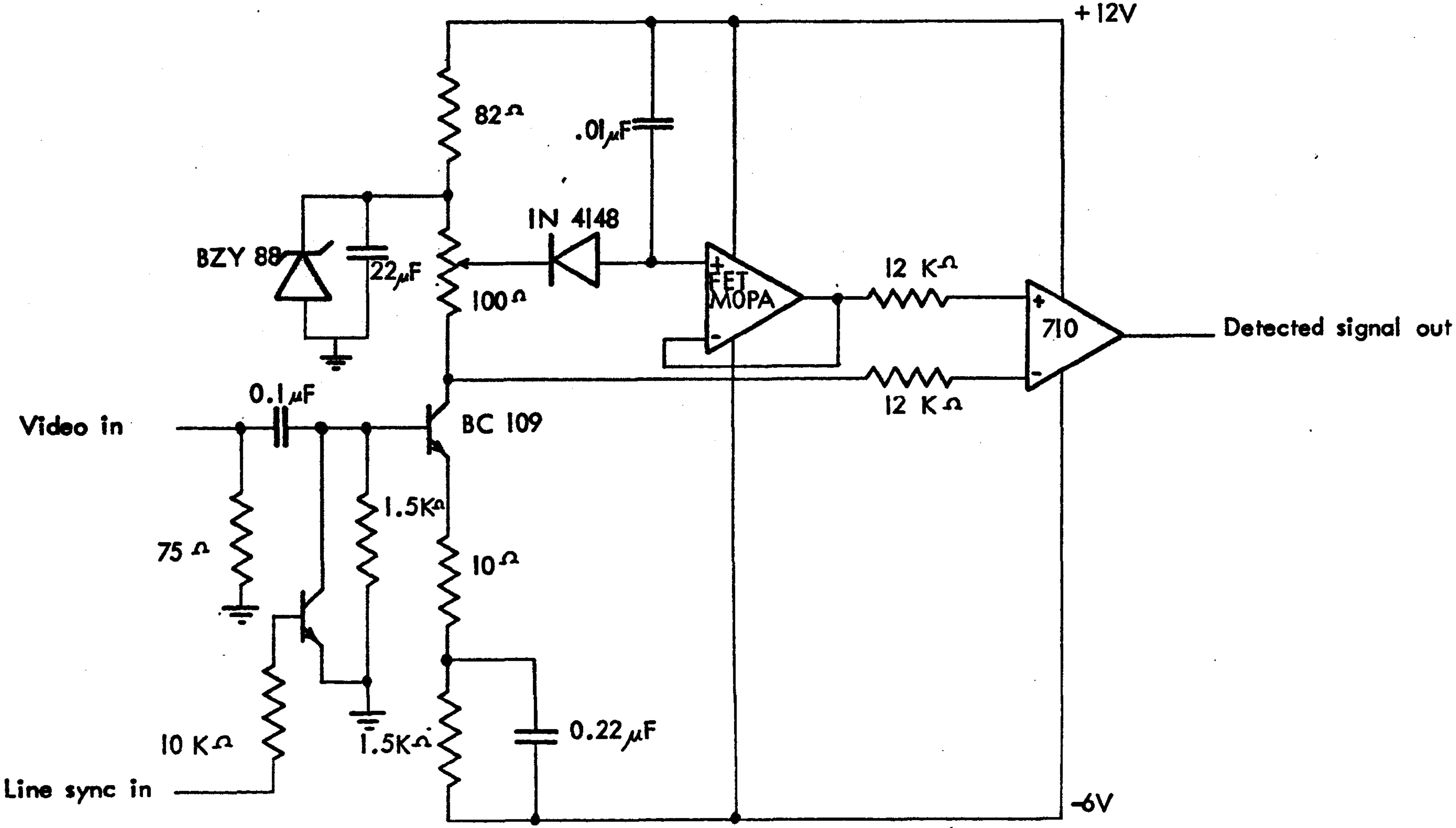


Figure 2.5. Circuit for the scheme shown in Figure 2.4 (developed by B. Andrews (1976)).

CHAPTER 3

THE INTERFACE

3.1 Introduction

The currently functioning television/computer systems for locomotion analysis are all limited in several respects. This interface was designed to overcome most of these limitations and provide a certain degree of flexibility in its mode of operation. The acquisition of kinematic data is but one of the requirements for locomotion analysis. In a few cases it may be the only requirement, however a complete analysis would include measurements of other parameters, such as external forces.

The requirements to be met by the interface were as follows:- 1) to be capable of measurement in three dimensions; 2) the ability to provide the co-ordinates of more than one marker on any single television scan line; 3) that the number of co-ordinates collected during one television field is limited by the computer and other considerations, not by the interface; 4) to allow extension of the system without loss of performance; 5) to provide a system of calibration; 6) to allow simultaneous and synchronous operation with other data acquisition systems; 7) to be simple to operate and maintain.

Any system which uses a small computer, such as a PDP 12, must have a restricted data rate. The method used by Winter (1972), in which the whole video signal is converted into a digital equivalent and stored, is not practicable. However it is not necessary to restrict the data rate so much that only a very limited number of co-ordinates can be collected in each television field. In the following systems the data rate is restricted by only generating co-ordinates when a marker signal is detected in the video.

Frequent reference will be made in this section to the basic terms and parameters of television systems, further explanation of these will be found in Appendix A1. Similarly where reference is made to the PDP 12 computer further details will be found in Appendix A2.

3.2 Analogue System

Initially an analogue method of interfacing the television cameras to the computer was considered (Jarrett (1973)). With this system detection of a marker pulse in the video signal caused the computer to sample two ramp voltages, the ramps being initiated by the line and field synchronising pulses of the television scan. The voltages sampled by the computer corresponded to the co-ordinates of the marker and were digitised and stored. A three dimensional system was proposed in which the video signal from the second camera was mixed with that from the first. The fields of view of the two cameras were arranged so that the side view camera observed the lower limb in the bottom half of its scan, and the front view camera (turned on its side) observed the lower limb in the top half of its scan. The relevant parts of the video signals containing co-ordinate information were then mixed to provide one composite video signal as shown in Figure 3.1. A block diagram of this system is shown in Figure 3.2, and it can be seen that this was a very simple method which required only three inputs to the PDP 12.

The advantages of this system were that it was extremely simple and could probably be used on different computers with little or no modification, and that it was possible to record three dimensional tests on a single video channel, allowing off line experiments to be conducted. The disadvantages far outweighed these merits in that the co-ordinates of only one marker on each television line could be acquired; the resolution was very limited; the system could not be expanded to cover several strides or the whole body without a further loss in resolution; ramp generators of high stability and linearity were required; and the potential data acquisition capabilities of the PDP 12 were wasted. Some of these limitations could undoubtedly have been overcome (using several sample and hold circuits, for instance, to immediately store the value of ramp voltages on detection of marker pulses), but investigations into a digital system (Jarrett (1973)) showed that it was possible to provide a much more powerful and flexible system in this way.

3.3 Digital System

The design of a digital system to meet the requirements listed at the beginning of this chapter requires that the performance capabilities of both television cameras and the computer are used to the full. One crucially important aspect is the means of data transfer between interface and computer.

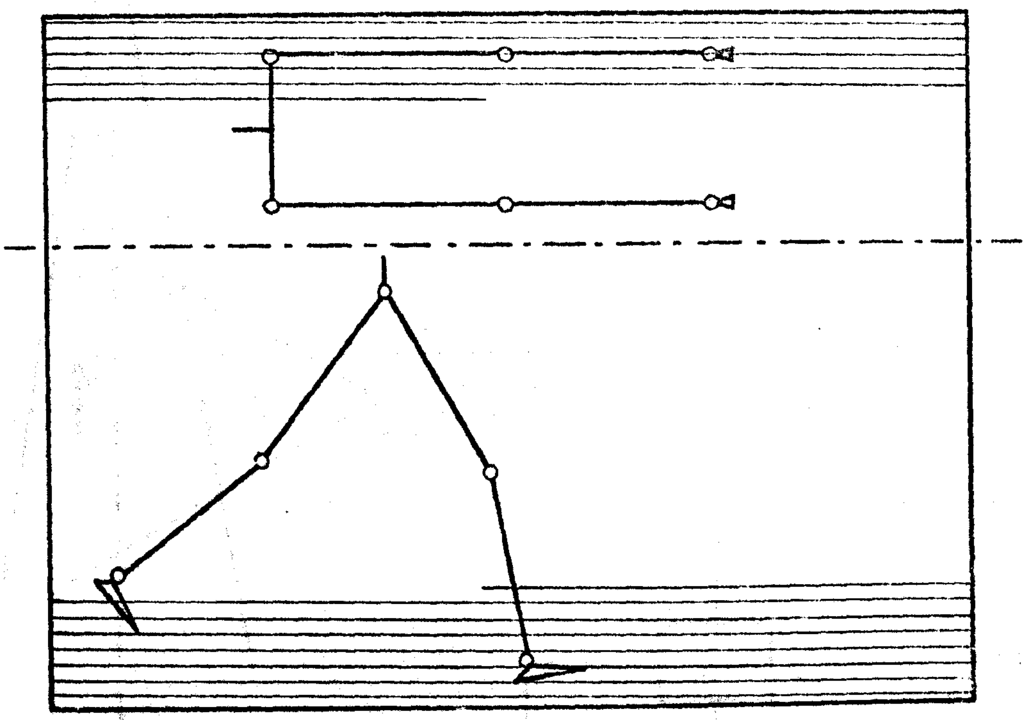


Figure 3.1. Division of television field for 3-D analogue system. Two camera video outputs are mixed as shown.

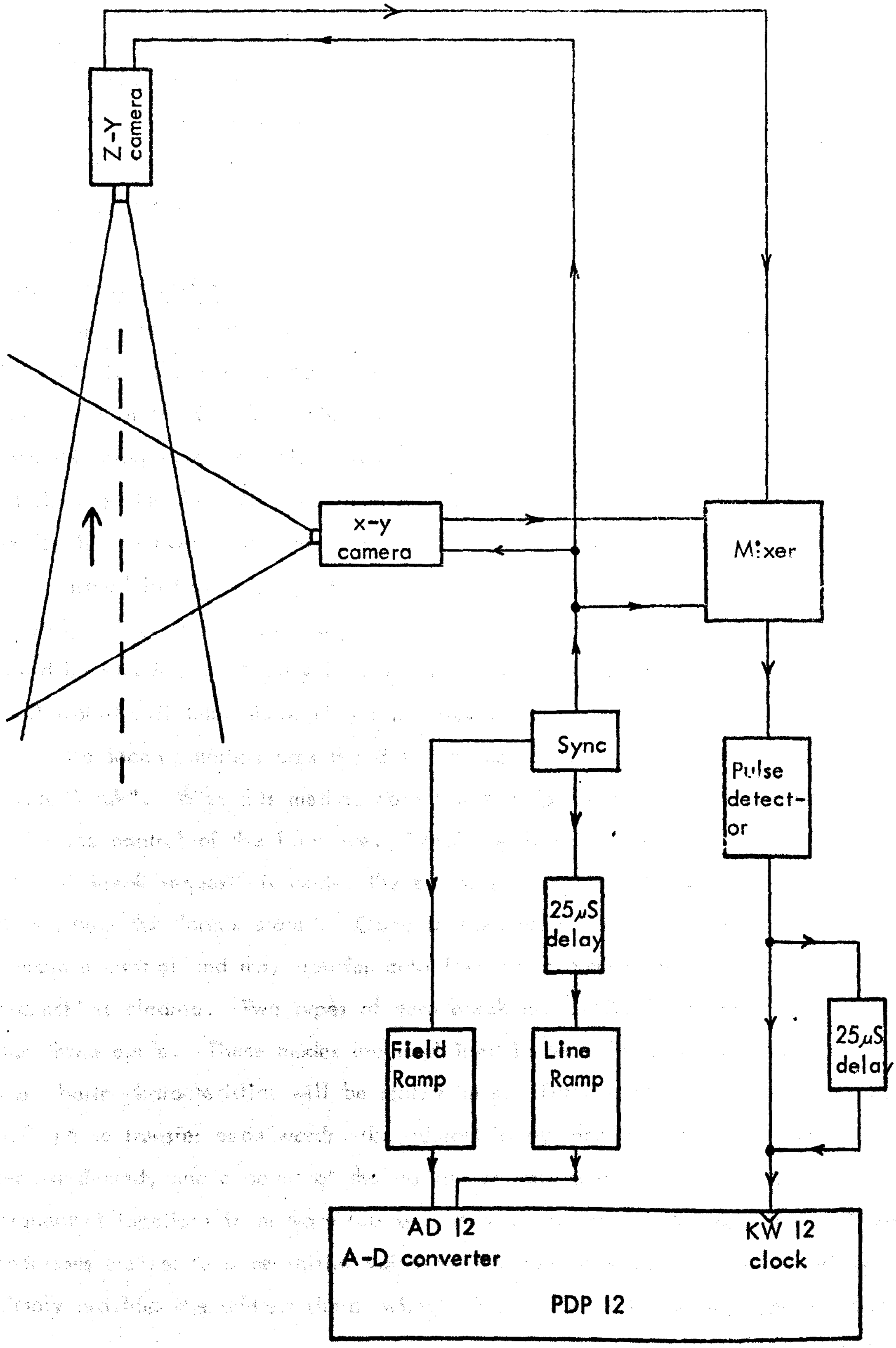


Figure 3.2. Three dimensional analogue system.

Other aspects that must be considered are the use of more than one camera to obtain three dimensional data, future extension of the system, simultaneous operation with other systems, control of the interface, calibration, and maintenance. By taking all these aspects into consideration at the design stage it should be possible to arrive at a near optimum solution with the minimum of compromise.

3.3.1 Data Transfer

There are two basic methods by which digital data can be transferred to the PDP 12. The first method, "programmed data transfer", requires that a flag is set in the interface when there is data ready to be transferred, a computer program senses this condition and transfers the data word from the interface to the Accumulator. The program must then store the data in memory, decide if any more data can be transferred, and clear the flag. This process is illustrated in Figure 3.3 with the time taken for each step shown in brackets, a total time of 19.05 μS being required to transfer each word. The operation could be speeded up slightly if a block of data was transferred each time, even so it would still take about 15 μS per word.

The second method uses the direct memory access facility of the PDP 12 - "Data Break". With this method data transfers to the computer are made under the control of the interface. When the interface is ready to transfer data a "break request" is made, the computer completes the current cycle and then enters the "break state". Once in the "break state" the interface has complete control and may transfer data from or to memory until the "break request" is cleared. Two types of data break are available - single cycle and three cycle. These modes are explained in detail in Appendix A2, but their basic characteristics will be stated here. Three cycle data break requires 4.8 μS to transfer each word; the address in memory to which the data is to be transferred, and a count of the number of data words is provided by two sequential locations in memory (current address and word count registers). These locations are set to some initial value by the computer program, the interface simply provides the address (hard wired) of the first of these locations together

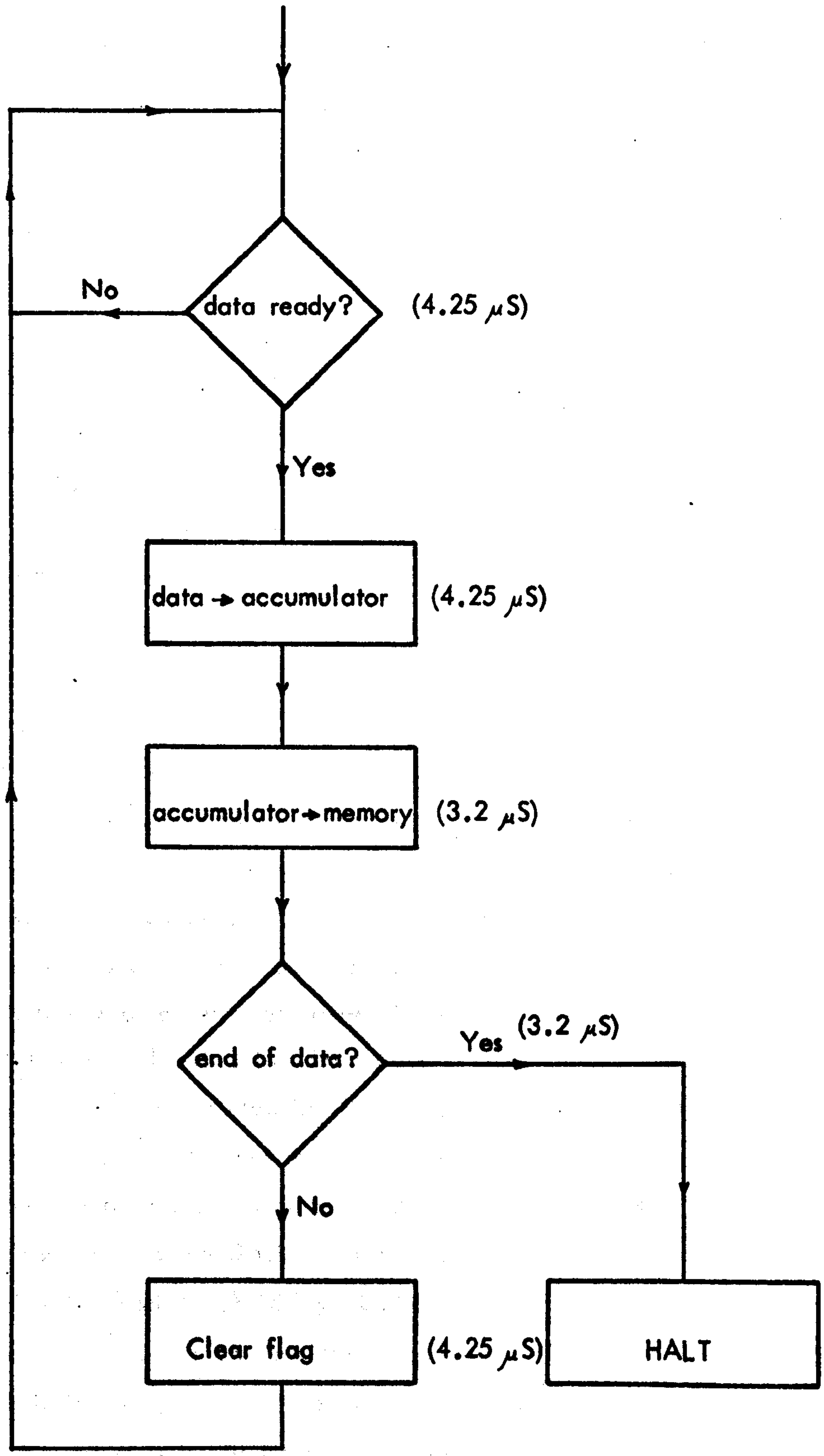


Figure 3.3. Programmed data transfer.

with the data word to be transferred. When data transfers are made the word count and current address registers are automatically incremented, overflow of the word count register indicating that all the data has been transferred. With single cycle data break the current address and word count functions are provided by the interface and only 1.6 μS is required to transfer each word. All of these data transfer methods can be used to transfer data in either direction.

The fastest of these methods still takes 1.6 μS to transfer each word, in addition to the time required to answer the break request (latency time; which could be anything up to 18.2 μS, but more usually around 1.6 μS). To transfer a vertical and a horizontal co-ordinate, therefore, will take 4.8 μS, which is approximately 10% of the active line time of the horizontal scan. In terms of distance, if a field of view of 2.5 m horizontal length were being covered, this would mean that co-ordinates could not be generated for markers which were closer than 25 cm and appeared on the same television line. If a second camera were being used then only markers separated by at least 4.8 μS scan time could be recorded. For some marker configurations this limitation is of little consequence, however if it is required to mark several points which lie close together (such as on the foot) then the limitation is unacceptable. This problem can be overcome, quite simply, by using a data buffer in the interface. As markers are detected their co-ordinates are immediately transferred to the buffer memory; allowing for the delays of the necessary control logic this operation may be completed in 100 nS or less, or 0.2% of the active line time (a distance of 0.5 cm in the above example).

The use of a buffer memory in the interface will still place some restrictions on data acquisition. However, these restrictions may be minimised by making the correct choice of data transfer time to load the buffer into computer memory. Three possible times are available for this operation. The first possibility requires the use of a double buffer memory - as one is being filled, the other is being unloaded into computer memory. The additional complexity and expense of a double buffer was considered to be unnecessary when the other methods were appraised. The second method uses the field blanking period, when there is no picture information, to transfer data. This period lasts for approximately 1.2 mS and therefore 750 words of data could be transferred using single cycle data break (250 using three cycle data break). It would be unwieldy as well as expensive to provide a buffer memory of such capacity in the interface, whereas a buffer size of, say, 50 words is practical but something of a compromise. The third, and chosen, time for data transfer is the line blanking period, which lasts for 12 μS. If single cycle data break is used then up to 7 words of data could be transferred within this period. Transfers could be made on every active line so a total of 2000 words could be transferred during any single television field.

3.3.2 Co-ordinate Generator (CG)

A block diagram of the basic co-ordinate generator system is shown in Figure 3.4. The crystal controlled sync generator provides a composite sync to control the camera scan. Line syncs increment a vertical counter which is reset by a field sync. To take account of the effect of interlaced scanning (see Appendix AI). and also to indicate the transition from one television field to the next, the vertical counter counts over two fields i.e. up to 625. This is done by only resetting the counter on every other field sync. A horizontal counter is incremented by a high frequency clock (20 MHz), and counts approximately 1000 intervals along the television line before being reset by the line sync. When a marker is detected in the video signal a marker pulse is generated which causes the latch to immediately read the current contents of the horizontal counter. This horizontal co-ordinate is then transferred to the buffer memory and the system is then ready to repeat this process if necessary - total time $\sim$ 100 n S. The horizontal co-ordinates of up to 5 markers can be stored in the buffer memory. At the end of the television line the contents of the vertical counter (i.e. the vertical co-ordinate) are transferred through the horizontal counter and the latch into the buffer memory. A "break request" is made and the contents of the buffer memory are transferred to the core memory of the PDP 12 during the line blank period. The interface is ready to repeat this procedure, if markers are detected, on the next line.

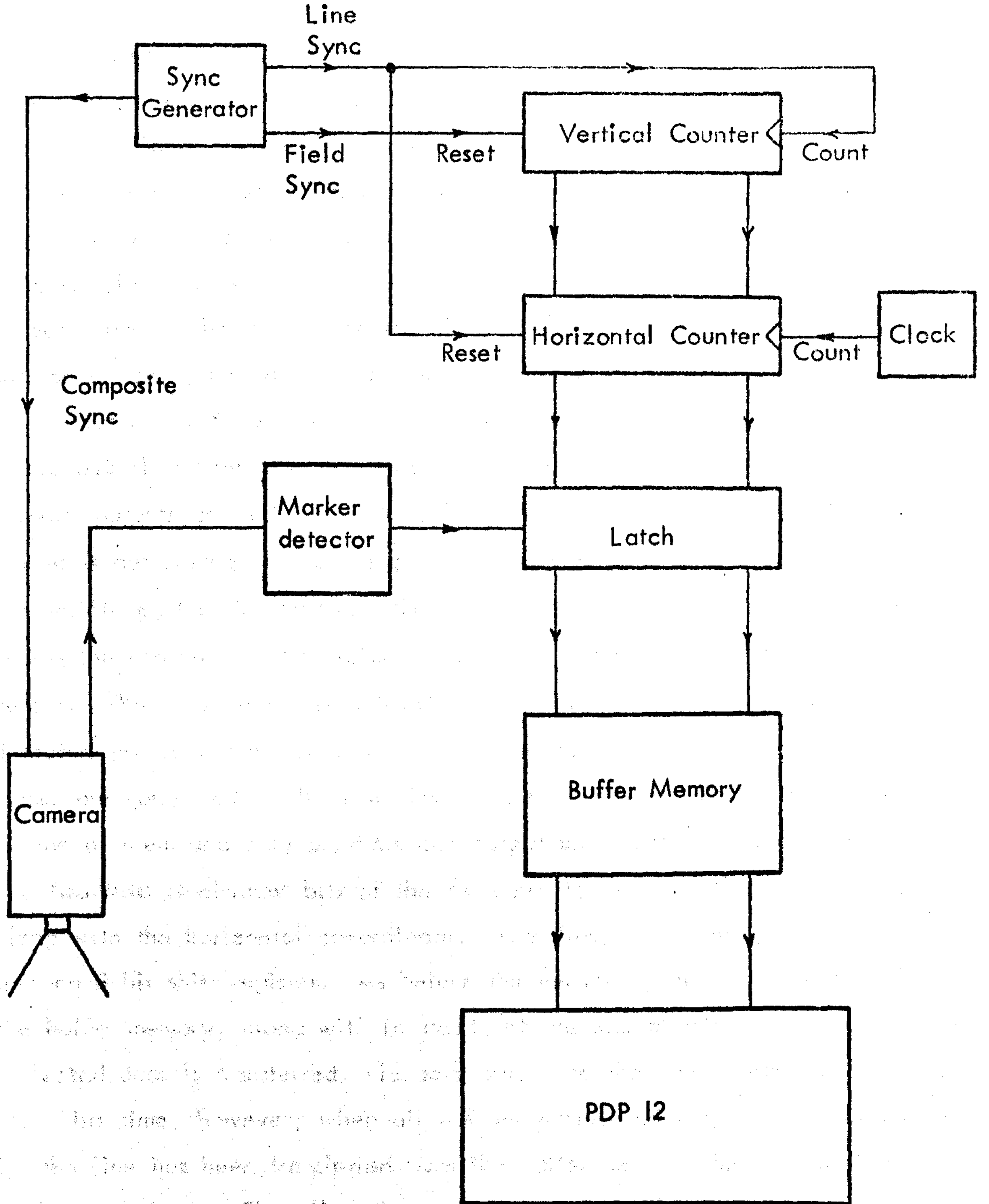


Figure 3.4. Basic Co-ordinate Generator.

The vertical and horizontal co-ordinates require a 10 bit word for binary representation. The word length of the PDP 12 is 12 bits, thus two bits are available for coding purposes (4 separate codes). As the number of horizontal co-ordinates collected during any one line are variable (up to 5) it is necessary to use one code to identify the vertical co-ordinate. The three remaining codes could be used to indicate three cameras. This would be adequate for the three dimensional requirement, but to allow future expansion of the system it was considered desirable to provide codes for up to six cameras. To do this a 3 bit code is required. The block diagram of Figure 3.5 illustrates how the system, with coding, operates. The 6 marker detector outputs are fed into a 6 to 3 coder and priority register. When a marker is detected in a video signal a marker pulse is generated by the appropriate marker detector and the priority register provides a pulse which causes the contents of the horizontal counter to be read by the latch, as before. The coder provides a 3 bit code to indicate which of the 6 marker detectors provided the marker pulse. In the event that two or more marker pulses are generated at the same instant the priority register allocates priority to one of them and only provides one output pulse and the appropriate code. The two most significant bits of the code are loaded into the buffer memory along with the horizontal co-ordinate. The third bit of the code is clocked into an 8 bit shift register. As before the vertical co-ordinate is loaded into the buffer memory, along with its code, at the end of the line; and then the collected data is transferred, via data break, to the core memory of the PDP 12. This time, however, when all the horizontal and vertical co-ordinate data for the line has been transferred from the buffer memory the shift register word is then transferred. The allocation of codes is shown in Figure 3.6, and it can be seen that the vertical co-ordinate is unique and independent of the third bit. Data is always transferred to computer memory in the same order, that is the vertical co-ordinate followed by up to five horizontal co-ordinates and lastly the shift register word. It is then a simple matter for the program to reconstruct the appropriate codes, and hence define the cameras from which a particular co-ordinate came.

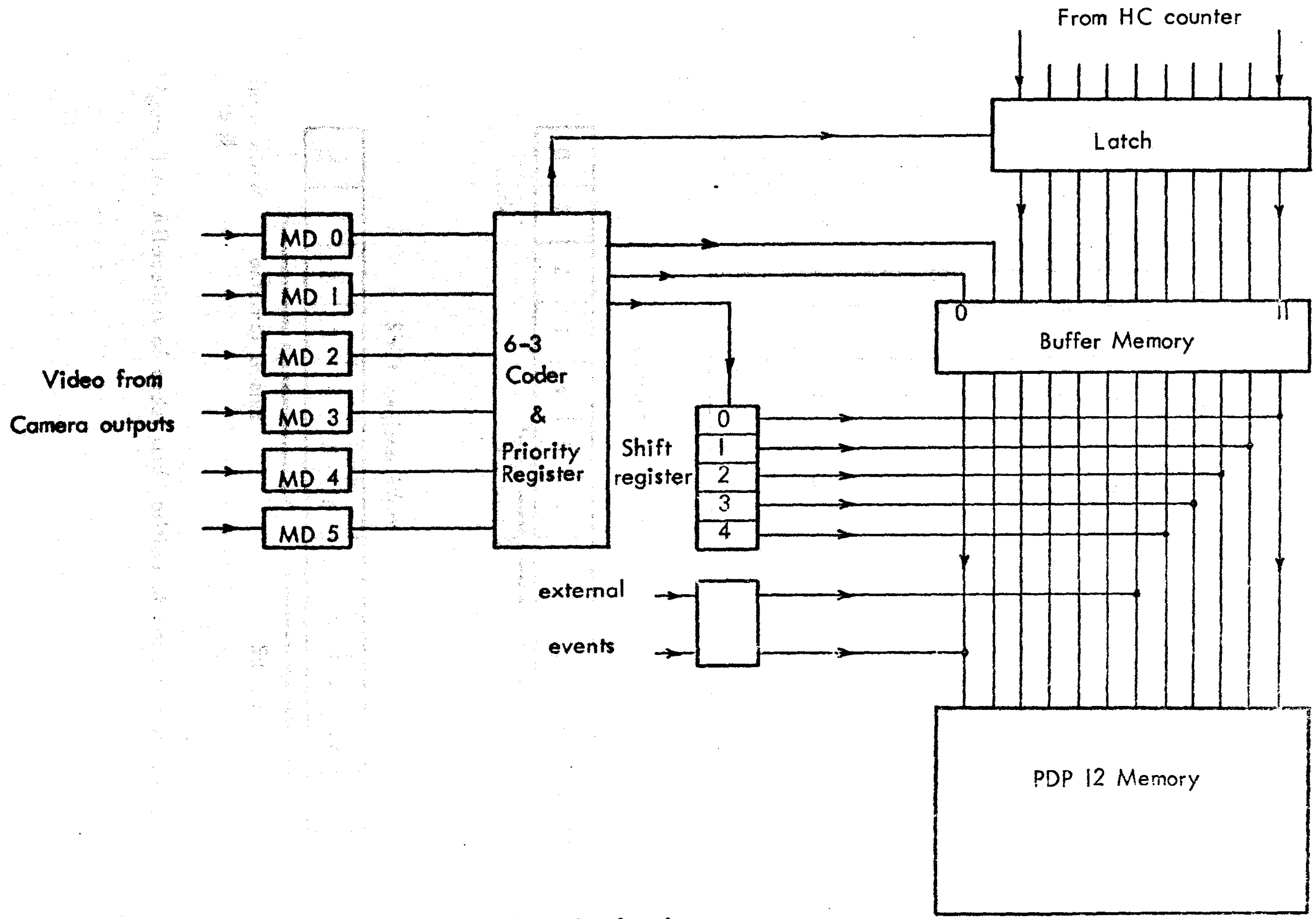
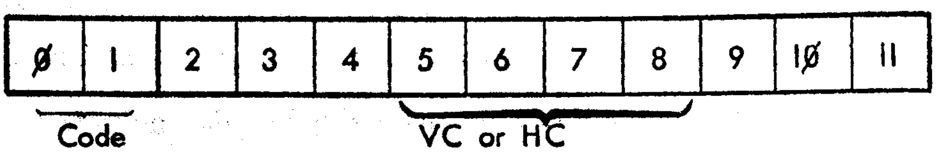


Figure 3.5. Scheme to provide codes for six cameras.

Code bits			Allocation
Ø	1	SR	
Ø	Ø	Ø	MD 0
Ø	Ø	1	MD 1
Ø	1	Ø	MD 2
Ø	1	1	MD 3
1	Ø	Ø	MD 4
1	Ø	1	MD 5
1	1	Ø	VC
1	1	1	VC

Co-ordinate Word



Shift Register Word

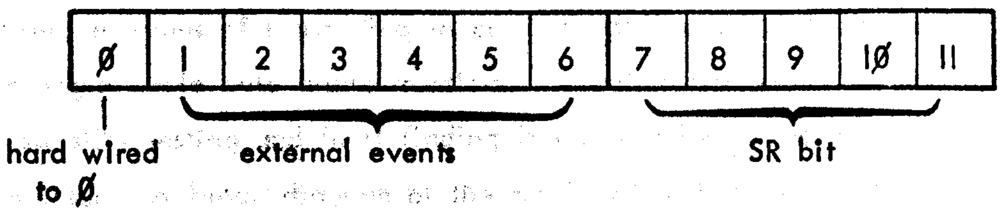


Figure 3.6. Allocation of codes and position of code bits in data.

With the data break method it is possible to run a program independently of data transfer (with due regard to areas of memory used for program and data transfer). As a maximum of 7 words are transferred during any one television line, and as data is only generated when a marker is detected, there is a considerable amount of time available for running programs. Some of this time can be used for collecting data, via the analogue to digital conversion facility, from other measurement systems such as a force plate. This data collection must be synchronised with the television system and the interface provides synchronising pulses for this purpose. To avoid the restriction of having to start data acquisition simultaneously a means is provided for indicating when additional measurements are started. This is done by using the spare bits in the shift register word (total 12 bits when transferred to the PDP 12). With this word the most significant bit is permanently set to '0' to avoid ambiguity with the vertical co-ordinate code. As the system is restricted to 5 horizontal co-ordinates on any one line then 6 bits of the shift register word are available for additional coding. When data collection from some other measurement system is started one of these bits is set to a '1'. As the shift register word is transmitted with every set of co-ordinates the exact starting point of this other data collection is stored. An example of a set of data is shown in Figure 3.7, together with the translation of the codes.

For its operation the co-ordinate generator requires a set of synchronising pulses, a means of responding to computer software and the control facilities for single cycle data break transfers. A calibration system is required, and to simplify testing and fault finding it was considered desirable to provide a simulator. A block diagram of the total system is shown in Figure 3.8.

3.3.3 Sync Generator and Simulator (SGS)

The SGS derives from the television line and field sync inputs six related synchronisation pulses which are required at various points in the system. These are:-

location	Ø	1		2	3	4	5	6	7	8	9	10	11	Octal value of bits 2-11
0	1	1	VC	Ø	Ø	Ø	1	Ø	1	1	Ø	1	Ø	Ø132
1	Ø	Ø	HC	1	Ø	1	1	Ø	Ø	Ø	1	1	Ø	13Ø6
2	Ø	Ø	HC	Ø	1	1	Ø	1	Ø	Ø	Ø	1	1	Ø643
3	Ø	1	HC	Ø	1	1	Ø	Ø	1	1	1	1	1	Ø637
4	Ø	Ø	HC	Ø	Ø	1	Ø	Ø	Ø	1	Ø	1	Ø	Ø212
5	Ø	Ø	SR	1	Ø	Ø	Ø	Ø	Ø	Ø	1	Ø	1	Third code bits
6	1	1	VC	Ø	Ø	Ø	1	Ø	1	1	Ø	1	1	Ø133

Data as received from the interface. Bit 2 of the shift register (SR) word being set indicates that an external event has occurred.

location	Ø	1	SR (bit)	Code
Ø	1	1	X	VC
1	Ø	Ø	1(11)	Camera 1
2	Ø	Ø	Ø(1Ø)	Camera Ø
3	Ø	1	1(9)	Camera 3
4	Ø	Ø	Ø(8)	Camera Ø
6	1	1	X	

Three bits codes for each HC. X = irrelevant.

Figure 3.7. Set of data showing de-coding.

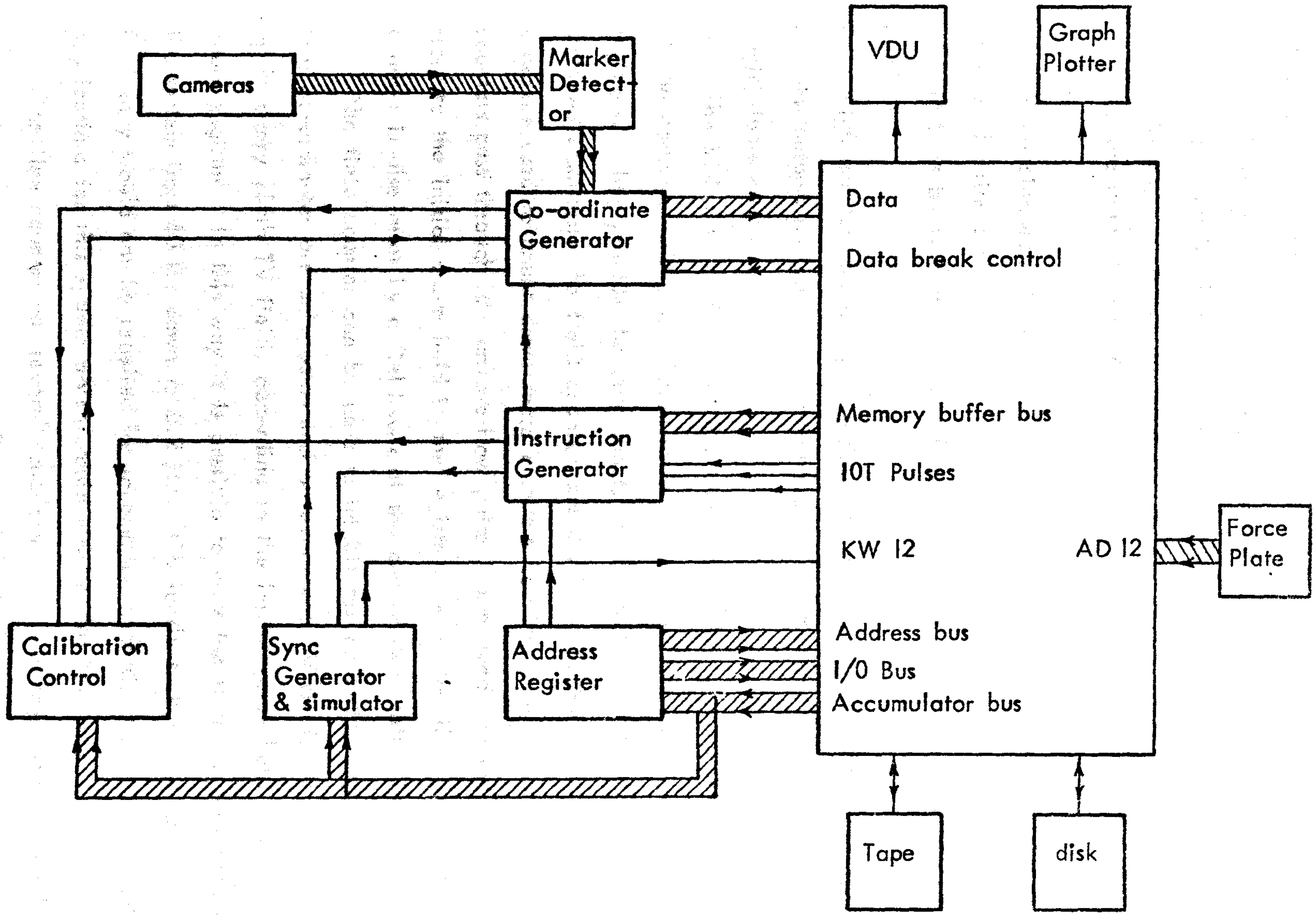


Figure 3.8. Complete System.

1) Field sync A - a 20 μS pulse occurring at the beginning of each TV field.

2) Field sync B - a 4.7 μS pulse which occurs when Field sync A and the Line sync are in phase, i.e. every second TV field (due to interlace).

3) Line sync - a 4.7 μS pulse at the start of each TV line.

4) Line blank A - a 12 μS pulse initiated by the leading edge of the Line sync.

5) Leading edge line sync - a 100 nS pulse initiated by the leading edge of the line sync.

6) Line blank B - an 11.9 μS pulse which starts 100 nS later than Line blank A.

High and low logic level versions are provided of all the above syncs and the outputs are capable of driving up to 30 standard TTL (Transistor Transistor Logic) loads each.

The SGS also contains two 8 bit registers which may be set to any value by the computer software. These registers are the Field count and Line count registers. They provide the data inputs for the initial values of two 8 bit up/down counters; the field counter and the line counter. Field or line syncs are used to count down these counters from the initial value. When the counters pass through Ø an overflow pulse is produced and the counters are reset to the initial value held in the register. With the line counter the counter is also reset by a field sync at the end of each television field.

The field counter can be used to inhibit the co-ordinate generator so that co-ordinates are only generated on every 2nd TV field, every 3rd etc. up to every 256th TV field, according to the initial value held in the field count register. In this way it is possible to vary the sampling frequency of the system from 50 Hz down to 0.2 Hz. Obviously such a low sampling frequency would not be required for locomotion analysis, but there are other applications for this system which would require this low rate.

The line counter has several functions. As with the field counter it is set to give an output pulse according to the initial value held in the line count register. The first use is to provide simulated marker signals. This is done by using the overflow pulse to trigger a series of 7 dual monostables. This arrangement produces seven 90 nS pulses at intervals of approximately 8 μS. Logic provides various combinations of these pulses, as shown in Figure 3.9. The outputs correspond to video signal levels and are capable of driving 75 Ω inputs. These signals can, therefore, be substituted for the camera inputs and be used to test the complete interface and assist in program development by providing known inputs. The number of lines on which these simulated pulses appear is controlled by the value held in the line count register which is under control of the computer program. The number of lines can be varied from every line to every 256th line. Computer instructions are available to enable and disable the simulator.

Another function of the line counter is to provide synchronisation pulses to control data acquisition from other measuring systems. The overflow pulse is used to generate these pulses so that the frequency at which they occur may be set by the program. Synchronization pulses will always start after the beginning of a field after receipt of an external enabling signal, i.e. at the request of the other measuring system. The time at which this occurs, in relation to co-ordinate generation, is stored in the shift register word as previously described.

A possible future use for the line counter is to provide a series of out of phase field syncs. This can be done using the logic shown in Figure 3.10. At the beginning of each normal field a '1' is clocked into the shift register. This causes a 160 μS field sync to be generated by monostable 1 at FS1. An overflow pulse from the line counter clocks this '1' along the shift register producing as it goes 160 μS field syncs at FS2, FS3 etc. From the table in Figure 3.10 it can be seen that a series of out of phase field syncs can be produced according to the value in the line count register. In this way sampling rates higher than 50 Hz could be achieved by using more than one camera to cover the same field of view and using these out of phase field syncs to initiate the vertical scan of each camera. If six cameras covered the same field of view a sampling frequency of 300 Hz would be achieved.

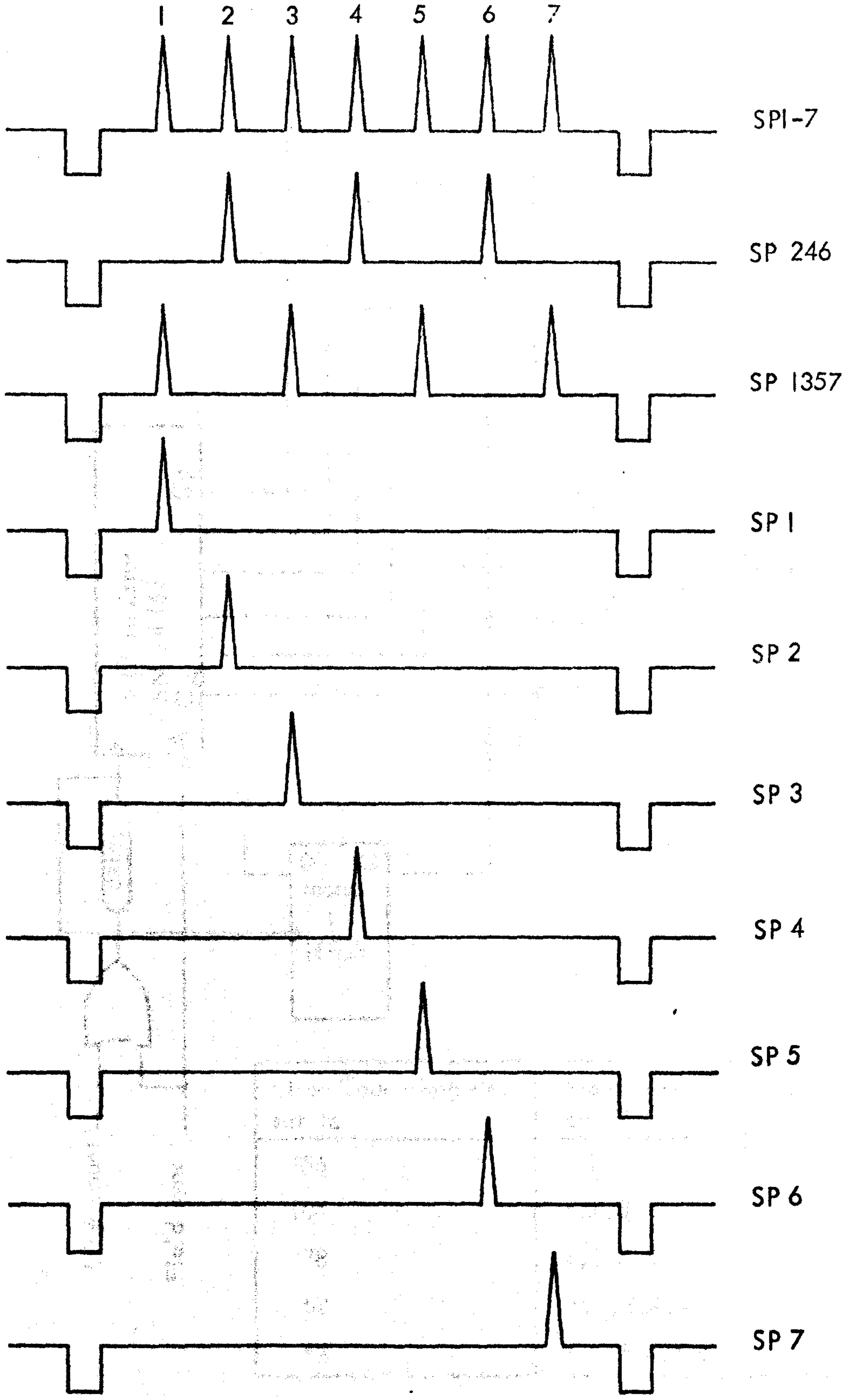
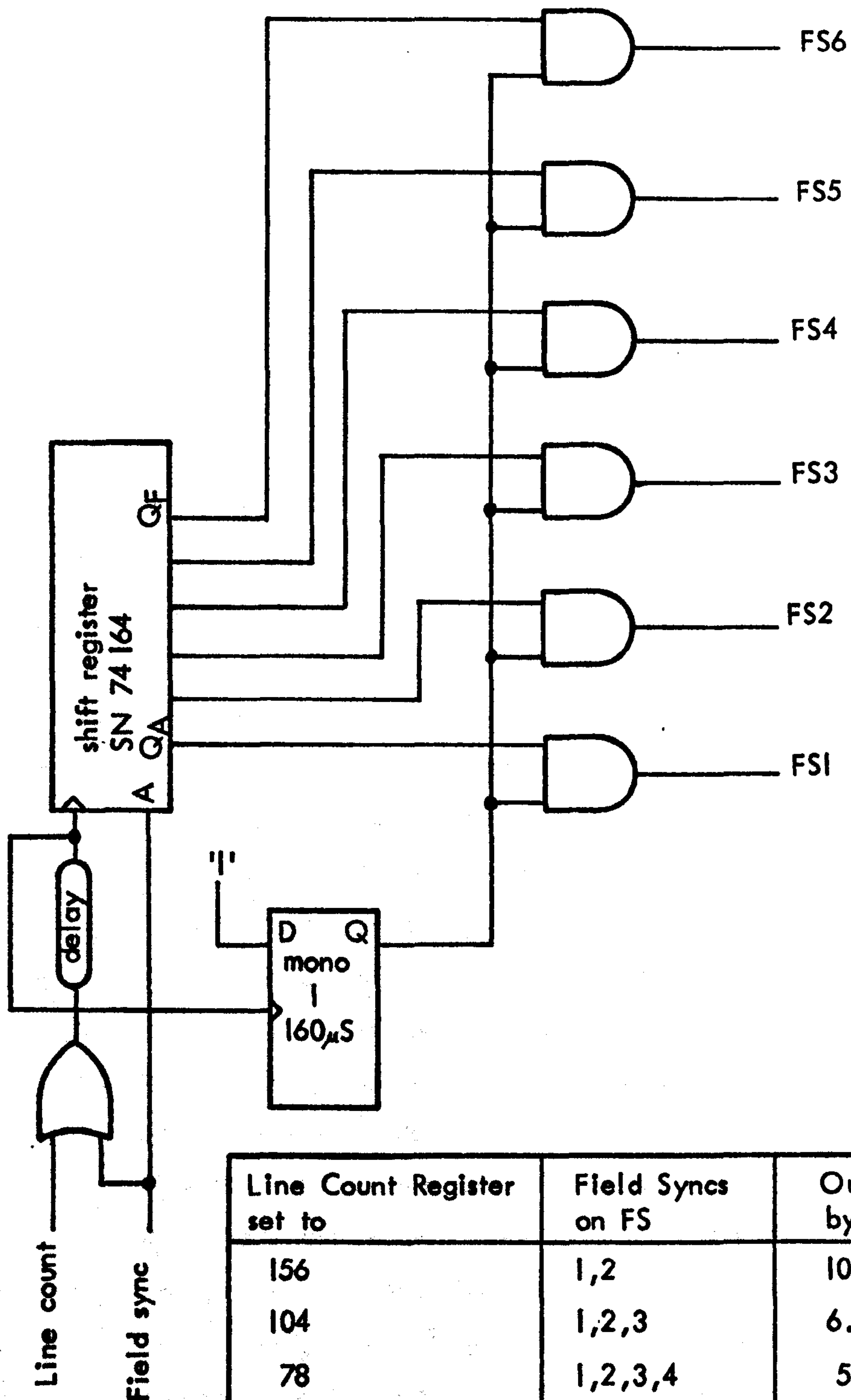


Figure 3.9. Simulated marker pulses.



Line Count Register set to	Field Syncs on FS	Out of phase by
156	1,2	10 mS
104	1,2,3	6.67 mS
78	1,2,3,4	5 mS
62	1,2,3,4,5	4 mS
52	1,2,3,4,5,6	3.33 mS

Figure 3.10. Logic to generate out of phase field syncs.

3.3.4 Address Register (AR)

The memory of the PDP 12 is organised in 4 K word segments up to a total of 32 K words. A 12 bit memory address is required to access locations within each 4 K segment, and a 3 bit extended address is required to address the segments – in total a 15 bit address. The address register provides this and a set of computer instructions have been created to control it. The initial address may be set up to any value which is a multiple of 8 (10 in octal notation). The reason for this slight limitation is that by fixing the initial value of the first 3 bits of the memory address to Ø both the memory address and the extended address can be set to their initial value with one computer instruction. This instruction loads a 12 bit word from the accumulator into the Initial Data Address register; bits 9, 1Ø and 11 of this word corresponding to bits Ø, 1 and 2 of the extended address (8-mode field address in software terms). The remaining bits (Ø – 8) are used to set bits Ø – 8 of the initial memory address. The address register itself is a 15 bit binary counter which is incremented by the Address Accept pulse – a control signal provided by the data break facility (see Appendix A2). The interface can therefore address any location in the PDP 12's memory up to the maximum of 32 K (only 16 K is available on the machine used at present, but it can be expanded to 32 K).

Computer instructions have been created to enable and disable the address register, and also to allow it to operate in a double (or circular) buffer mode. In this mode memory locations 1ØØØØ$_8$ to 27777$_8$ (4 K to 12 K) are used. When the interface has used all the locations up to 17777$_8$ (4 K to 8 K) the computer is signalled and the program starts to unload this area of memory onto a mass storage device (such as magnetic tape or disc), while the interface is filling up locations 2ØØØØ$_8$ to 27777$_8$ (8 K to 12 K). Similarly when the interface has used up these locations the address register is reset to 1ØØØØ$_8$ and locations 2ØØØØ$_8$ to 27777$_8$ are dumped onto mass storage. By using this facility it is possible to have continuous data rates of at least 4 K words/sec if a disk is available as the mass storage device. This effectively means that the duration of data acquisition is not limited by the core memory size of the computer. The capacity of an R K05 disk, as used on the PDP 12, is 1.6 M words. With an incoming data rate of 4 K words/sec (approximately

26 co-ordinate pairs per television field) a test could be run continuously for 6 minutes. Clearly this does not present a limitation as far as data acquisition is concerned, but there would be problems (of time) in processing such a large amount of data. Utilisation of the Double Buffer mode for transferring data to disk is further discussed in section 6.6.

Computer instructions to read the current memory address and extended (field) address are also available, and may be used at any time.

3.3.5 Calibration (CAL)

To calibrate the field of view of each camera a grid of markers is placed in the relevant plane and the system acquires the co-ordinates of this grid. A computer program organises this data into a calibration matrix for the particular camera and all subsequent data generated by the camera is referred to this matrix, and calibrated. This is done by finding the nearest grid point to the data point, the position of this grid point in the matrix defines its true spatial position; the difference between the grid point and the data point is then taken and calibrated by assuming a linear relationship between adjacent grid points, this difference is then added to the known spatial position of the nearest grid point. This procedure can be stated as follows for the x co-ordinate:-

$$x_{ic} = x_{gn} \cdot K + L - \frac{x_{gdn} - x_i}{\left| x_{gdn} - x_{gd} \begin{array}{l} (n - 1 \text{ if } x_{gdn} > x_i) \\ (n + 1 \text{ if } x_{gdn} < x_i) \end{array} \right|} \cdot K$$

where -

x_{ic} = calibrated co-ordinate of marker

x_{gn} = position of nearest grid point in calibration matrix

x_{gdn} = co-ordinate of nearest grid point (grid data point), matrix column n.

x_i = marker co-ordinate (data point)

K = calibration constant

L = shifting factor - to position origin

A similar equation is used to calibrate the y co-ordinate.

The spacing of the elements of the grid should be based on the expected non-linearity of the system. The camera specifications state a linearity within 1%; to allow for this a grid spacing of 100 units is required. A non-linearity of 1% in 100 units would be 1 unit, and therefore the non-linearity becomes indistinguishable from quantization errors. For the fields of view used for locomotion analysis a grid spacing of 10 cm is suggested.

For a field of view of 2.5 m width there would be 25 grid points in the horizontal scan. The co-ordinate generator is limited to taking in a maximum of 5 co-ordinates in the horizontal scan line, therefore a system is required to overcome this limitation for the calibration grid. One way of doing this, of course, would be to slope the grid so that no more than 5 grid co-ordinates could appear on the same line. A correction would have to be made to compensate for this slope during calibration of data and this was considered to be inconvenient. An alternative solution was found by designing a hardware calibration control. This control operates by allowing the CG to successively generate the co-ordinates of columns of 2 markers from the grid until the whole field of view has been covered, the computer is then signalled that calibration co-ordinates have all been acquired. This process is shown, schematically, in Figure 3.11, and may be considered as a window 2 grid points wide moving over the grid. Co-ordinates for the calibration grid are generated over two TV fields, so that the effects of interlaced scanning may be taken into account (see Appendix A1). A set of computer instructions are provided to operate the calibration control, and for maintenance purposes there is a "free run" mode which allows the control to operate continuously.

Ingen Schenau (1973) found, with his TV/computer system, that the linearity in the horizontal was independent of the linearity in the vertical and derived quadratic functions for correction terms of the form:-

$$f(x') = bx\,(x' - Kx)^2$$

$$g(y') = by\,(y' - Ky)^2$$

where bx, by, Kx and Ky are constants. The K constant fixed the origin, and the b constant was found by fitting the quadratic functions to values obtained

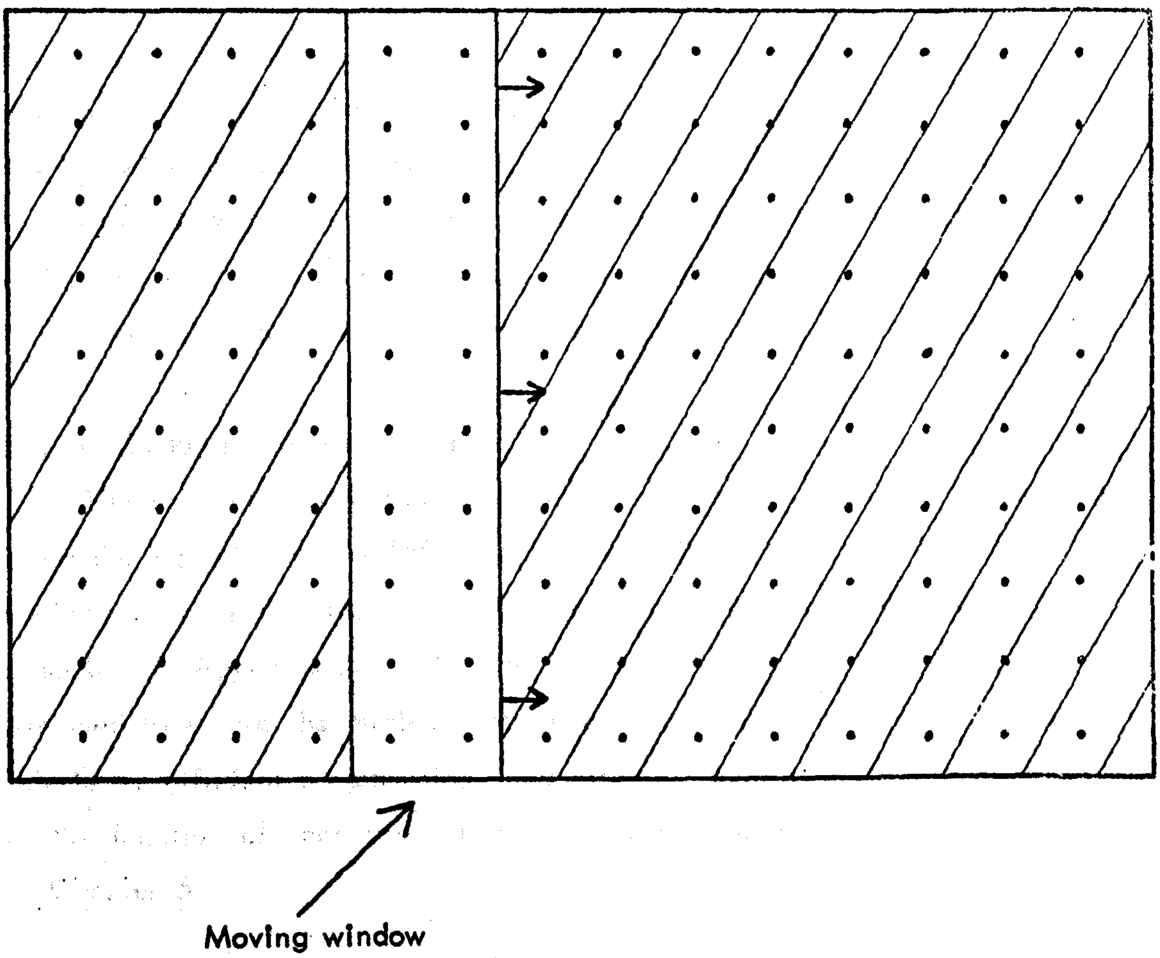


Figure 3.11. Schematic of calibration grid data acquisition.

for the co-ordinates of a grid of points. This gave the following equations with which data could be calibrated.

$$x = x' - 4.7.10^{-4} (x' - 128)^2$$

$$y = y' - 4.0.10^{-4} (y' - 128)^2$$

These equations applied to the particular camera and lens used and assumed that the characteristics would remain constant. With ageing of components the linearity of the television camera could change over a period of time. It is considered desirable, therefore, to provide a calibration system which can easily be used for different cameras and lens and take account of any change in linearity that may occur over a period of time.

3.3.6 Computer Instructions (INS1 and INS2)

The computer instructions required to control the interface are generated using the Input/Output (6ØØØ) class of the PDP 12 instruction set. The method of converting these software instructions into hardware operations is described in Appendix A2. A total of 28 instructions have been created, designed to ensure the minimum of manual intervention during use of the interface, efficient programming, and effective maintenance facilities. Details of the function of each instruction and examples of programming will be found in Chapter 5.

CHAPTER 4

INTERFACE LOGIC

4.1 Introduction and Nomenclature

4.2 Marker Detectors. MD.

4.3 Sync Generator and Simulator. SGS.

4.3.1 Internal Synchronisation Pulses. SGS-A.

4.3.2 Line Count and Field Count Functions. SGS-B.

4.3.3 The Simulator. SGS-C.

4.3.4 External Synchronisation. SGS-D.

4.4 Co-ordinate Generator. CG.

4.4.1 Enable Logic and Clock. CG-A.

4.4.2 Priority Register and Coding. CG-B.

4.4.3 Co-ordinate Counters and Latch. CG-C.

4.4.4 Buffer Memory. CG-D.

4.4.5 Buffer Memory Address and Control Logic. CG-E.

4.4.6 Additional Code Bits. CG-F.

4.5 Address Register. AR.

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4.5.2 Address Increment Logic and Computer Bus Drivers. AR-B.

4.5.3 Computer Bus Drivers. AR-C.

4.6 Calibration Control. CAL.

4.6.1 Calibration Initialisation and Control Logic. CAL-A.

4.6.2 Counter and Right Hand Limit Latch. CAL-B.

4.6.3 Left Hand Limit Latch and Margin Logic. CAL-C.

4.6.4 Window Control Logic. CAL-D.

4.7 Instruction Generator 1. INS1.

4.7.1 Calibration Control Instructions. INS1-A and INS1-B.

4.7.2 Sync Generator and Simulator Instructions. INS1-C.

4.8 Instruction Generator 2. INS2.

4.8.1 Co-ordinate Generator Instructions. INS2-A.

4.8.2 Address Register Instructions. INS2-B to INS2-E.

4.9 Construction and Planning

4.1 Introduction and Nomenclature

A complete description of the logic of the interface is given in this section. In describing the function of the logic the signal naming and drawing conventions used by DEC have been adopted. This system was chosen because it allows the logic functions to be followed easily and is, of course, compatible with the PDP 12 manuals. Each drawing is allocated a name and a number, the number usually being an abbreviation of the name. Logical signal names are used in the drawings to minimise the number of signal line crossings and to facilitate explanation. The signal name consists of abbreviations which give the origin, function and assertion condition of the signal:-

The origin is specified by the first word of the signal name and is the drawing number upon which the signal is generated.

The signal description (function) is a description of the logical function of the signal when asserted.

The asserted condition is either H (high) or L (low) corresponding to +3 or 0 volts respectively, and is the signal level which indicates that the intended function has occurred (i.e. is True). The signal is considered not asserted when the signal level differs from the assertion level.

Example:-

[SGS-A] LE LSY L	Refers to a signal which originates on the Sync Generator and Simulator drawing part A. The signal will be low when the Leading Edge of the Line Sync occurs.
[CG-B] SGC H	Refers to a signal which originates on the Co-ordinate Generator drawing part B. The signal Sets the Generate Co-ordinate flip flop when it is high.

Signals originating from flip flops are defined in terms of the flip flop state, as shown in the following table:-

Signal Name	State of flip flop	Signal Voltage
[CG-B] GC (0) H	0	+3
[CG-B] GC (0) L	0	0
[CG-B] GC (1) H	1	+3
[CG-B] GC (1) L	1	0

Example:-

[CG-B] GC (1) L — Refers to a signal which originates on the Co-ordinate Generator drawing part B. The signal line is low when the Generate Co-ordinate flip flop is set.

On the drawings and in the description of the logic of each drawing the origin part of the signal name is omitted if the signal is generated on that drawing, otherwise it is shown enclosed in square brackets. The logic symbols used are those which convey the function of the logic element (conceptual logic) rather than the actual hardware device used, although the reference number of the actual device is also shown. These logic symbols are shown in Figure 4.22 at the end of the logic drawings.

The computer generates the signals [100] BA INITIALIZE H and [100] BB INITIALIZE H which are used to initialize the interface. These signals may be generated by the use of the IO PRESET console switch or by the program.

In the following description of the logic frequent cross references are made between logic drawings. For this reason these drawings will be found together at the end of this section. The drawing numbers are referenced by the sub-headings of the logic descriptions. Other figures, which may show timing diagrams for instance, are placed by the relevant text.

4.2 Marker Detectors. MD.

The circuits for the two types of marker detector used have been shown in Figures 2.3 and 2.5. The MD circuit board also contains circuitry used to condition the field and line syncs from the television sync pulse generator. These circuits are simple comparators with TTL compatible outputs, as shown in Figure 4.15.

4.3 Sync Generator and Simulator. SGS.

The drawings for the SGS are shown in Figure 4.16, SGS-A to SGS-D. Generation of internal syncs is shown in SGS-A, line count and field count functions are on SGS-B, simulator logic is on SGS-C, and external sync control is on SGS-D.

4.3.1 Internal Synchronisation Pulses. SGS-A.

TTL compatible field and line syncs from the Marker Detector board (MD) are fed into schmitt trigger input gates and used to generate the signals shown on this drawing. FSYB is a field sync of 4.7 μS duration which occurs on every other television field, due to the interlace feature of the camera sync generator. Generation of the other signals is self explanatory from the logic.

4.3.2 Line Count and Field Count Functions. SGS-B.

The Field Counter (FC) is an 8 bit binary up/down counter. The clock input, [SGS-A] FSYA H, will count down the counter from a preset binary number held in the Field Count Register (FCR). A low level borrow pulse occurs when the clock input is low and the counter is at zero. This borrow pulse is fed back to the load input of the counter and will cause the counter to be set to correspond to the data inputs, provided by the FCR. As soon as the counter becomes non-zero the conditions required to generate the borrow pulse are not met and the borrow output is returned to its normal high level. The borrow pulse lasts for approximately 40 nS, and is also used to preset ENCG when the Field Count mode is enabled ([INSI-C] ENFC (1) H). ENCG (1) H enables the Co-ordinate Generator inputs for the duration of one television field until ENCG is cleared by [SGS-A] FSYA H. When the Field Count mode is disabled, [INSI-C] ENFC (0) L, ENCG is held permanently set. The Field Count Register is loaded with the contents of the Accumulator (bits 4 - 11) by [INSI-C] LDFC H.

The Line Counter (LC) is a similar up/down counter except that its clock input is the television line sync [SGS-A] LSY H. In this case the counter is also preset at the beginning of each television field by [SGS-A] FSYA L. The borrow pulse is produced as before and is used for several functions. The Line Count Register (LCR), which provides the data inputs to the counter, is loaded with the contents of the Accumulator (bits 4 - 11) by [INSI-C] LDLC H.

4.3.3 The Simulator. SGS-C.

The logic in this drawing shows how [SGS-B] LC L is used to generate the simulated marker pulses. The simulator is enabled by the signal [INSI-C] ENSM (I) H, and when this condition is met the leading edge of [SGS-B] LC L will trigger the seven monostables SPT 1 to SPT 7. The -ve going edge of the pulse produced by each monostable triggers a second monostable to produce 90 nS duration pulses SP 1 - SP 7. These outputs are combined and buffered to provide various simulated marker pulse configurations capable of driving 75Ω inputs as previously shown in Figure 3.9.

4.3.4 External Synchronisation. SGS-D.

External data acquisition is synchronised by the SYN flip-flop. When synchronisation is requested by [EXT] SYN (I) H (a signal provided by the external device, which may originate from a flip flop, as shown here, or may simply be a level) SYN is set on the -ve going edge of the next field sync, [SGS-A] FSYA H. SYN (I) H is then available to signify that synchronisation has started. It is used here in conjunction with a pulse generated by [SGS-B] LC L to gate line blank pulses. [SGS-B] LC L triggers monostable LBK GATE which is set to provide a 400 μS pulse. Whenever this pulse occurs, and SYN is set, six buffered line blank pulses will be available as BSYN H. Any number of pulses can be provided by changing the timing components of LBK GATE; the six pulses generated here are used as external sync inputs to the KW12 clock of the PDP 12. The frequency at which this pulse train occurs is controlled by the frequency of [SGS-B] LC L, which in turn is set by the contents of the line count register, LCR.

4.4 Co-ordinate Generator. CG.

The drawings for the CG are shown in Figure 4.17 CG-A to CG-F. Enable logic and the clock is shown on CG-A, the priority register and coding is on CG-B, co-ordinate counters and the high speed latch is on CG-C, the buffer memory is on CG-D, buffer memory address and control logic is on CG-E, and CG-F contains the logic for the additional code bit storage.

4.4.1 Enable Logic and Clock, CG-A.

The marker detector inputs to the CG are enabled by the signal EMDI L. The detector inputs are inhibited during the line blank period by [SGS-A] LBKA L and also, at any time, by the signal [CAL-A] DISCG L. The facility to exercise external control over the CG is provided here by the switch inputs, whose conditions are sampled at the beginning of each television field. SWITCH 1 H and SWITCH 2 H will both set ENABLE on the occurrence of [SGS-A] FSYA H. SWITCH DISCG H will clear ENABLE when the field sync occurs. [100] BB INITIALIZE H (originated by program or console switch) will also clear ENABLE and hence inhibit the marker detector inputs.

The clock for the horizontal counter is shown here, it is a simple R-C multivibrator as described in Texas Instruments (1973a). The clock is reset on the trailing edge of [SGS-A] LE LSY L by a 35 nS pulse. This arrangement has proved to be entirely satisfactory as will be seen by the stability test described in the Results and Discussion chapter.

4.4.2 Priority Register and Coding. CG-B.

The marker detector inputs are controlled by the priority register PRI. The cascading input P_o is fully over-riding and will inhibit each package when high. A marker detected pulse [MD] CHx H will produce the signal SGC H which clocks a '1' into GC. GC (1) L immediately latches the data in the priority register and inhibits the PRI inputs. The timing diagram for this sequence of events is shown in Figure 4.1. The times shown in this diagram are maximums and in practice the operation is faster. In the event that marker detected pulses occur at the same time on more than one input,

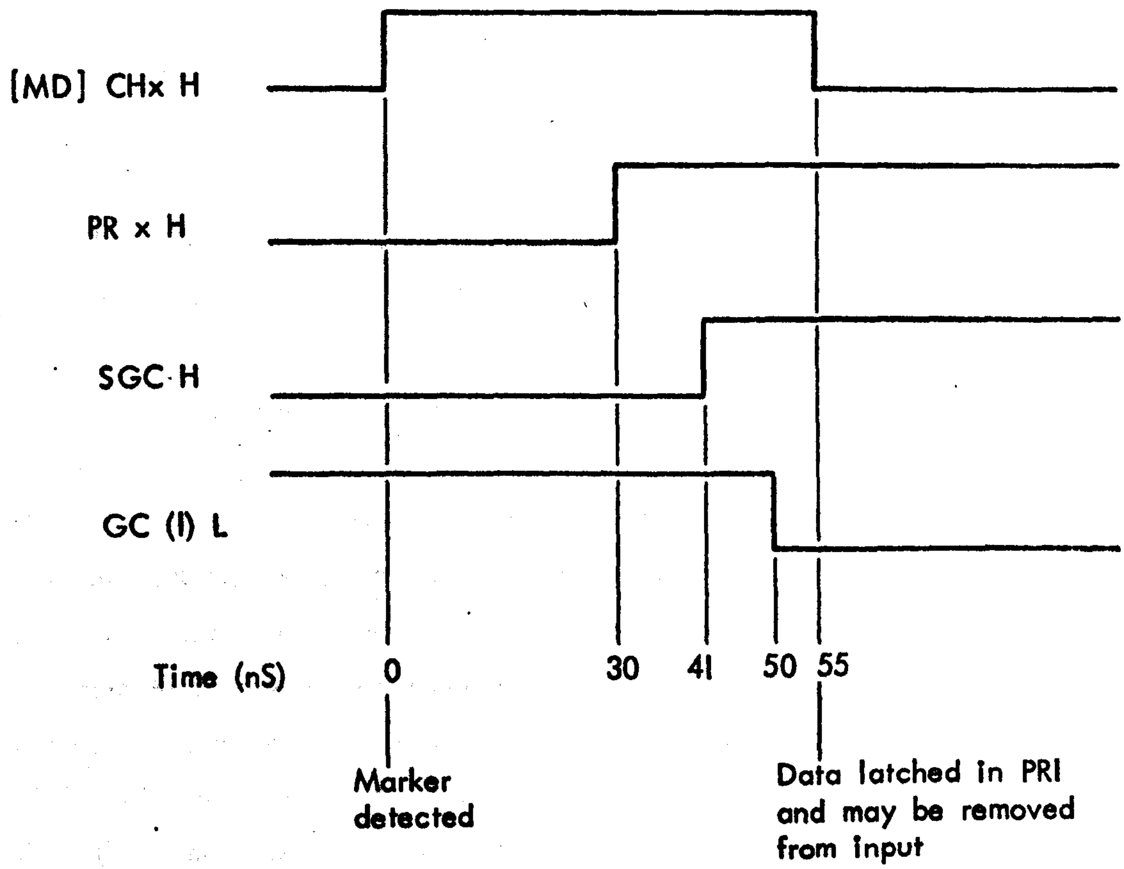


Figure 4.1. Timing diagram showing the latching of the camera channel data in the Priority Register.

the PRI will only give one output which will correspond to the input of highest priority at the time the data is latched. DØ has the highest priority and D5 the lowest. A 3 bit code, to indicate which input generated SGC H, is provided by C0 Ø H, C0 1 H and C0 2 H according to the truth table shown in Figure 4.2. SGC H also sets the break request flag BRF, which will request data transfer to computer memory during the next line blank period by asserting BR L. The Break Request signal BR L is held asserted by the computer generated signal [100] BREAK (1) L until the last transfer is about to take place when [CG-F] TSR L clears BRF.

4.4.3 Co-ordinate Counters and Latch. CG-C.

The 10 bit vertical co-ordinate counter VC is incremented by the -ve going edge of [SGS-A] LSY H, and reset to zero by [SGS-A] FSYB H. The VC outputs are fed to the data inputs of the high speed, synchronous horizontal co-ordinate counter HC. The HC is incremented by the +ve going edge of [CG-A] CK H and reset to zero by [SGS-A] LBKB L. The contents of the HC are continuously strobed into the LATCH on the -ve going edge of [CG-A] CK H. When a marker is detected in the video [CG-B] GC (1) L is asserted and the strobe is disabled, the latch will now contain the horizontal co-ordinate of the detected marker. The timing diagram for this sequence of events is shown in Figure 4.3. At the end of each scan line [SGS-A] LE LSY L will be asserted and the HC will be preset to equal the contents of the VC on the next +ve going clock pulse. This data will then be available in the LATCH, and is the vertical co-ordinate corresponding to horizontal co-ordinates generated on that line.

4.4.4 Buffer Memory. CG-D.

The outputs of the LATCH together with the code bits [CG-B] CO Ø H and [CG-B] C0 1 H provide the data inputs to the 16 word (12 bits/word) random access memory RAM. The data inputs are written in to the location addressed by [CG-E] UDC Ø to UDC 3 when [CG-E] RAM CE L and [CG-E] RAM WE L are both asserted. During write operations the data outputs OD Ø to OD 11 are high. Data is read from the location addressed by [CG-E]

CO Ø	CO 1	CO 2	INPUT
Ø	Ø	Ø	Ø
Ø	Ø	1	1
Ø	1	Ø	2
Ø	1	1	3
1	Ø	Ø	4
1	Ø	1	5
1	1	Ø	None, VC code
1	1	1	None, VC code

Figure 4.2. Truth table for camera code.

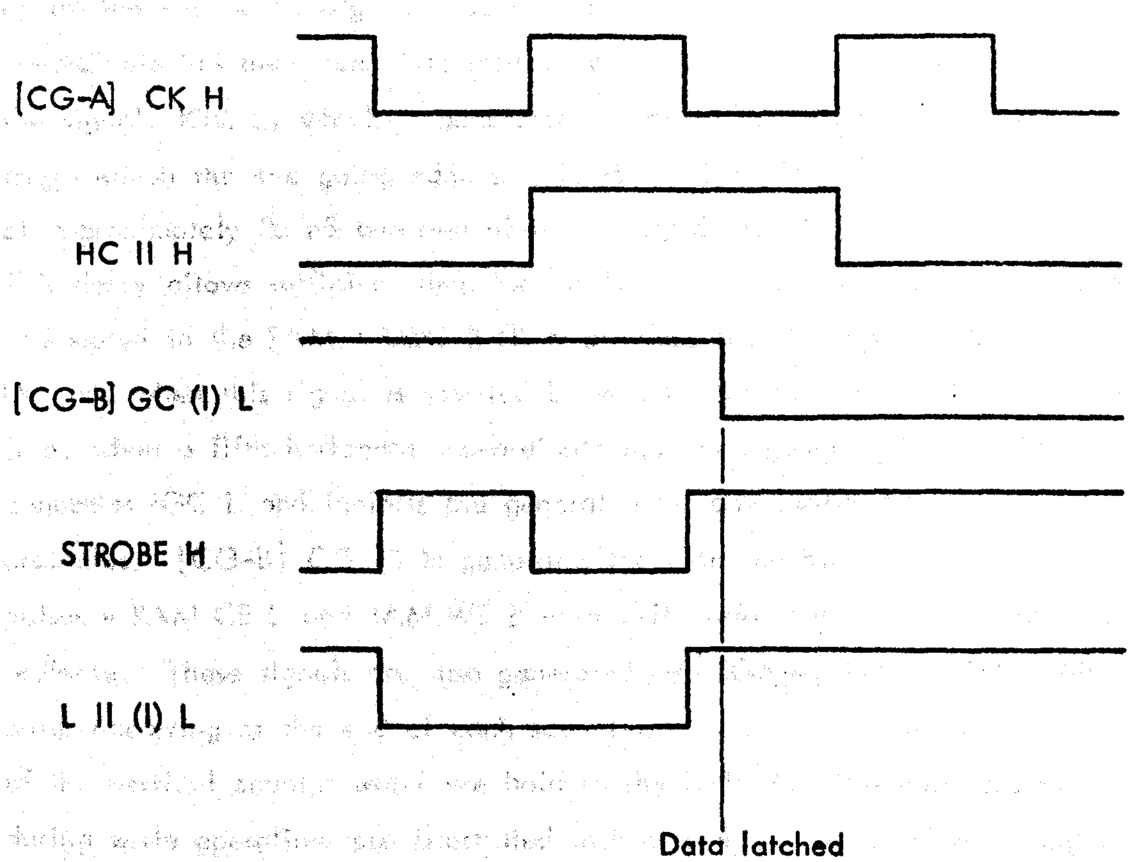


Figure 4.3. Timing diagram to latch horizontal co-ordinate.

UDC Ø to UDC 3 when [CG-E] RAM CE L is asserted and the write enable input (WE) is held high. During read operations the accessed data is placed on the computer data bus via bus drivers. The timing diagram for write operations is shown in Figure 4.4, the CE input must be held low for 50 nS (Access time) and the data input must be available for 20 nS and held for 5 nS after the WE input has been returned to a high level. These times are maximums and typical times are quoted as 35 nS, 18 nS and 0 nS respectively, Signetics (1974). The timing for read operations is not critical as will be described under CG-E. The address inputs are always set up in anticipation of any read or write operation.

4.4.5 Buffer Memory Address and Control Logic. CG-E.

The address of the location to be accessed in the RAM is provided by the up/down counter UDC. [CG-A] IO INIT L sets the UDC to zero, which is the first location to be used for write operations. The UDC is incremented up on the +ve going edge of [CG-B] GC (I) L, i.e. when the horizontal co-ordinate has been read into memory and GC is cleared. GC is cleared by the signal IGC L, which is generated by the RESET monostable. RESET is triggered on the +ve going edge of [CG-B] GC (I) H and provides a pulse of approximately 35 nS duration after a delay of 80 nS (maximum delay 130 nS). This delay allows sufficient time for the horizontal co-ordinate to be latched and stored in the RAM. UDC 2 (I) H provides the 'D' input to the limit flag LF, and when this signal is asserted LF will be set on the next RESET pulse (i.e. when a fifth horizontal co-ordinate has been generated). LF (I) L generates IGC L and inhibits the generation of any further horizontal co-ordinates. [CG-B] GC (I) H generates the chip enable and write enable pulses - RAM CE L and RAM WE L - to write into memory a horizontal co-ordinate. These signals are also generated by [SGS-A] LE LSY H (a 100 nS pulse occurring at the end of each scan line) to write into memory the contents of the vertical counter which are held in the LATCH. The functions of the UDC during write operations are illustrated in Figure 4.5. A complete timing diagram for generation of the horizontal co-ordinate is shown in Figure 4.6.

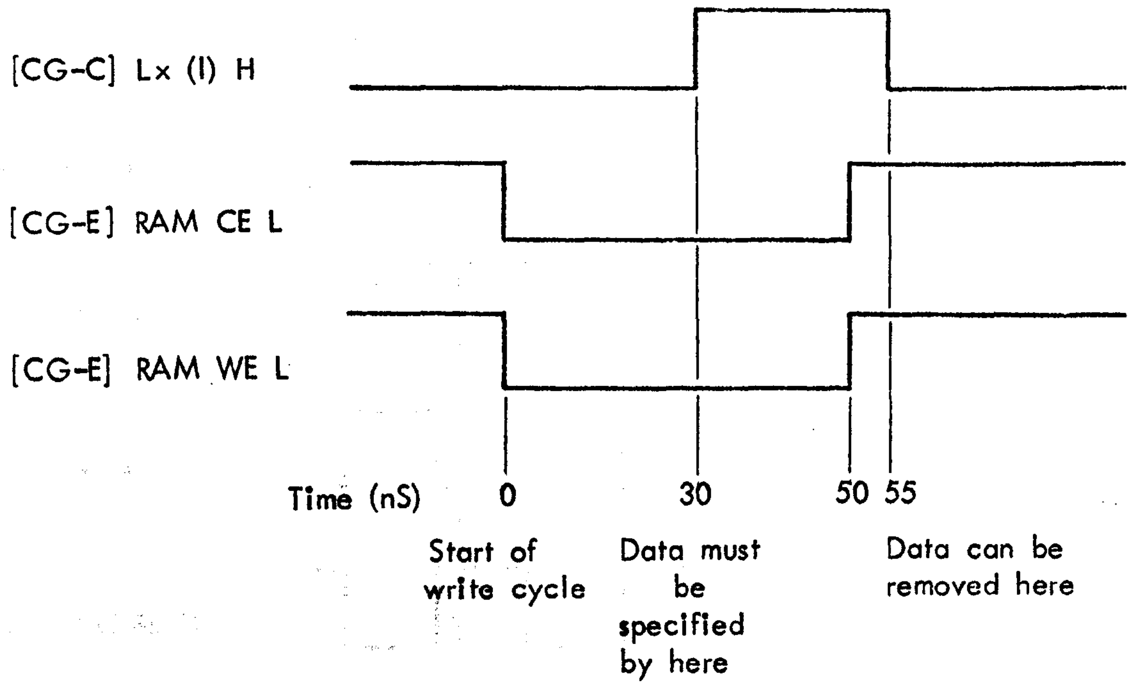


Figure 4.4. Timing for writing data into the Random Access Memory.

3	2	1	Ø	Write	Additional Functions
Ø	Ø	Ø	Ø	HC 1	None
Ø	Ø	Ø	1	HC 2	None
Ø	Ø	1	Ø	HC 3	None
Ø	Ø	1	1	HC 4	None
Ø	1	Ø	Ø	HC 5	Set limit flag
Ø	1	Ø	1	VC	None

NB. The number of HC's is variable, the VC will always be written after the last HC, and is therefore not a function of the UDC address.

Figure 4.5. Random Access Memory address counter (UDC) functions during write operations. (up count).

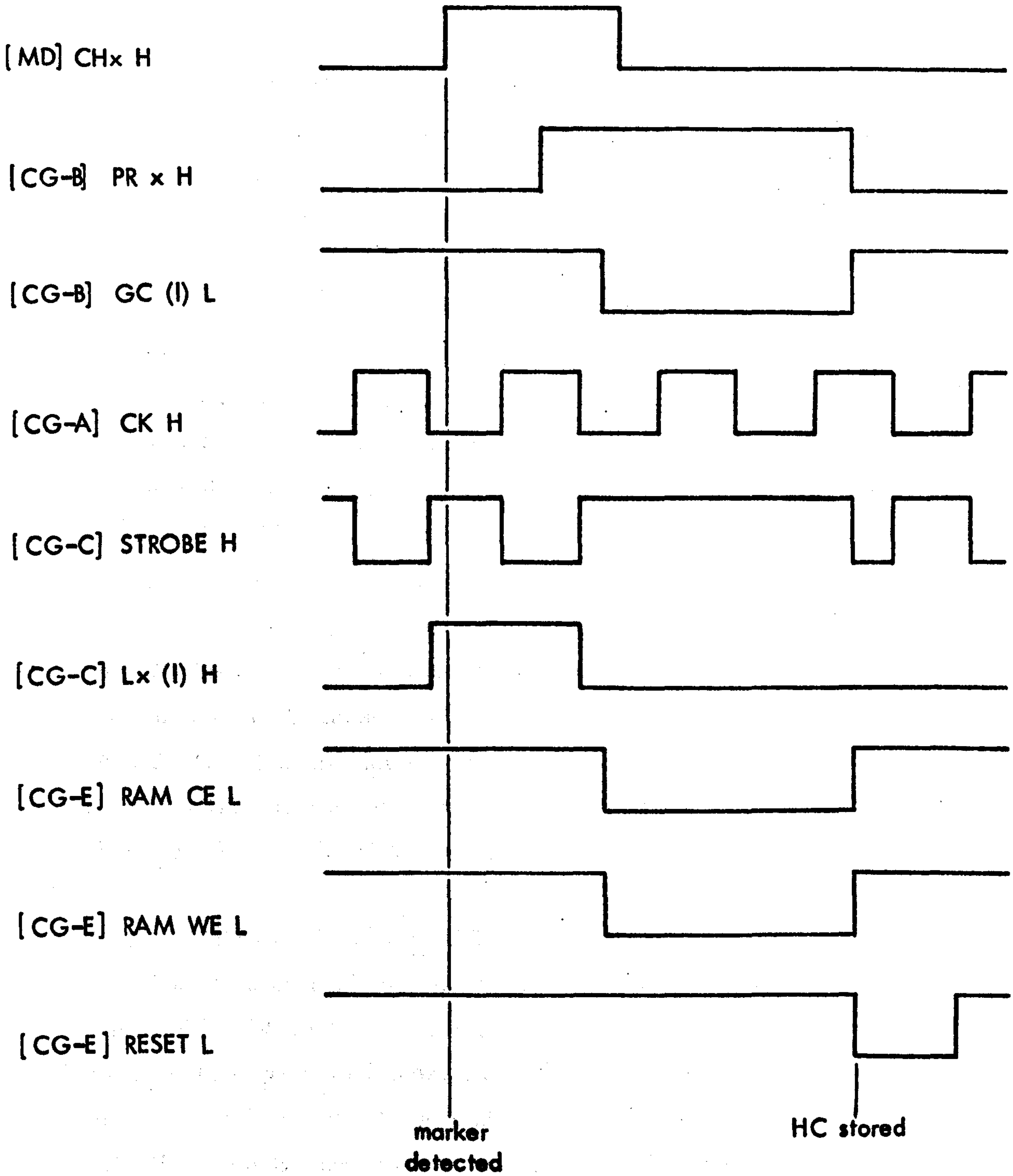


Figure 4.6. Complete timing diagram for storing horizontal co-ordinate.

If horizontal co-ordinates have been generated the break request flag [CG-B] BRF will be set and a break request will be made at the beginning of the line blank period (break request enabled by [SGS-A]LBKA L, and held enabled by [100] BREAK (I) L until all transfers have been made - see CG-B). When the break request is accepted the computer generates [100] ADD ACCEPTED (I) L which is used to trigger a 1 μS pulse from monostable AA. This pulse in turn generates RAM CE L which makes the contents of the currently addressed location of the RAM available at the RAM outputs. As this data is provided on the computer IO bus some 500 nS before it is required the access time of the RAM is not critical. These outputs are taken via buffer amplifiers with open collector outputs and put onto the EXT DATA bus of the computer.

The first word of data to be transferred will be the last word that was read into the RAM, i.e. the vertical co-ordinate. On the -ve going edge of AA L the UDC is down counted by 1, and addresses the RAM location containing the next data word (a horizontal co-ordinate) which is then transferred to computer memory as before. This process is repeated until all the horizontal co-ordinates have been transferred, which is indicated by the UDC underflowing (i.e. UDC output = 1111). When this occurs UDC 3 (I) H generates RAM CE H which disables the RAM outputs. The next AA L pulse will down count the UDC to 1110 which provides a clear pulse and resets the UDC to zero. These functions of the UDC during read out of data are shown in Figure 4.7.

4.4.6 Additional Code Bits. CG-F.

The third code bit for the horizontal co-ordinate is clocked into the SHIFT REGISTER by the +ve going edge of[CG-B] GC (I) L. As each horizontal co-ordinate is generated codes are shifted along by one bit; the code for the last horizontal co-ordinate generated on any line will be at G_A. The SHIFT REGISTER data is transferred to the computer when the UDC underflows on down count. [CG-E] UDC 3 (I) H gates [CG-E] AA H to generate TSR L. This signal enables the EXT DATA bus drivers and the contents of the shift register are transferred to computer memory. Bit Ø of this word is permanently set at zero to maintain the uniqueness of the vertical co-ordinate code. Bit 3

3	2	1	Ø	Read	Additional Functions
Ø	1	Ø	1	VC	None
Ø	1	Ø	Ø	HC 5	None
Ø	Ø	1	1	HC 4	None
Ø	Ø	1	Ø	HC 3	None
Ø	Ø	Ø	1	HC 2	None
Ø	Ø	Ø	Ø	HC 1	None
1	1	1	1	-	Read shift register word and clear break request flag
1	1	1	Ø	-	Reset UDC to Ø

NB. The number of horizontal co-ordinates is variable and the VC will always follow the last HC and will be read out first.

Figure 4.7. Random Access Memory address counter (UDC) functions during read operations. (down count).

is set by [SGS-D] SYN (I) H which will indicate if an external device is being sampled; bits I, 2, 4, 5 and 6 can be used in a similar way if required. TSR L also clears the break request flag [CG-B] BRF, to end the sequence of data transfer to the computer.

4.5 Address Register AR.

The drawings for the AR are shown in Figure 4.18 AR-A to AR-C. The initial data address register and the 15 bit data address counter is shown on AR-A, address increment logic and some computer bus drivers are on AR-B, and the rest of the bus drivers are on AR-C.

4.5.1 Initial Data Address Register and 15 bit Address Register. AR-A.

This drawing shows the Initial Data Address Register IDA, the 12 bit Memory Data Address register DA and a 3 bit Data Field Address register DFA. IDA is loaded with data from the accumulator, AC, by the +ve going edge of [AR-B] STO IDA H. QØ to Q2 of the IDA provide the data inputs DØ to D2 of the DFA. Q3 to Q11 of the IDA provide the data inputs DØ to D8 of the DA. The DA and DFA are preset to equal these data inputs by AR-B LO IDA L. The DA and DFA is a 15 bit synchronous counter which is incremented (or preset to the value held in the IDA if [AR-B] LO IDA L is asserted), by the +ve going edge of [AR-B] IA L.

4.5.2 Address Increment Logic and Computer Bus Drivers. AR-B.

The computer instruction 6331 (LDCA) generates [INS2-B] BIOT 6331 L and [INS2-B] LDCA L. These two signals are combined to produce STO IDA H, the combination being used to improve noise immunity. This signal generates LO IDA L, and triggers the monostable LDCA CLOCK to produce a 300 nS pulse which in turn generates IA L. These signals load the IDA register with the data held in the Accumulator and preset the DA and DFA with the new contents of the IDA register on the +ve going edge of IA L. A timing diagram of this sequence of events is shown in Figure 4.8. The delays introduced by the various logic elements have not been included as their effect on the timing

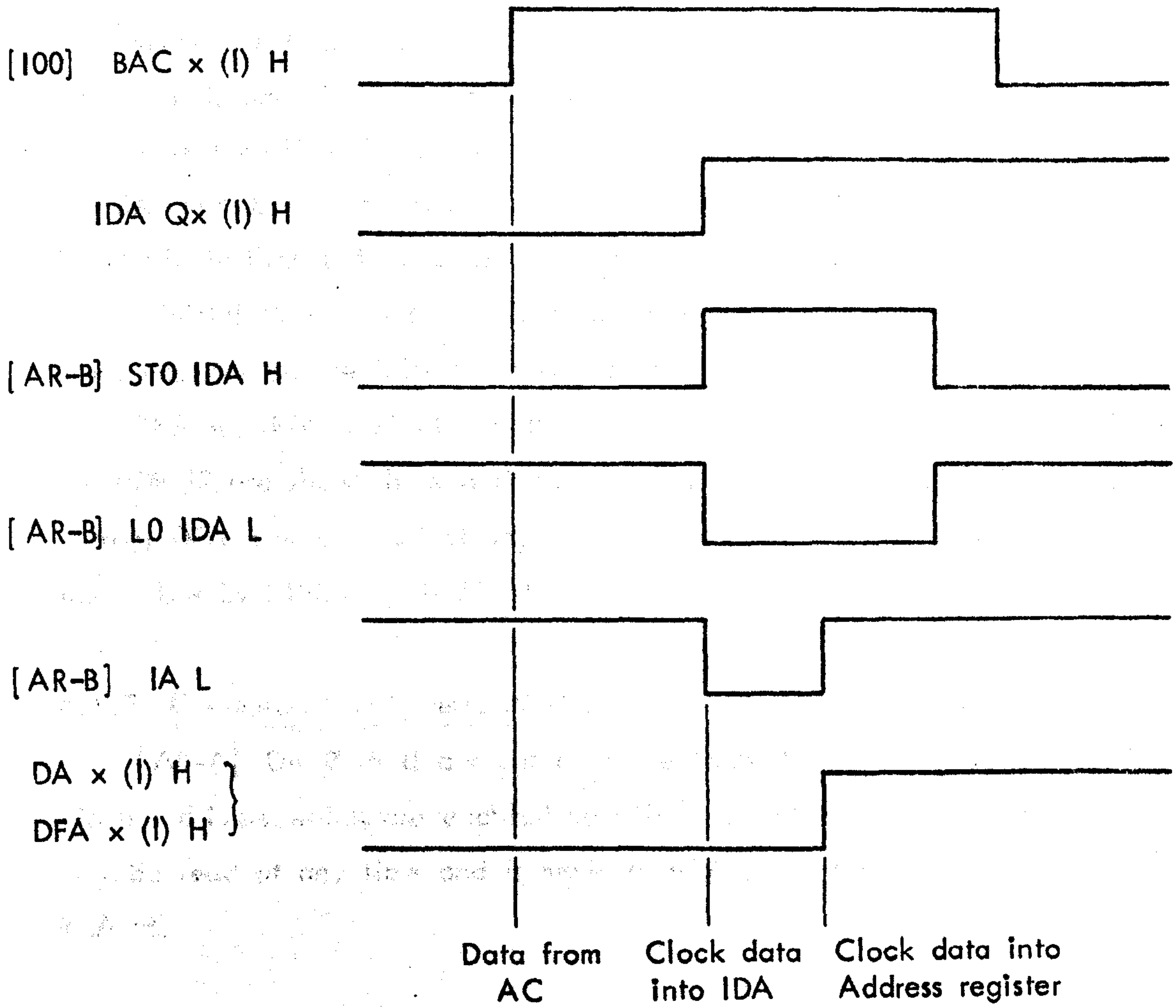


Figure 4.8. Timing diagram for loading and setting up initial address.

has been designed out. IA L is also produced by the [100] ADD ACCEPTED (1) L signal from the computer, the DA and DFA being incremented on the +ve going edge of this signal to provide the next address in computer memory in readiness for the next data transfer.

When the Double Buffer Mode of operation is set ([INS2-E] DBM (1) H) LO IDA L is generated whenever the DA is at 7777_8 and DFA bit 1 is high; on the next clock pulse (IA L) the contents of the IDA register are loaded into the DA and DFA. The timing diagram for this operation is shown in Figure 4.9. The table in Figure 4.10 shows the areas of memory used by the AR according to the initial DFA. The start location within the first memory field of these areas depends on the initial contents of the DA register.

The bus drivers which put the DFA on the Extended Data Address bus of the PDP 12 are shown here and are enabled by [INS2-C] ENFAD (1) H. The current DFA may be read at any time and is made available on bits 9-11 of the IO bus by [INS2-B] RCFA H.

4.5.3 Computer Bus Drivers. AR-C.

[AR-A] DA Ø to 11 are put onto the Data Address bus of the PDP 12 via bus drivers which are enabled by [INS2-C] ENAD (1) H. The current DA may be read at any time and is made available on the IO bus by [INS2-B] RCA H.

4.6 Calibration Control. CAL.

The drawings for the CAL are shown in Figure 4.19 CAL-A to CAL-D. Calibration initialisation and control logic is shown on CAL-A, the counter and right hand limit latch are on CAL-B, left hand limit latch and margin logic is on CAL-C, and the window control logic is on CAL-D. Three of the terms used in the description of the CAL logic are explained here. The Left Hand Limit (LHL) is the horizontal co-ordinate of the left hand edge of the calibration window. The calibration control will enable the co-ordinate generator from this point until the Right Hand limit (RHL) is reached. This limit being the horizontal co-ordinate of the right hand edge of the calibration window. The co-ordinate generator is inhibited once this RHL has been passed. The window will move

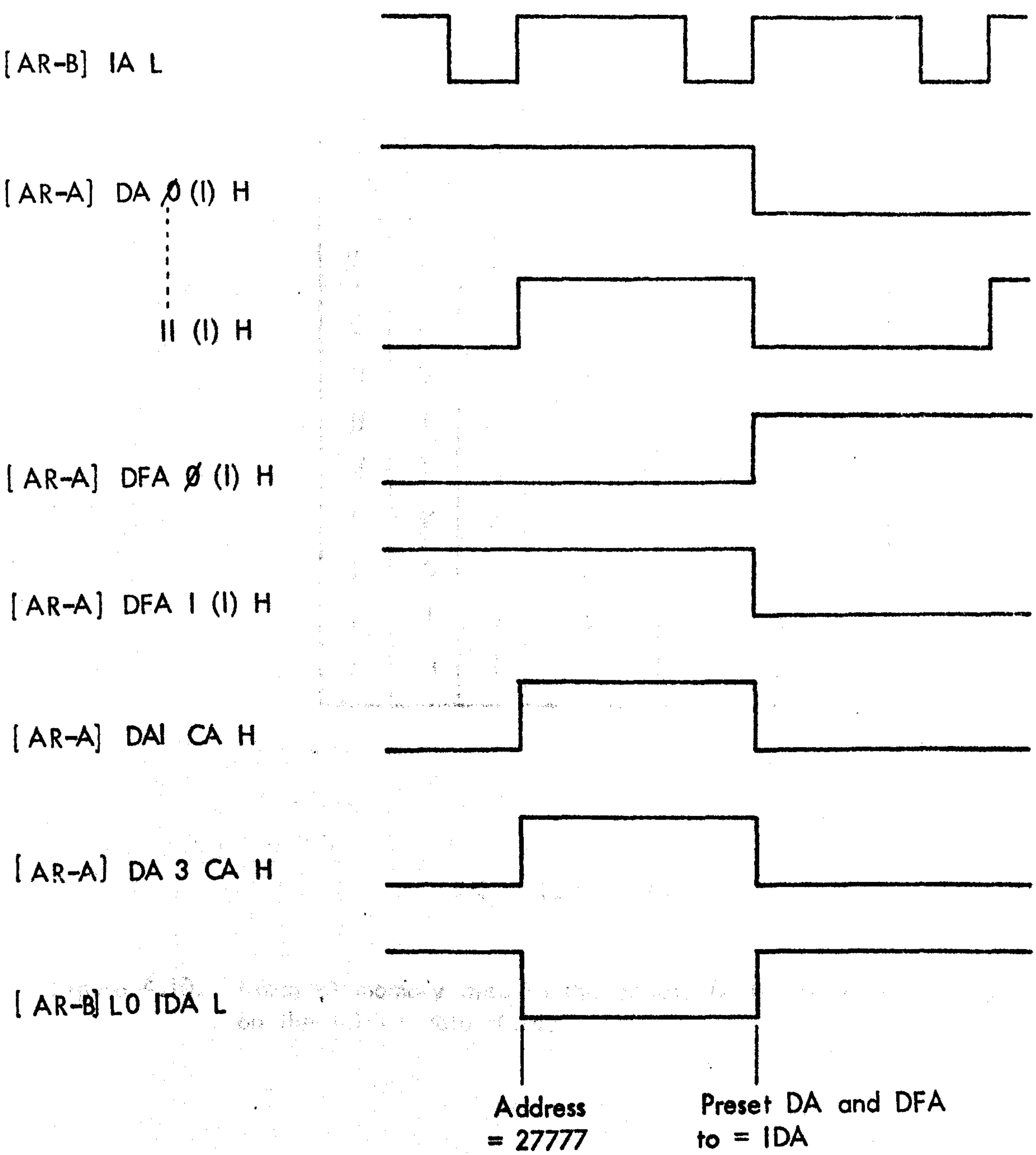


Figure 4.9. Double buffer mode timing diagram.

Initial contents of DFA			Initial data field	Area of Memory used in DBM
∅	1	2		K
∅	∅	∅	0	0-12
∅	∅	1	1	4-12
∅	1	∅	2	8-12
∅	1	1	3	12-16
1	∅	∅	4	16-28
1	∅	1	5	20-28
1	1	∅	6	24-28
1	1	1	7	28-32

(K = 1024 words)

Figure 4.10. Areas of memory used in the double buffer mode depending on the initial data field.

across the television field until the Right Hand Margin (RHM) is passed by the LHL, the co-ordinate generator is inhibited when this happens and the calibration complete flag is set. This moving window has already been shown in Figure 3.11.

4.6.1 Calibration Initialisation and Control Logic. CAL-A.

The calibration control is initiated by [INSI-B] CALGO H, which triggers the CAL GO monostable to generate a 45 mS pulse. The START and ZERO LHL flip flops are cleared and then reset as shown in the timing diagram of Figure 4.11. These flip flops set up the initial conditions for the calibration control. START (0) L generates DISCG L and inhibits the CG until the beginning of a television field. ZERO LHL (0) L makes the Left Hand Limit zero; this condition may also be generated when the control is in the Free Run mode ([INSI-B] FR (1) L) and [CAL-C] RHM CONT L is asserted. To indicate that calibration has been completed CAL COMP H is generated by [CAL-C] RHM STOP L.

The calibration control is made operative by [INSI-B] CAL MODE (1) H and will inhibit the Co-ordinate Generator when DISCG L is asserted. This inhibit signal may be generated by any of the four signals shown and will control the times during the line scan in which co-ordinates may be generated. When a co-ordinate is being generated [CG-B] BGC (1) L is asserted and will clock a '1' into the shift register, CAL SR, on its +ve going edge (i.e. at the end of co-ordinate generation). CAL SR Q_B provides the 'D' input to the SET RHL flip flop which is clocked by bit 9 of the horizontal co-ordinate counter [CG-C] BHC9 H. The timing diagram of Figure 4.12 shows how SET RHL (1) H is asserted. CAL SR and the SET RHL flip flop are both cleared by FSYB L.

4.6.2 Counter and Right Hand Limit Latch. CAL-B.

The calibration control has it own horizontal counter, HC, which is incremented by [CG-C] BHC9 H. The right hand limit latch, RHL LATCH, stores the current contents of the HC when [CAL-A] SET RHL (1) H is asserted. At the start of alternate television fields the RHL is set to all '1's by [CAL-A] FSYB L.

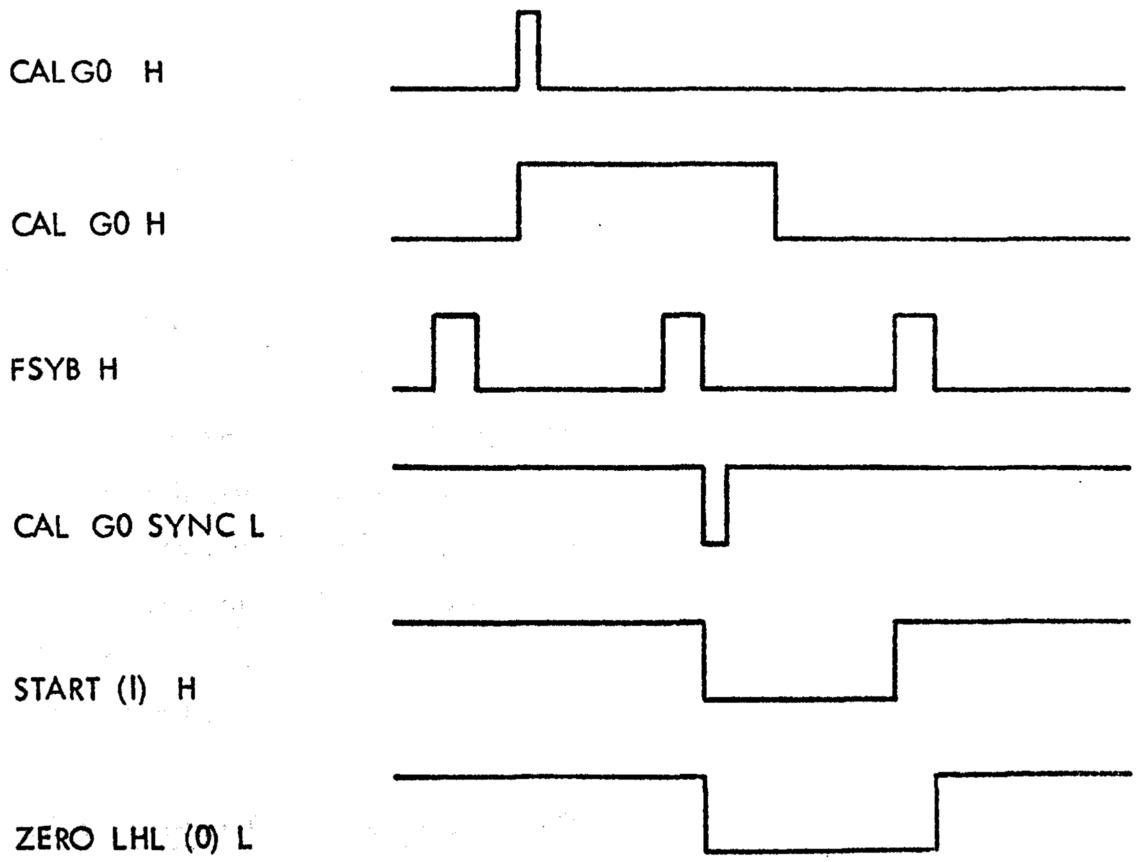


Figure 4.11. Initialisation of calibration control timing diagram.

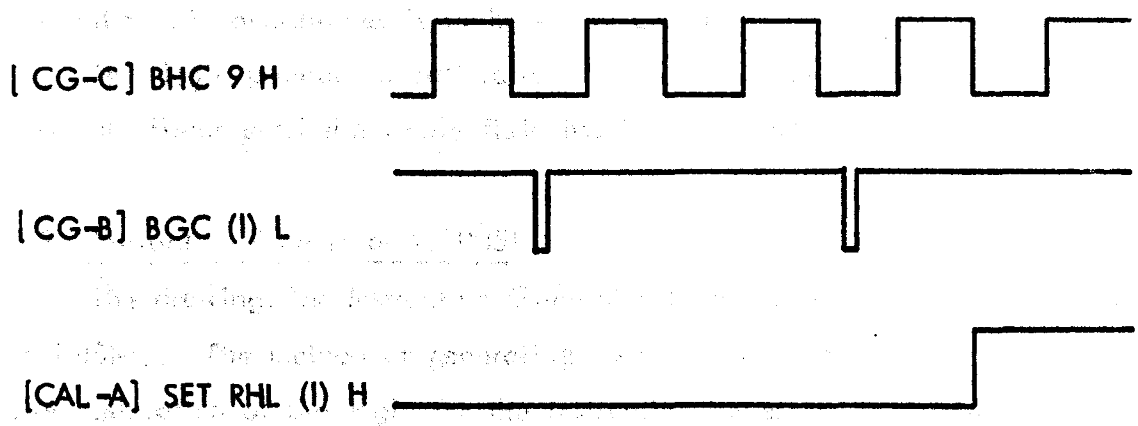


Figure 4.12. Timing diagram to set the right hand limit of the calibration window.

4.6.3 Left Hand Limit Latch and Margin Logic. CAL-C.

The left hand limit latch, LHL LATCH, is loaded with the contents of the RHL LATCH at the start of alternate television fields by the leading edge of [SGS-A] FSYB H. The timing of this operation is shown in Figure 4.13, in which typical propagation times are given for the various signals (from Texas Instruments (1973b)). The data for the LHL LATCH inputs must be held for 5 nS from the +ve edge of the clock signal [SGS-A] FSYB H as shown. The LHL LATCH is set to zero at the start of calibration by [CAL-A] ZERO LHL (0) L. The contents of the LHL LATCH are compared with the contents of the right hand margin register, CAL RHM REG, and as soon as the left hand limit is greater than or equal to the right hand margin RHM STOP L is generated to inhibit further co-ordinate generation. The RHM REG is loaded with the contents of bits Ø - 3 of the accumulator by [INSI-B] LDCAM H. When the calibration control is in the free run mode [INSI-B] FR (I) L inhibits RHM STOP L.

4.6.4 Window Control Logic. CAL-D.

The right hand limit comparator, RHL COMP, compares the contents of the RHL LATCH (A) with the outputs of the horizontal counter [CAL-B] HC Ø-7 (B), and when A is less than B, RHL L is generated to inhibit the CG. Similarly the left hand limit comparator LHL COMP compares the contents of the LHL LATCH (A) with [CAL-B] HC Ø - 7 (B), and as long as A is less than B generation of co-ordinates is inhibited by LHL L.

This logic provides a calibration "window" whose limits are reset on alternate fields until the whole field has been covered.

4.7 Instruction Generator I. INSI.

The drawings for Instruction Generator I are shown in Figure 4.20 INSI-A to INSI-C. The method of generating instructions is described in Appendix A2. The description of the logic for the instruction generator is limited here to a list of the instructions in the form of the octal code for each instruction followed by its function. The signal or combination of signals required to generate the function is shown after the function description.

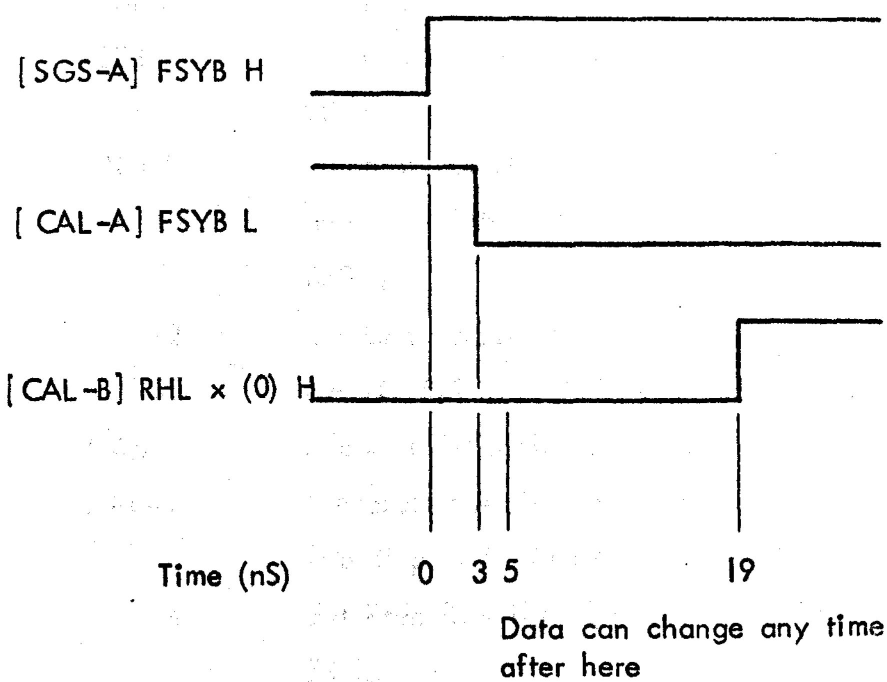


Figure 4.13. Timing diagram for loading the left hand limit latch.

4.7.1 Calibration Control Instructions. INSI-A and INSI-B.

The device selector for the 630X (Calibration Control) instructions is shown on INSI-A together with the appropriate buffering for [100] BMB 9-11, and [100] BA INITIALIZE H. The decoding and associated logic for this set of instructions is shown on INSI-B as follows:-

6301	Set MON EN flip flop. [INSI-A] IOT 6301 L.
6302	Load CAL RHM REG with bits Ø-3 of the accumulator. LDCAM H.
6303-1	Generate CALGO H to start calibration, clear CC flag, and set MON EN flip flop. CAGO L and [INSI-A] IOT 6301 L.
-2	Set CAL MODE flip flop, which also enables the interrupt. CAGO SET CAL MODE L.
6304	Clear all flip flops. CLR L
6305-1	Generate CALGO H to start calibration, set MON EN flip flop. CAGO FR L and [INSI-A] IOT 6301 L.
-4	Set Free Run flip flop and clear CC FLAG. CAGO FR SET FR L.
6306	Clear CC FLAG. [INSI-A] IOT 6304 L.
6307-1	Set MON EN flip flop. [INSI-A] IOT 6301 L.
-2	Skip if calibration has been completed. SCAC H.
-4	Clear CC FLAG. [INSI-A] IOT 6304 L.

[INSI-A] IO INIT L also clears all the flip flops.

4.7.2 Sync Generator and Simulator Instructions. INSI-C.

The device selector and decoding with associated logic for the 631X instructions is shown here as follows:-

6311	Load Field Count Register FCR with bits 4-11 of the accumulator. LDFC H.
6312	Load Line Count Register LCR with bits 4-11 of the accumulator. LDLC H.

6313-1	Field Count Mode; sets Enable Field Count flip flop ENFC, which allows [SGS-B] ENCG to be controlled by the contents of the FCR. ENFC L.
6314	Set Enable Simulator flip flop ENSM. ENSM L.
6315-1	Clear ENFC. CFC L.
6316-2	Clear ENSM. CSM L.

[INS1-A] IO INIT L also clears ENFC and ENSM.

4.8 Instruction Generator 2. INS2.

The drawings for Instruction Generator 2 are shown in Figure 4.21 INS2-A to INS2-E. The method of instruction generation and the presentation of the logic description is the same as for Instruction Generator 1.

4.8.1 Co-ordinate Generator Instructions. INS2-A.

The device selector and decoding for the 632X instructions is shown here, together with the appropriate buffering for [100] BMB 9-11. These instructions are as follows:-

6321	Enable CG, sets ENCG flip flop. ENCG L.
6322	Disable CG, clears ENCG. DISCG L.

[INS2-A] IO INIT L also clears ENCG.

4.8.2 Address Register Instructions INS2-B to INS2-E.

The device selector for the 633X instruction set is shown on INS2-B together with the decoding and logic for some of the instructions as follows:-

6333-1	Load Initial Data Address register IDA with the contents of the accumulator LDCA L.
-2	Clear Change Buffer Half flags, FLAG 1 and FLAG 2 (on INS2-E). LDCA CL FL L.
6335-1	Clear accumulator. RCA CLA L.
-4	Read current Memory data Address into the accumulator. RCA H.

6336-2 Clear accumulator. RCFA CLA L.

-4 Read current data Field Address into the accumulator. RCFA H.

The decoding for the rest of the 633X instructions is shown on INS2-C as follows:-

6331 Set ENAD flip flop to enable Memory data Address onto address bus. ENAD L.

6332 Set ENFAD flip flop to enable data Field Address onto field address bus. ENFAD L.

6334 Clear ENAD and ENFAD flip flops. CLAD L.

[INS2-A] IO INIT L also clears ENAD and ENFAD.

The device selector for the 634X instructions is shown on INS2-D together with some of the decoding. These instructions are also associated with the Address Register as follows:-

6341 Set Double Buffer Mode flip flop, DBM. DBM L.

6342 Clear DBM. CDBM L.

6343-1 Enable Double Buffer Mode interrupt, DBI. ENDBI L.

6344 Disable DBI. CDBI L.

6345-1 Skip if Change Buffer Half Flag is set, FLAG 1 or FLAG 2 (on INS2-E). SCBH H.

-4 Clear FLAG 1 and FLAG 2. SCBH CL FL L.

The decoding for the rest of the 634X instructions is shown on INS2-E together with the interrupt and skip logic for the Double Buffer Mode of operation. The following instructions are included here:-

6346-2 Skip if Upper Buffer Half is being filled. SUBH H.

6347-1 Clear FLAG 1 and FLAG 2. CDBF L.

[INS2-A] IO INIT L also clears FLAG 1, FLAG 2, DBM and DBI.

FLAG 1 is set when data Field Address bit 1 changes from Ø to 1 and FLAG 2 is set when data Field Address bit 2 changes from Ø to 1.

4.9 Construction and Planning

Texas Instruments 7400 series TTL logic is used throughout the interface with the exception of the random access memories which are Signetics 8000 series. The technical specifications for the devices used will be found in Texas Instruments (1973b) and Signetics (1974). The integrated circuits (I C's) are mounted on "Veroboard" and all interconnections are hand wired. The layout of the I C's was designed to minimise the length of the interconnections. Two methods of describing the wiring were used. The first consisted of a series of drawings showing the positions of the I C's and the interconnections between them, a separate drawing being provided for each colour of wire used. This method allowed the position of each wire to be specified precisely so that some attempt to minimise critical cross talk effects could be made. The wiring for the Co-ordinate Generator and the Sync Generator and Simulator was described in this way. The second method of wiring description was simply to provide a list of interconnections as shown in Figure 4.14. A drawing of the I C layout and pin configurations was also provided. The technician then made the appropriate connections keeping wire lengths as short as possible. Checking of the wiring was carried out before the components were inserted by testing for continuity between the specified interconnected points.

De-coupling capacitors (0.1 μF ceramics) were connected between the +ve supply and ground on at least every other I C. These de-coupling capacitors were also provided for every I C that had a clock input, (such as D type flip flops etc.), to reduce the possibility of the devices being clocked by noise on the power lines. 47 μF electrolytic capacitors were also mounted on each board for de-coupling. Unused inputs to logic elements were held at the appropriate logic level, or paralleled to other inputs. For low logic levels the input was connected direct to ground, but where high levels were required these were provided by the output of an unused gate, this method providing the best noise immunity.

PIN A	PIN B	Colour	No A	No B	Comments	Signal Name
A1-6	A2-6	Green	2	2		BMB 3 (0) H
A1-5	A2-5	"	2	2		BMB 4 (1) H
A1-4	A2-4	"	2	2		BMB 5 (1) H
PIN 71	A2-12	"	2	1		BMB 6 (0) H
PIN 74	A2-11	"	2	1		BMB 7 (1) H
PIN 75	A2-1	"	2	1		BMB 8 (0) H
A2-8	B6-13	Green	1	2		632 Select L
B6-13	B6-12	Wire	2	1		" " L
B6-11	B6-10	Wire	1	2		632 Select H
B6-10	B6-5	Green	2	2		" " H
B6-5	B6-2	"	2	1		" " H
PIN 55	B6-9	Yellow	2	2	A side	BIOP 1 H
PIN 57	B6-4	"	2	2	"	BIOP 2 H
PIN 59	B6-1	"	2	2	"	BIOP 4 H
B6-6	B7-5	Yellow	1	1	A side	IOT 6322 L
B6-3	B7-3	"	1	1	"	IOT 6324 L
B6-8	B7-9	"	1	1	"	IOT 6321 L
B7-8	B8-13	Yellow	1	1	A side	IOT 6321 H
B7-6	B8-5	"	1	1	"	IOT 6322 H
B8-12	A8-10	Yellow	1	1	A side	ENCG L
B8-6	A7-5	"	1	1	"	DISCG L
A7-6	A8-13	White	1	1		Clear ENCG L
B2-8	A7-4	"	1	2		IO INIT L
1	2	3	4	5	6	7

Columns 1 and 2 give the pin numbers to be interconnected.

Column 3 gives the wire colour to be used

Columns 4 and 5 give the number of connections on each pin.

Figure 4.14. Extract from the wiring list for Instruction Generator 2.

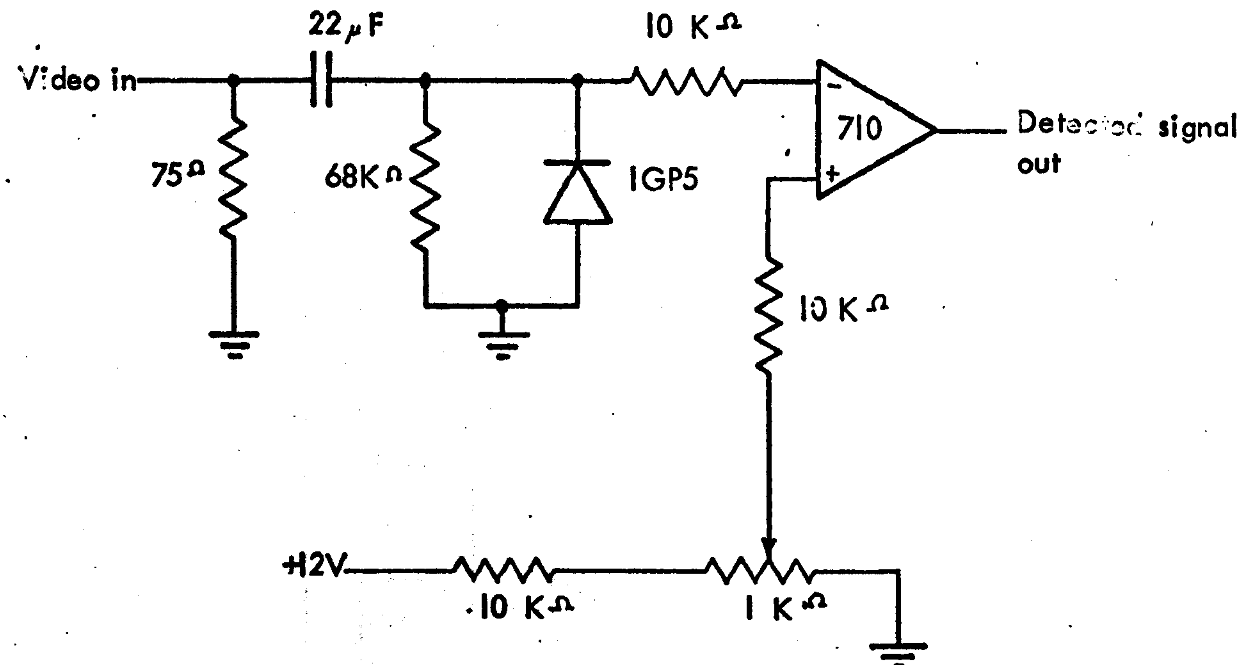


Figure 4.15. Comparator circuit used to generate TTL compatible field and line synchronising pulses from standard sync pulse generator syncs.

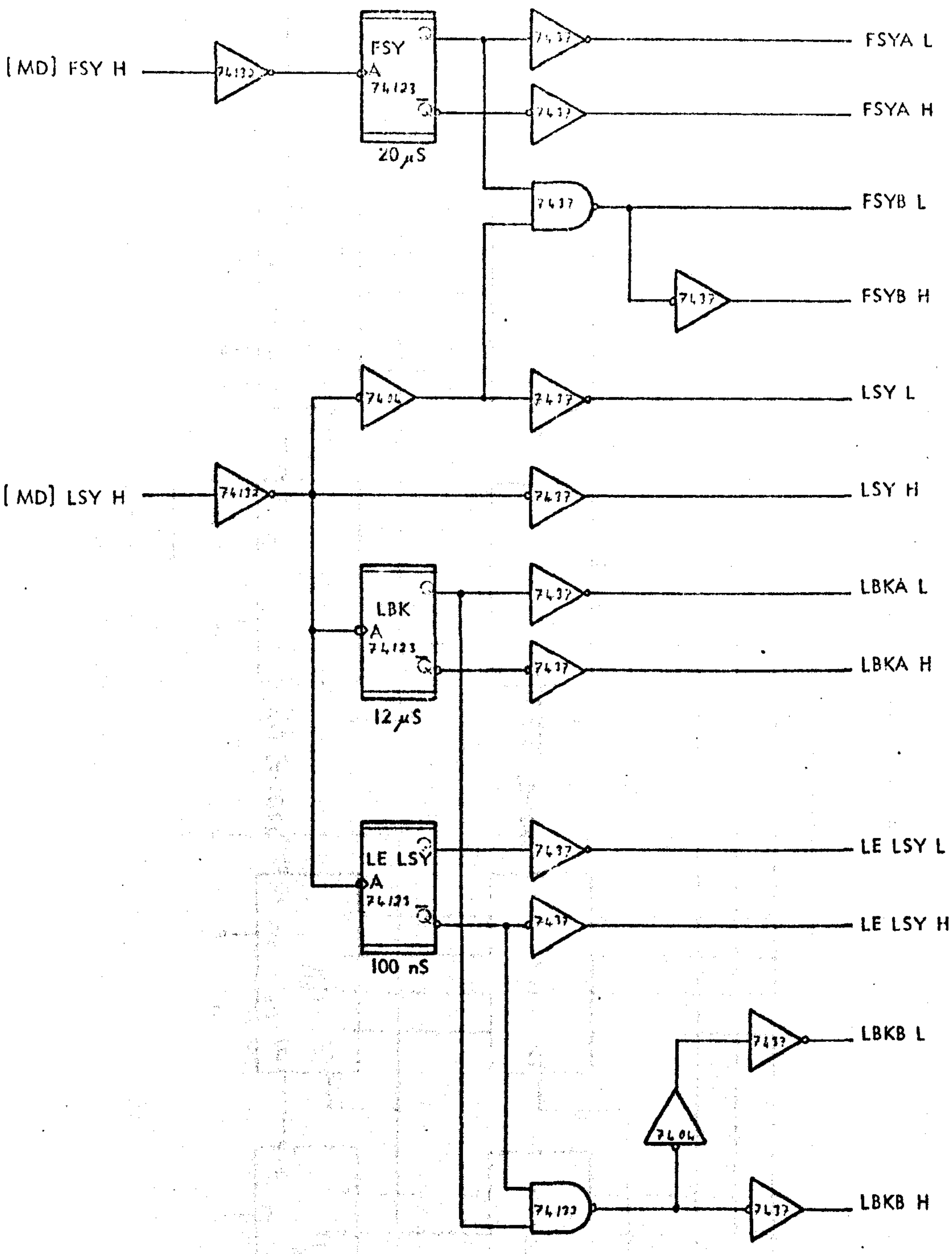


Figure 4.16 SGS-A. Sync generator and simulator - internal syncs.

Drawing Number SGS-A

SYNC GENERATOR AND SIMULATOR

Internal Syncs

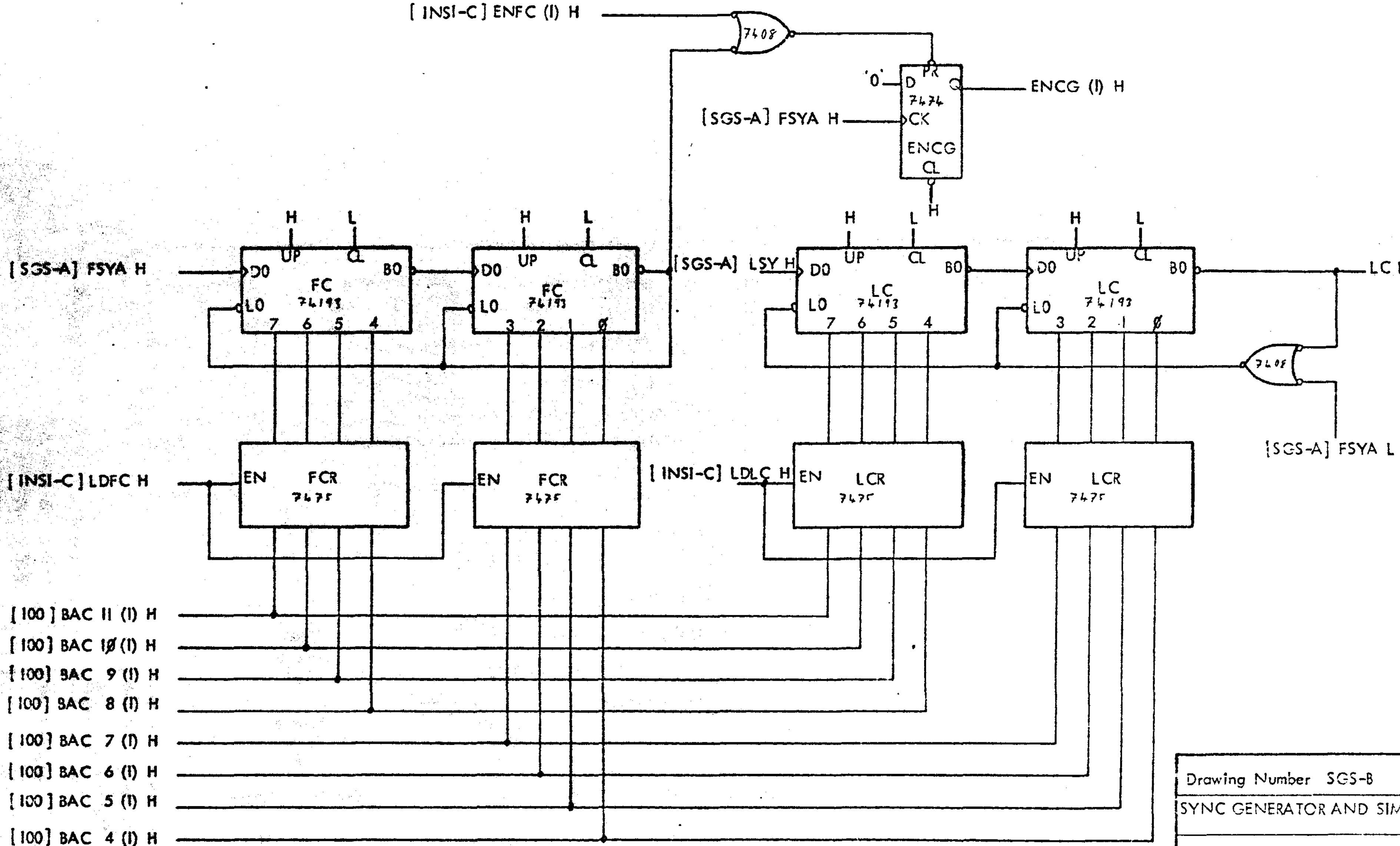


Figure 4.16 SGS-B. Sync generator and simulator - line count and field count functions.

Drawing Number SGS-B

SYNC GENERATOR AND SIMULATOR

Line Count and Field Count Functions

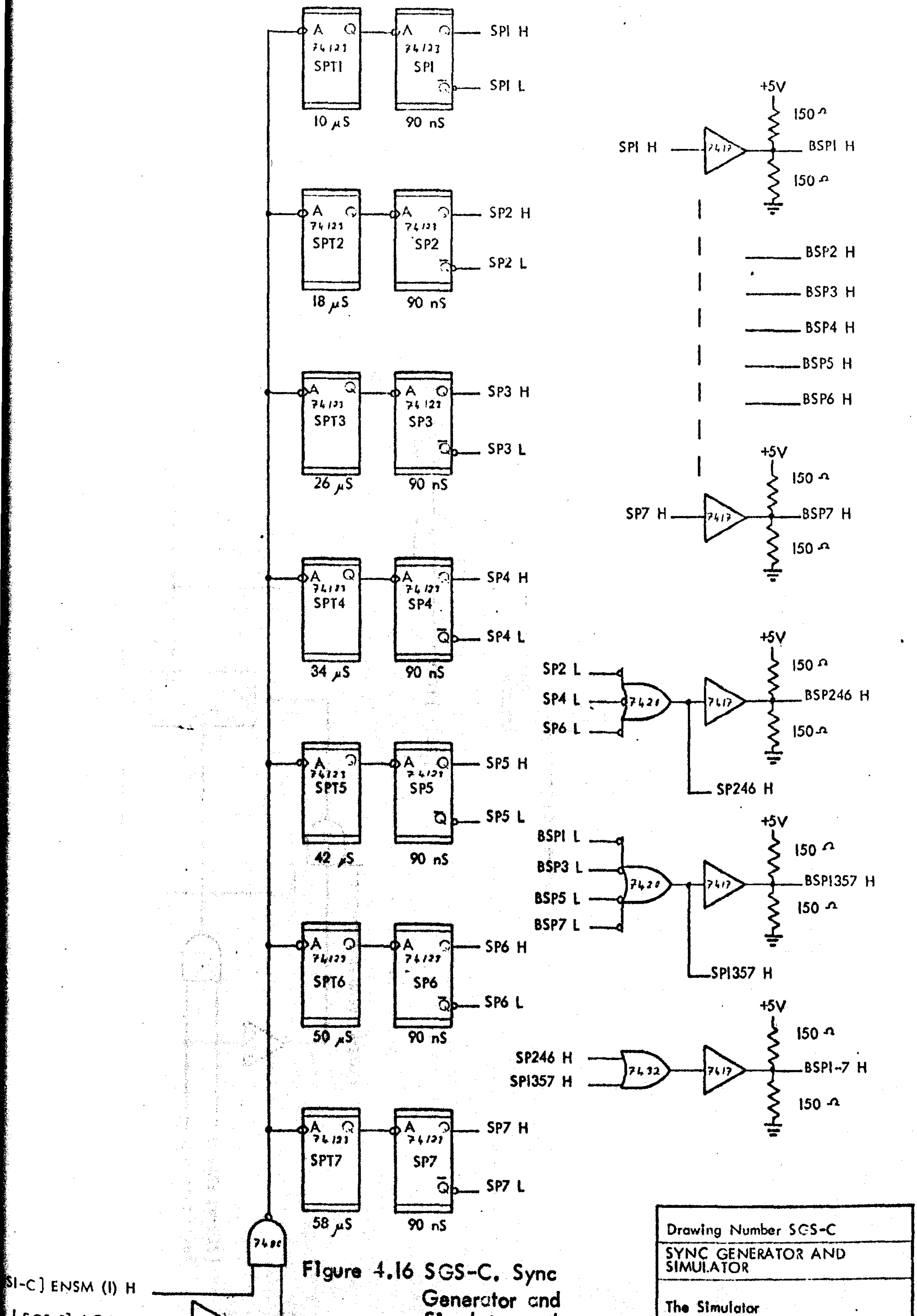


Figure 4.16 SGS-C. Sync Generator and Simulator - the simulator.

Drawing Number SGS-C
SYNC GENERATOR AND SIMULATOR
The Simulator

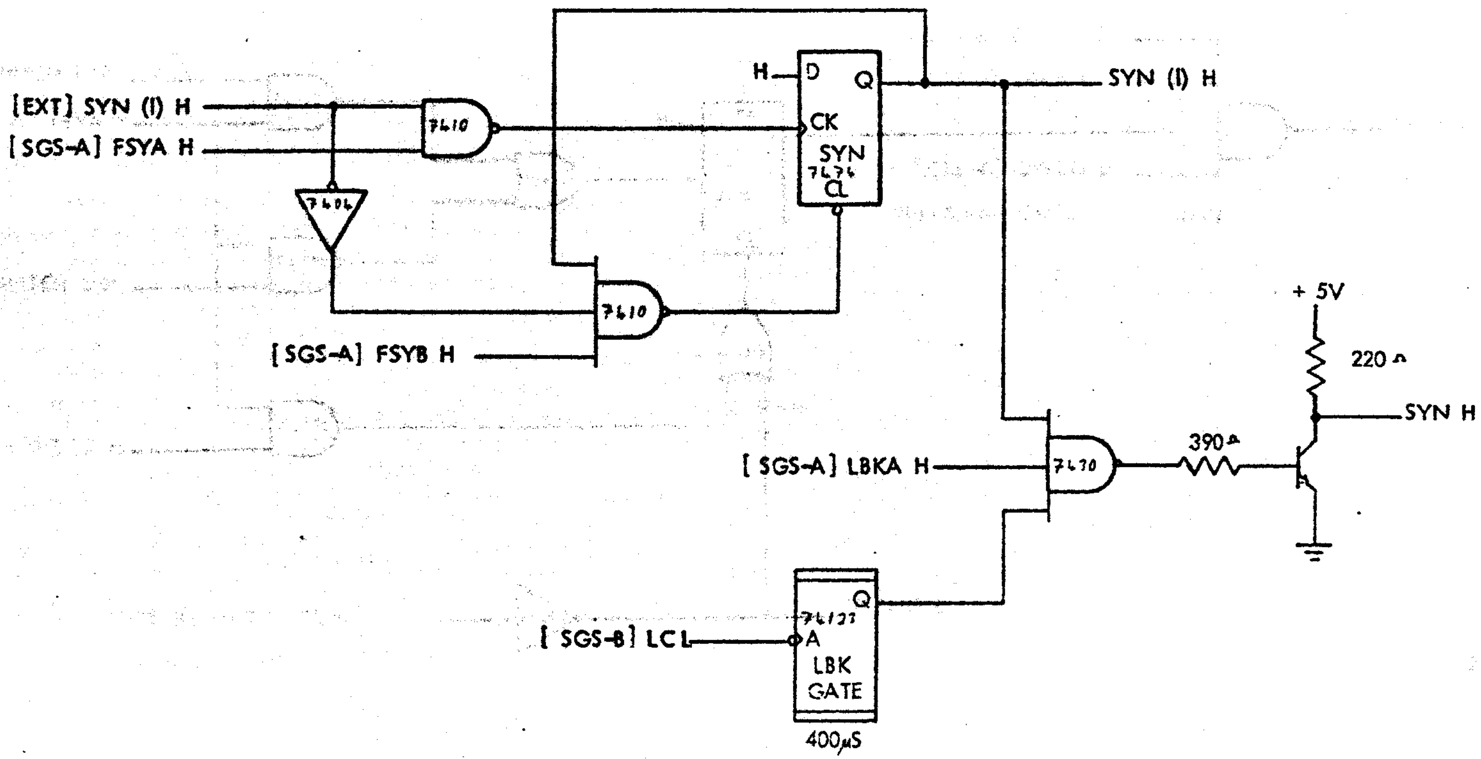


Figure 4.16 SGS-D. Sync generator and simulator - external synchronisation and sync pulse generator.

Drawing Number SGS-D
SYNC GENERATOR AND SIMULATOR
External Synchronisation and Sync Pulse Generator

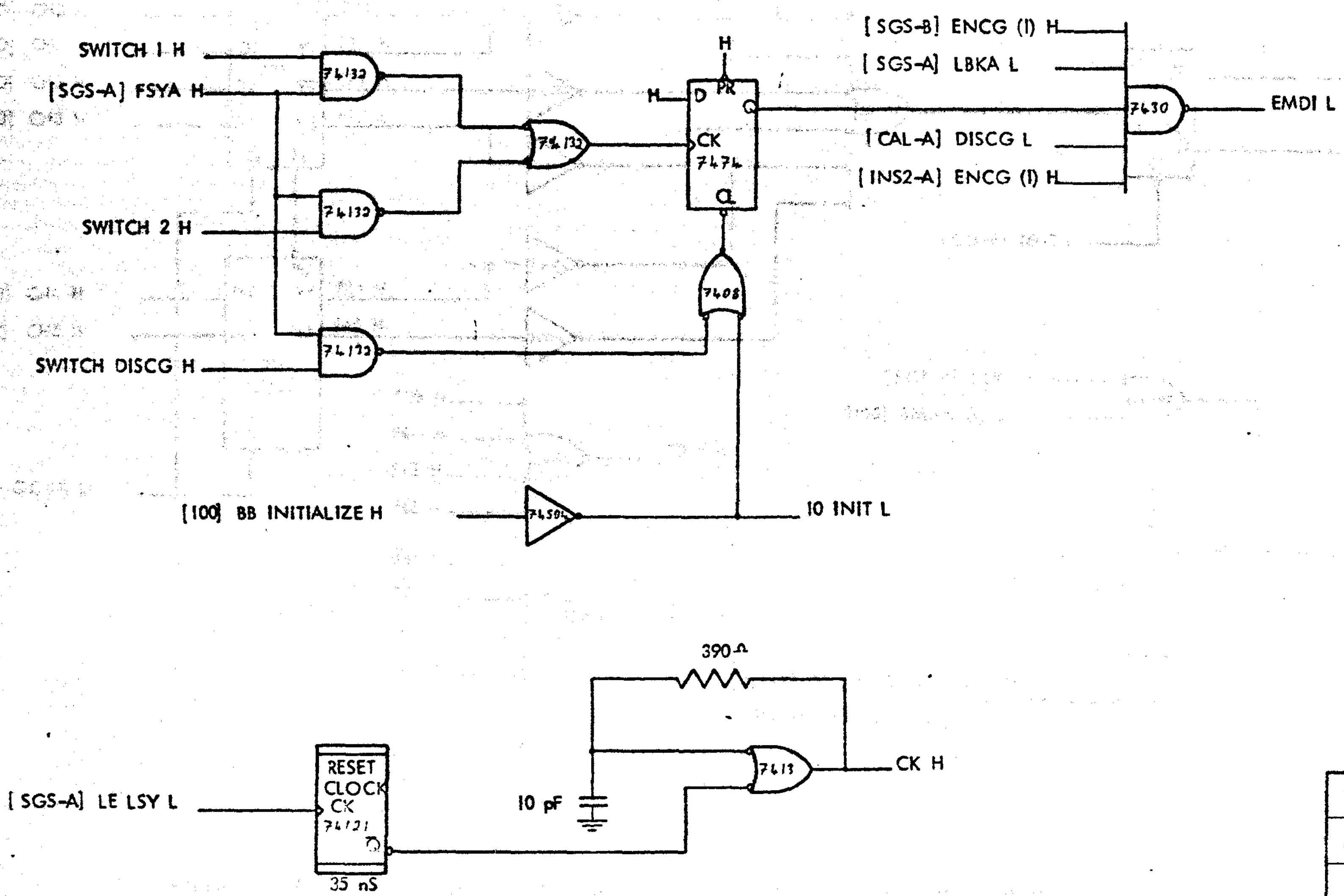


Figure 4.17 CG-A. Co-ordinate generator - enable logic and clock.

Drawing Number CG-A
CO-ORDINATE GENERATOR
Enable Logic and Clock

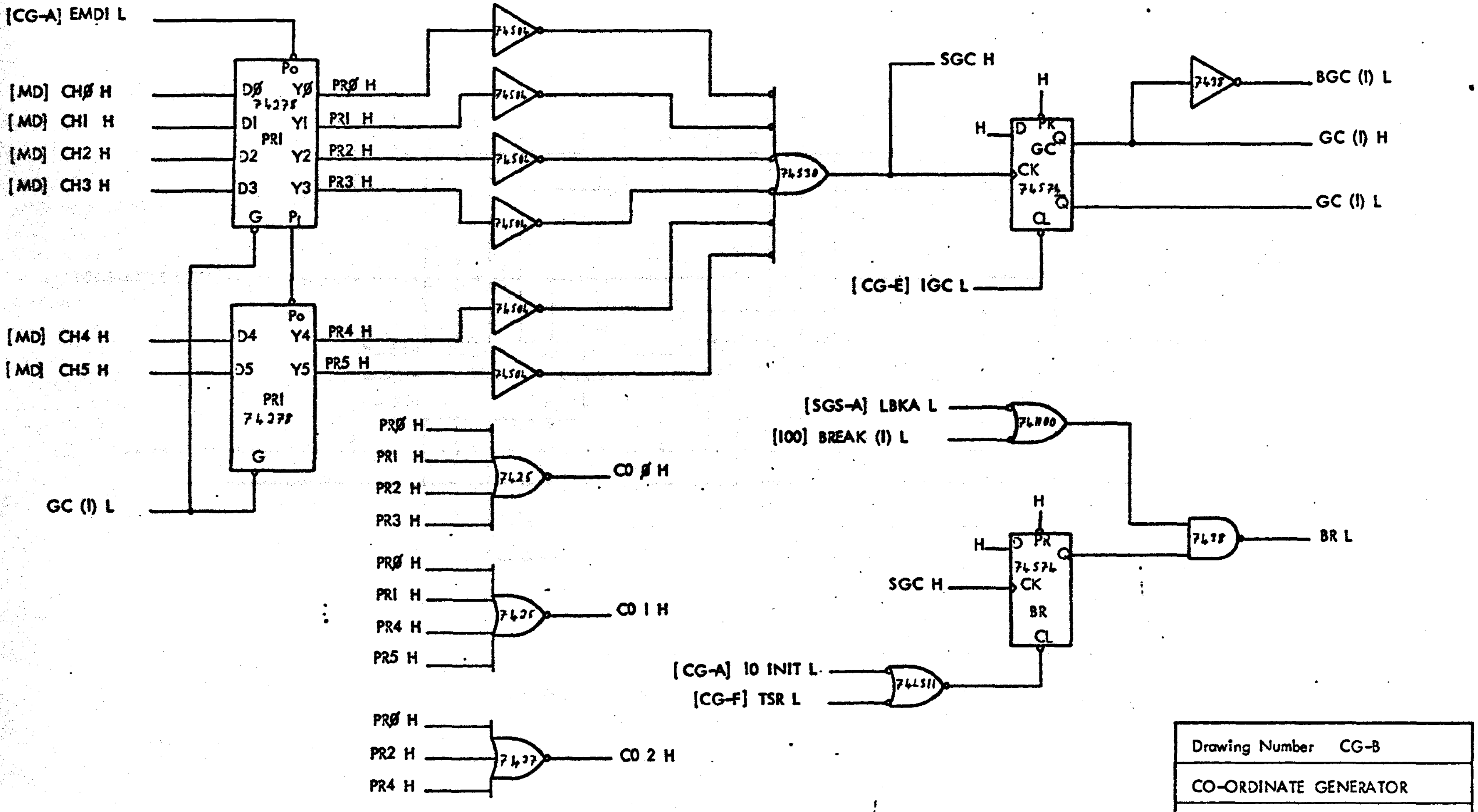


Figure 4.17 CG-B. Co-ordinate generator - priority register and coding.

Drawing Number	CG-B
CO-ORDINATE GENERATOR	
Priority Register and Coding	

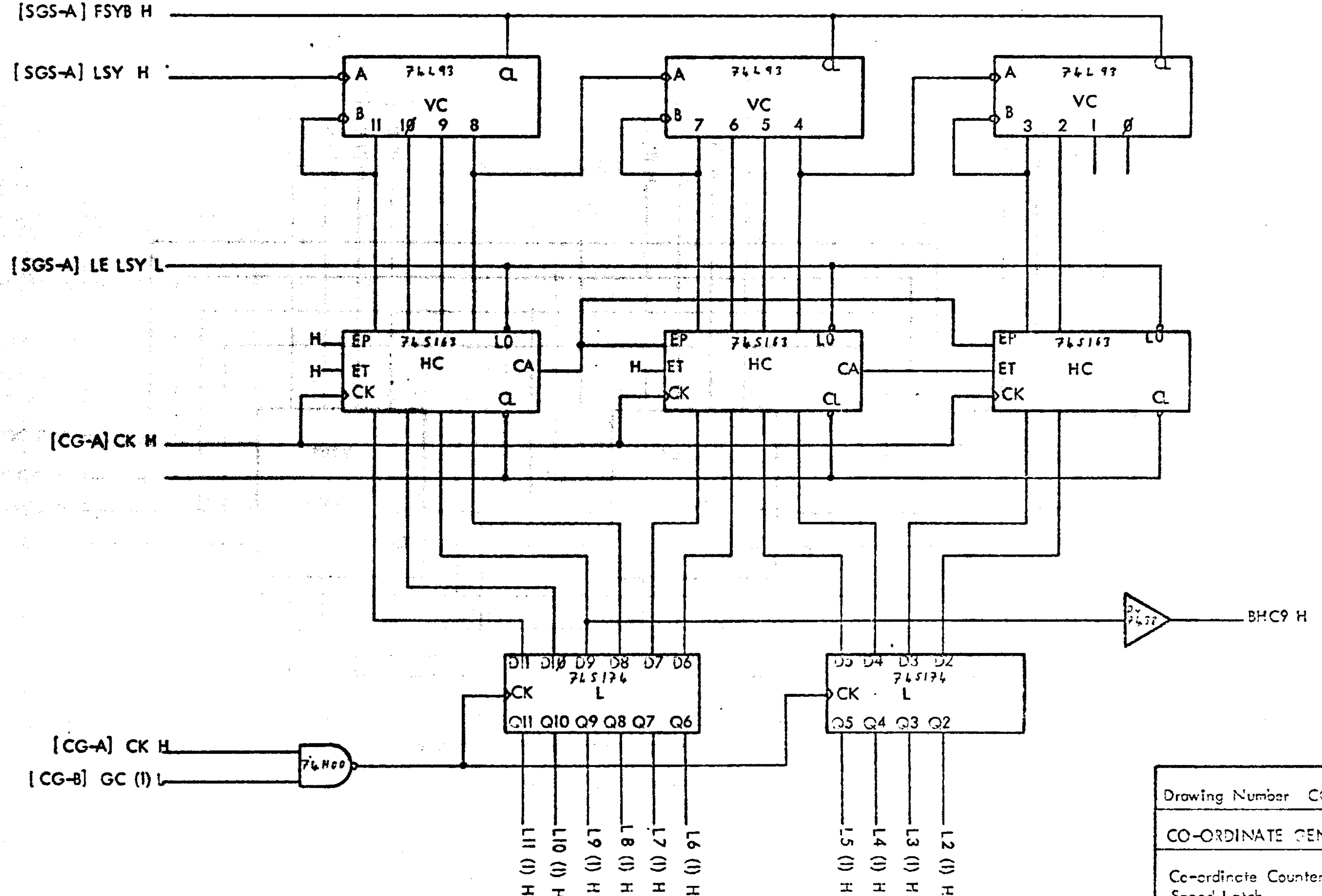


Figure 4.17 CG-C. Co-ordinate generator - co-ordinate counters and high speed latch.

Drawing Number CG-C
CO-ORDINATE GENERATOR
Co-ordinate Counters and High Speed Latch

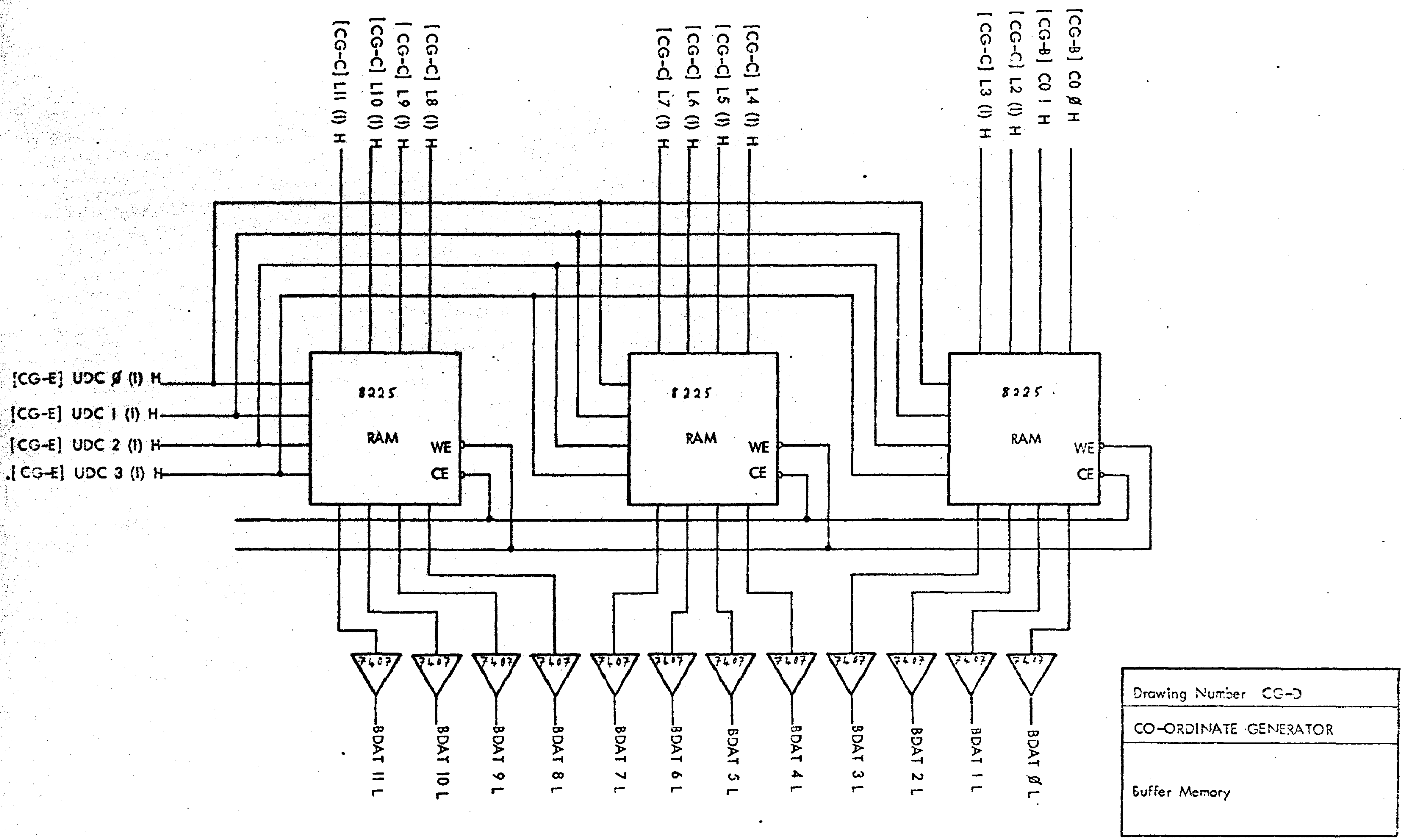


Figure 4.17 CG-D. Co-ordinate generator - buffer memory.

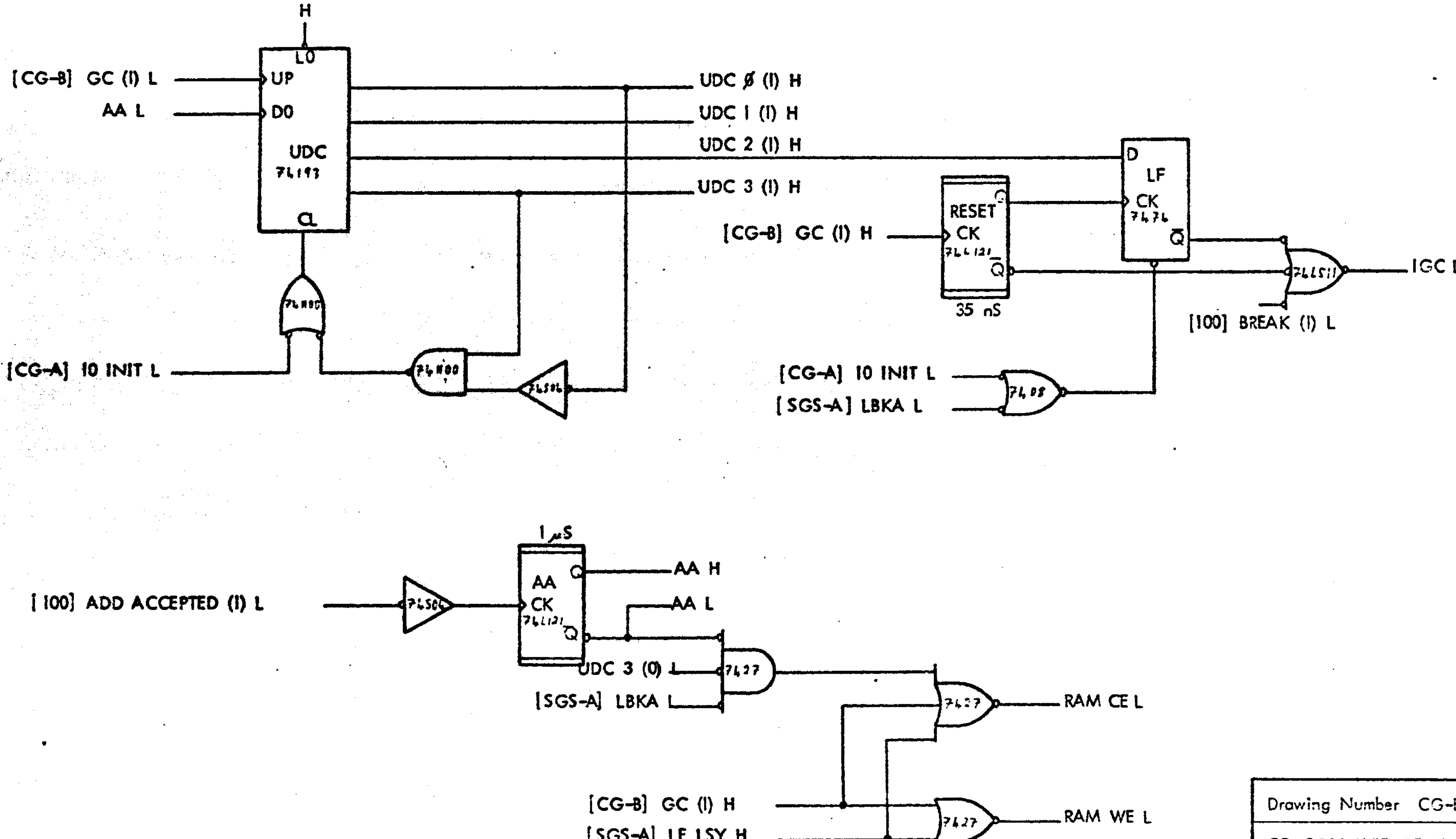


Figure 4.17 CG-E. Co-ordinate generator - buffer memory address and control logic.

Drawing Number CG-E
CO-ORDINATE GENERATOR
Buffer Memory Address and Control Logic

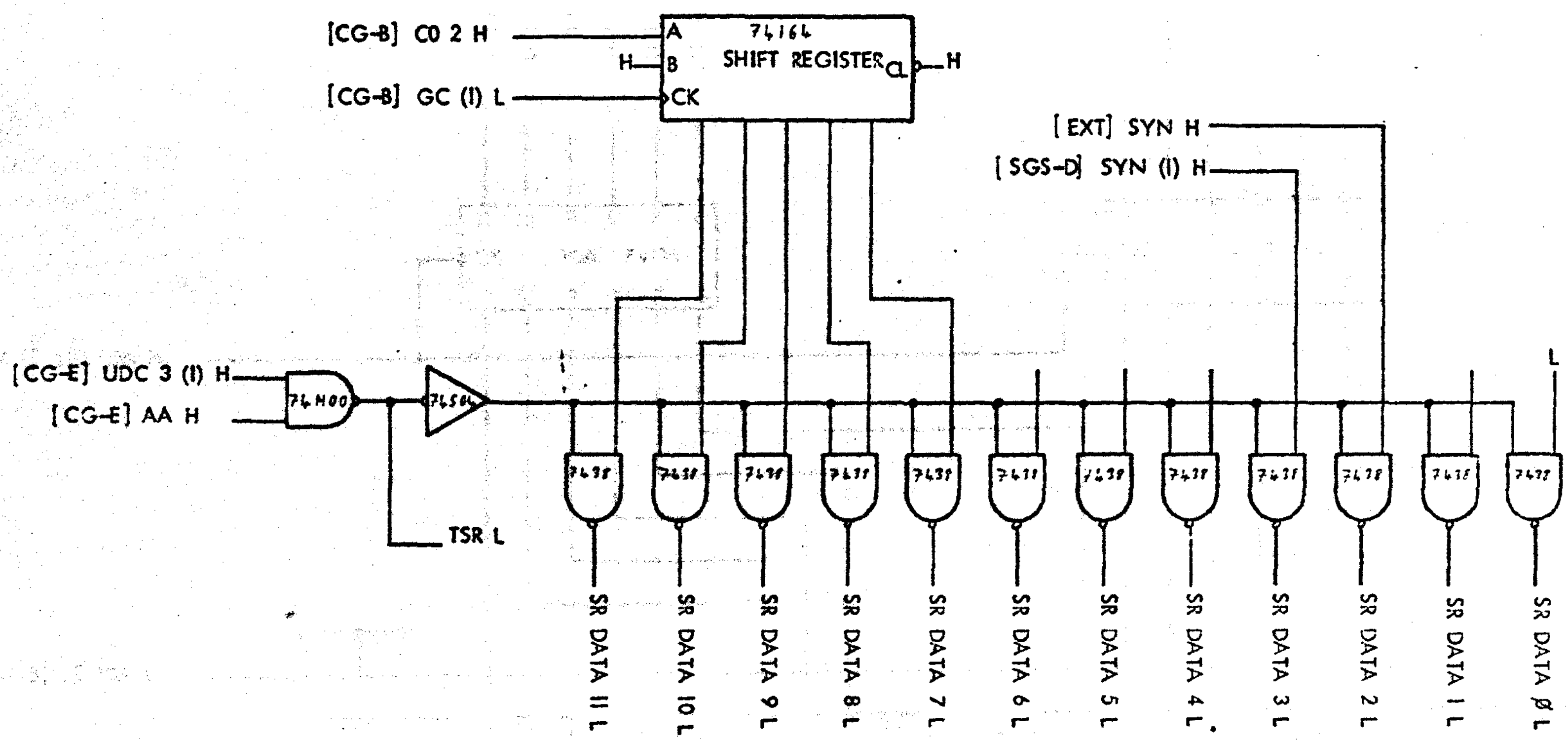


Figure 4.17 CG-F. Co-ordinate generator - additional code bit.

Drawing Number CG-F
CO-ORDINATE GENERATOR
Additional Code Bit

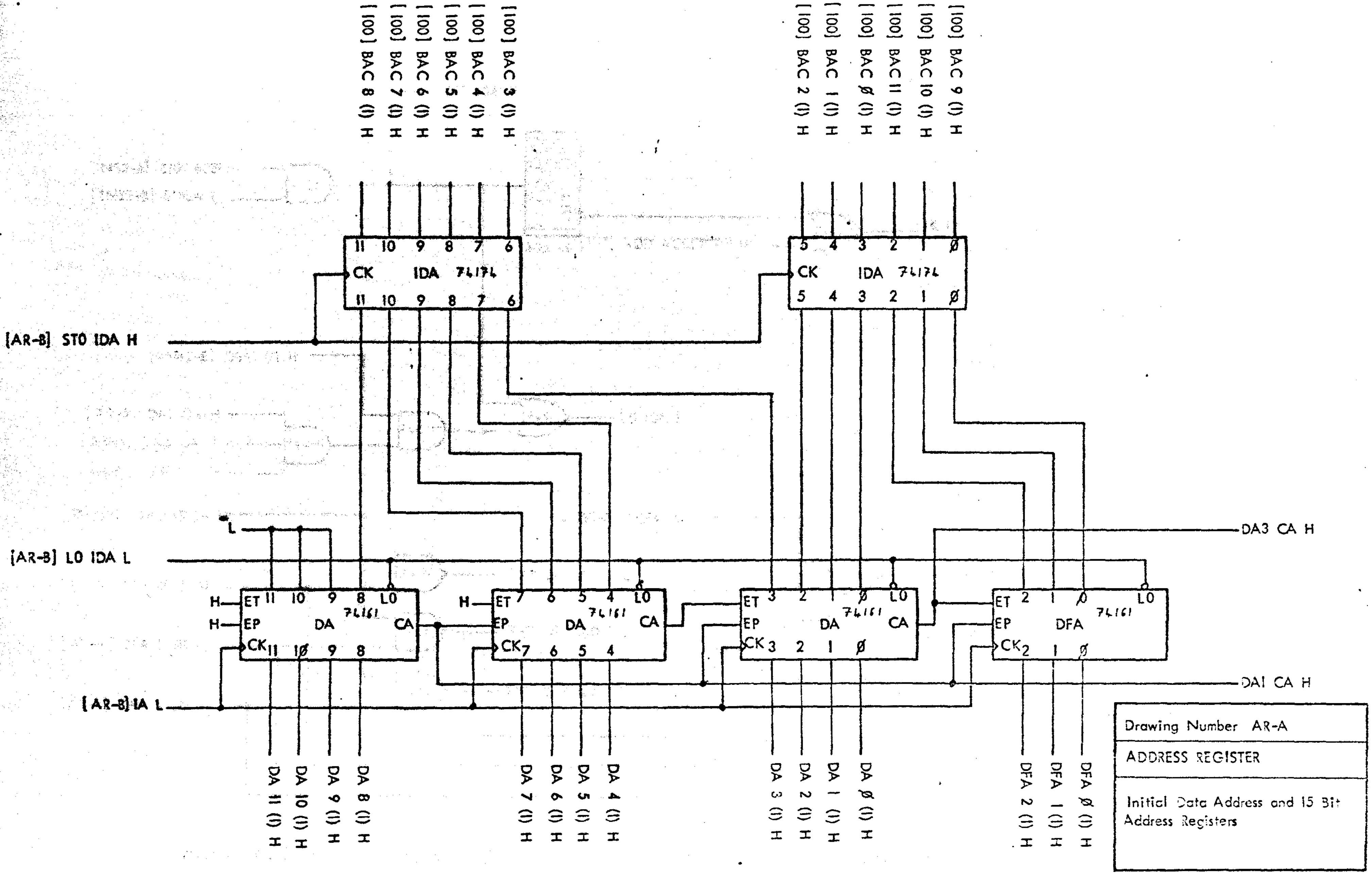


Figure 4.18 AR-A. Address register - initial data address and 15 bit address registers.

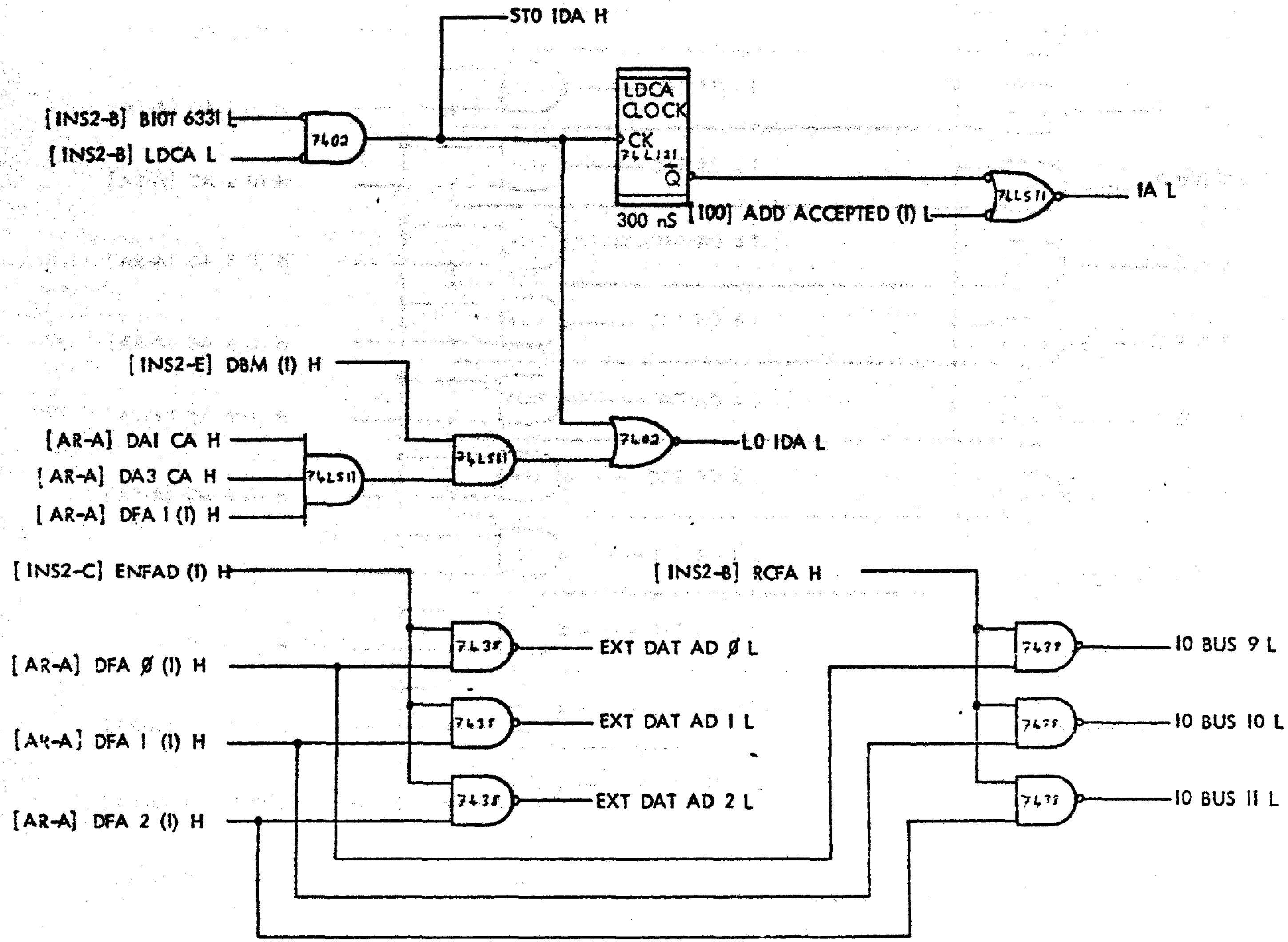


Figure 4.18 AR-B. Address register - address increment logic and computer bus drivers.

Drawing Number AR-B
ADDRESS REGISTER
Address Increment Logic and Computer Bus Drivers

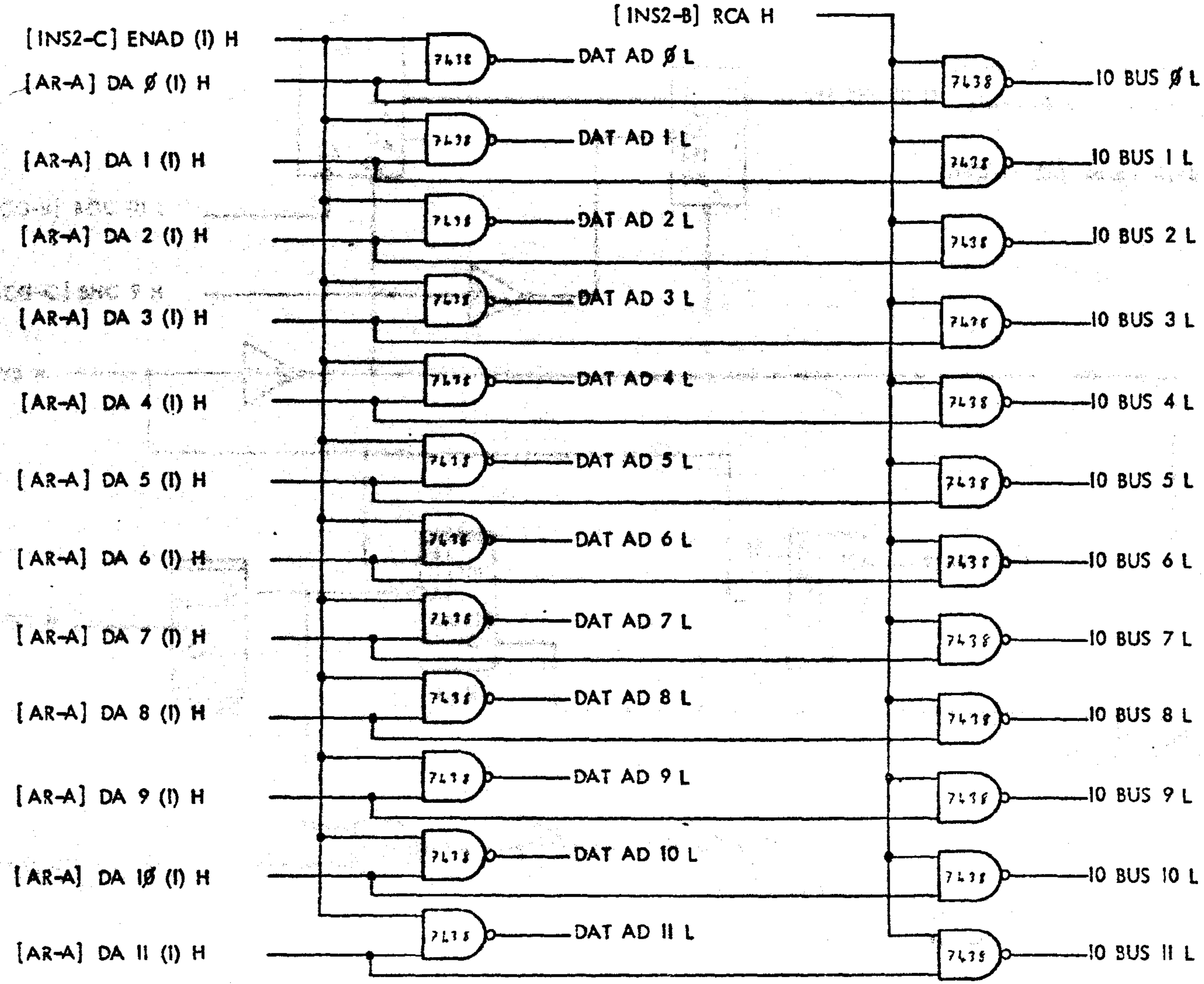


Figure 4.18 AR-C. Address register - computer bus drivers.

Drawing Number AR-C
ADDRESS REGISTER
Computer Bus Drivers

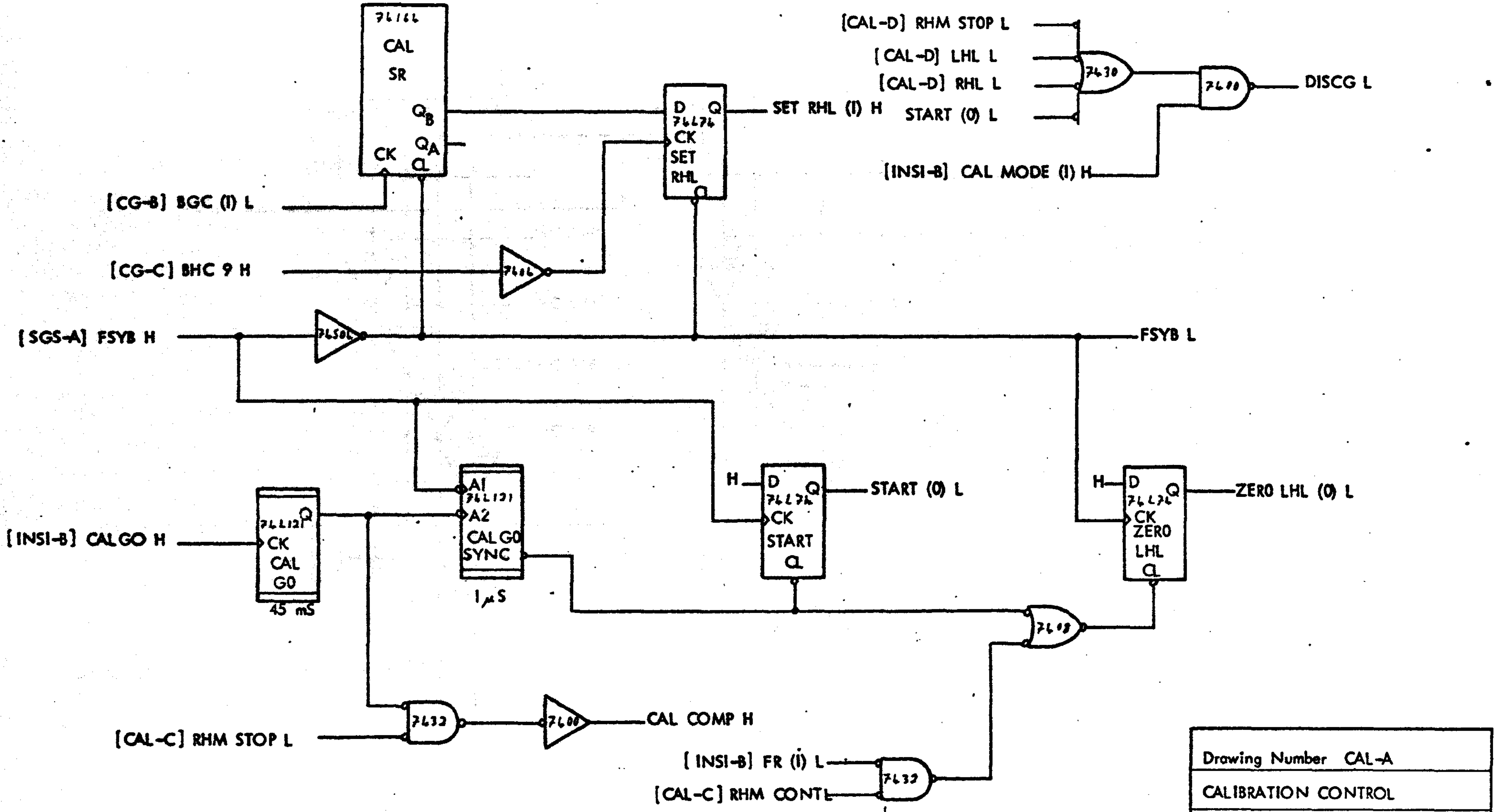


Figure 4.19 CAL-A. Calibration control - calibration initialisation and control logic.

Drawing Number CAL-A
CALIBRATION CONTROL
Calibration Initialisation and Control Logic

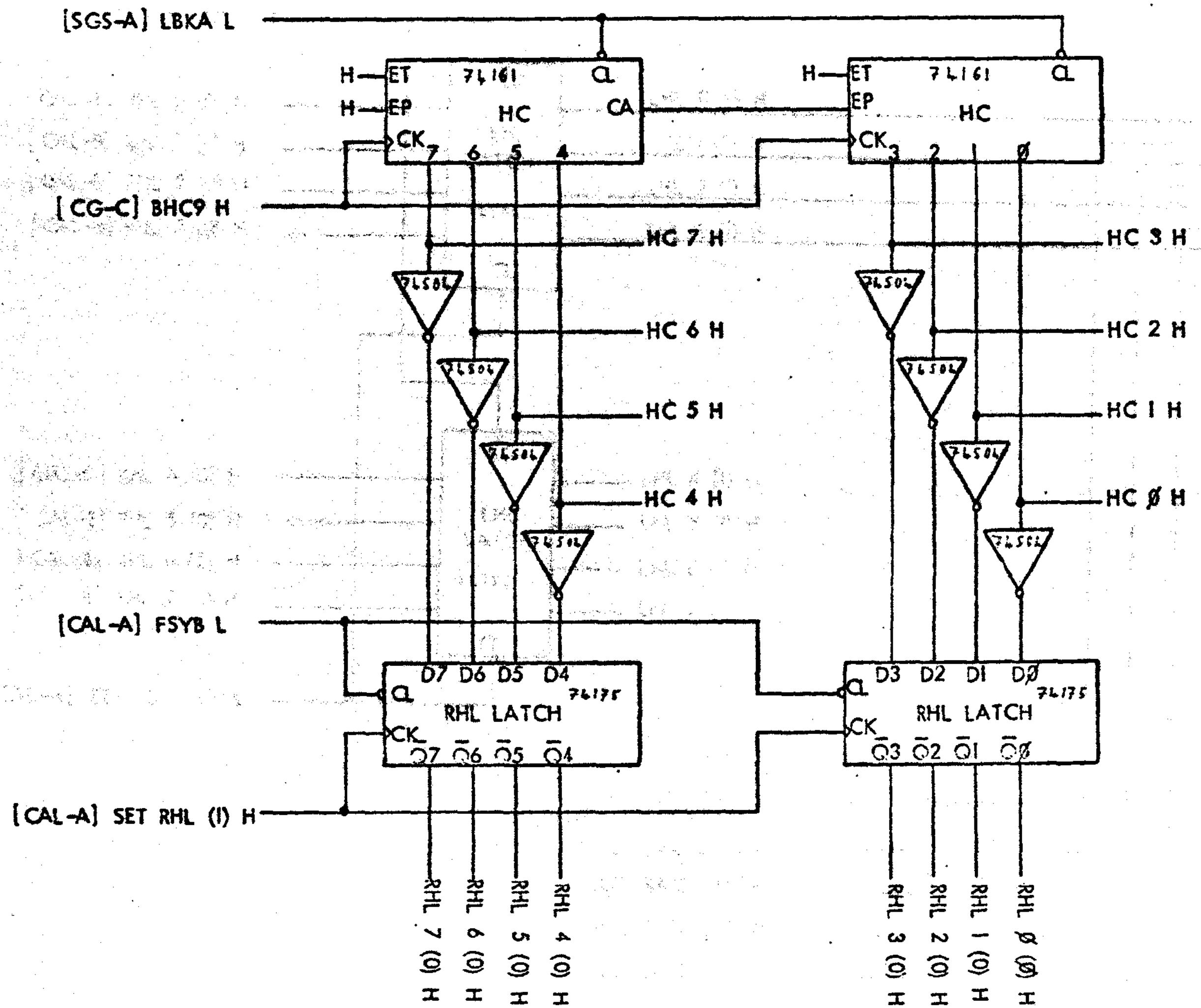


Figure 4.19 CAL-B. Calibration control - horizontal counter and RHL latch.

Drawing Number CAL-B
CALIBRATION CONTROL
Horizontal Counter and RHL Latch

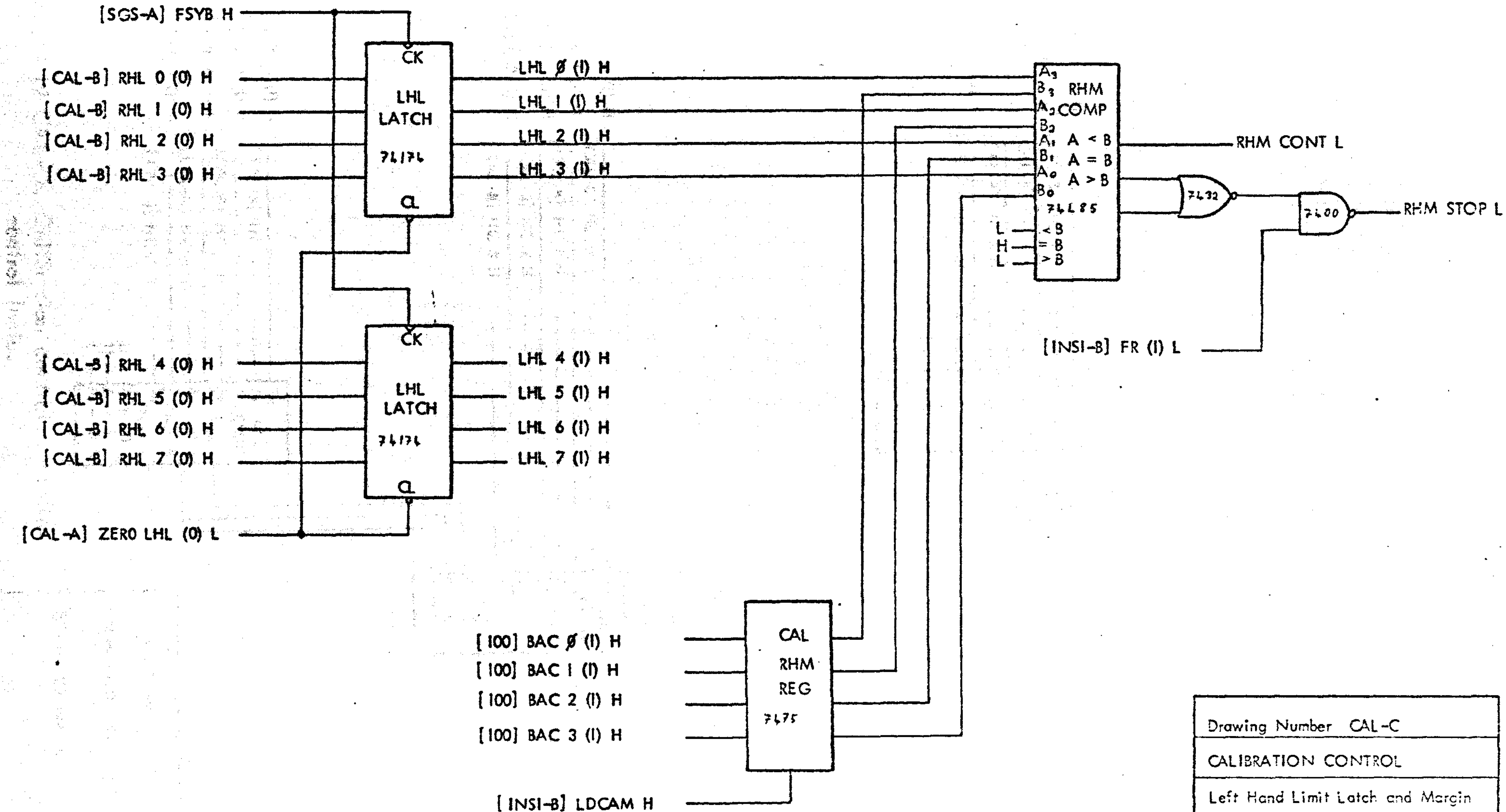


Figure 4.19 CAL-C. Calibration control - left hand limit latch and margin logic.

Drawing Number CAL-C
CALIBRATION CONTROL
Left Hand Limit Latch and Margin Logic

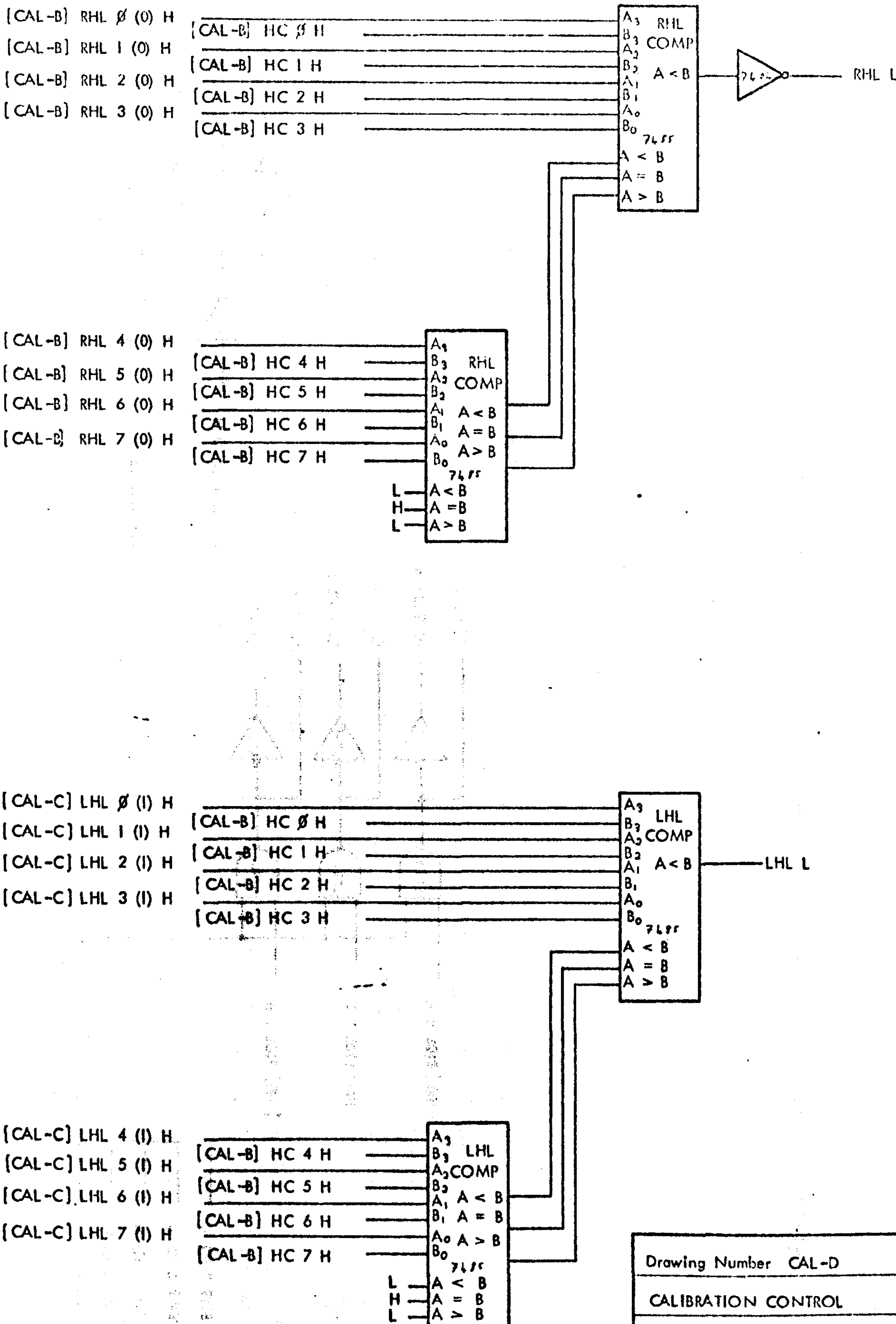


Figure 4.19 CAL-D. Calibration control - window control logic.

Drawing Number CAL-D
CALIBRATION CONTROL
Window Control Logic

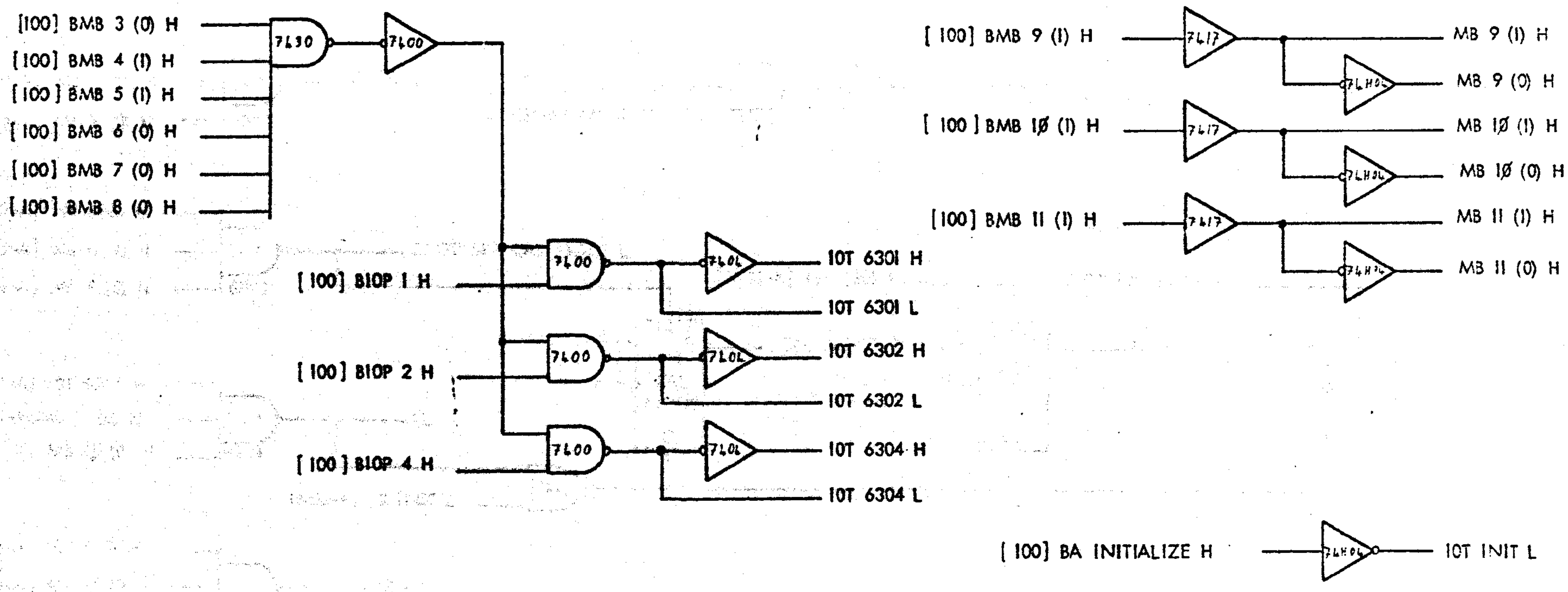


Figure 4.20 INSI-A. Instruction generator I - calibration control instructions 630X.

Drawing Number INSI-A
INSTRUCTION GENERATOR I
Calibration Control Instructions 630X

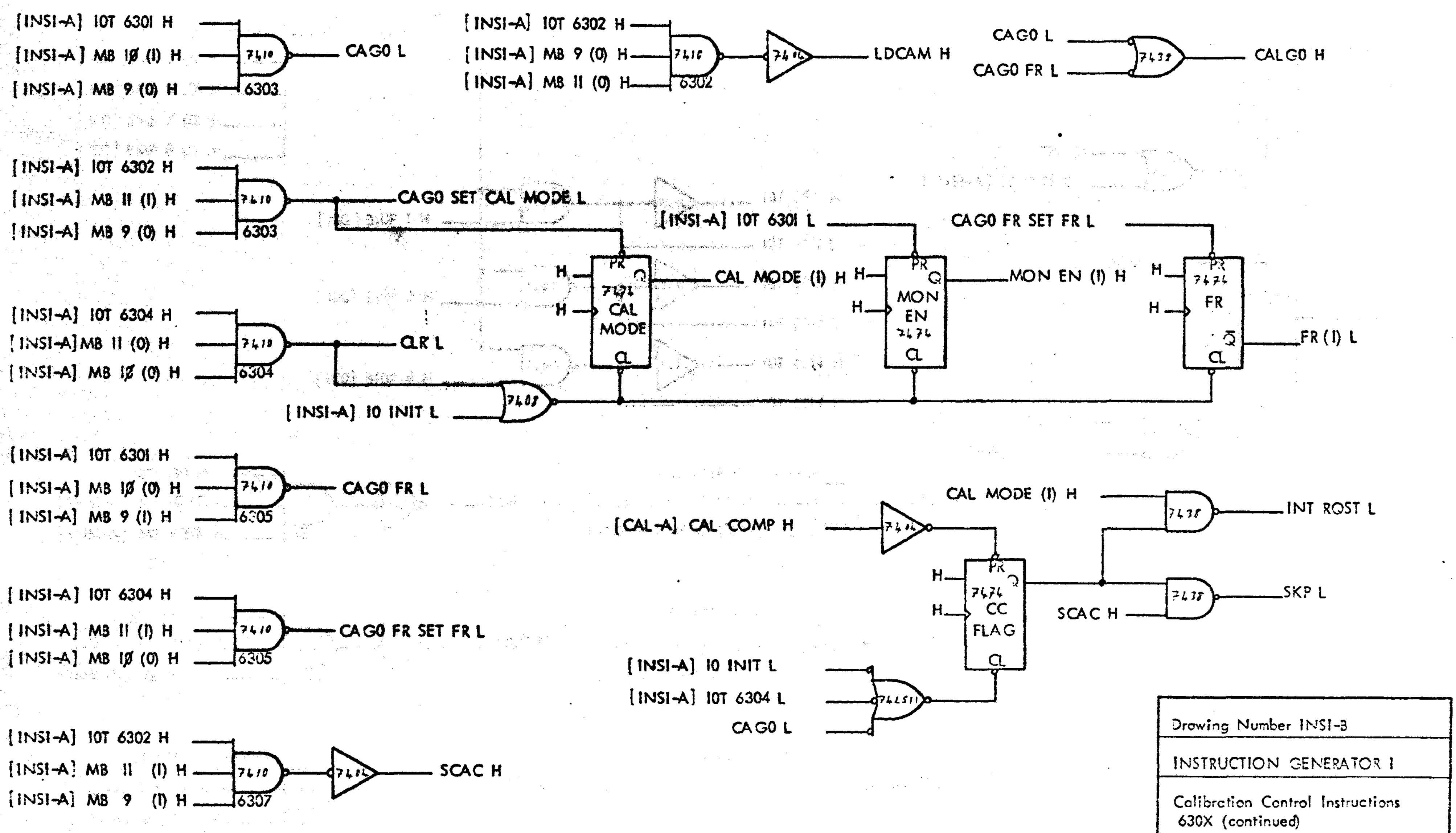


Figure 4.20 INSI-3. Instruction generator I - calibration control instructions 630X (continued).

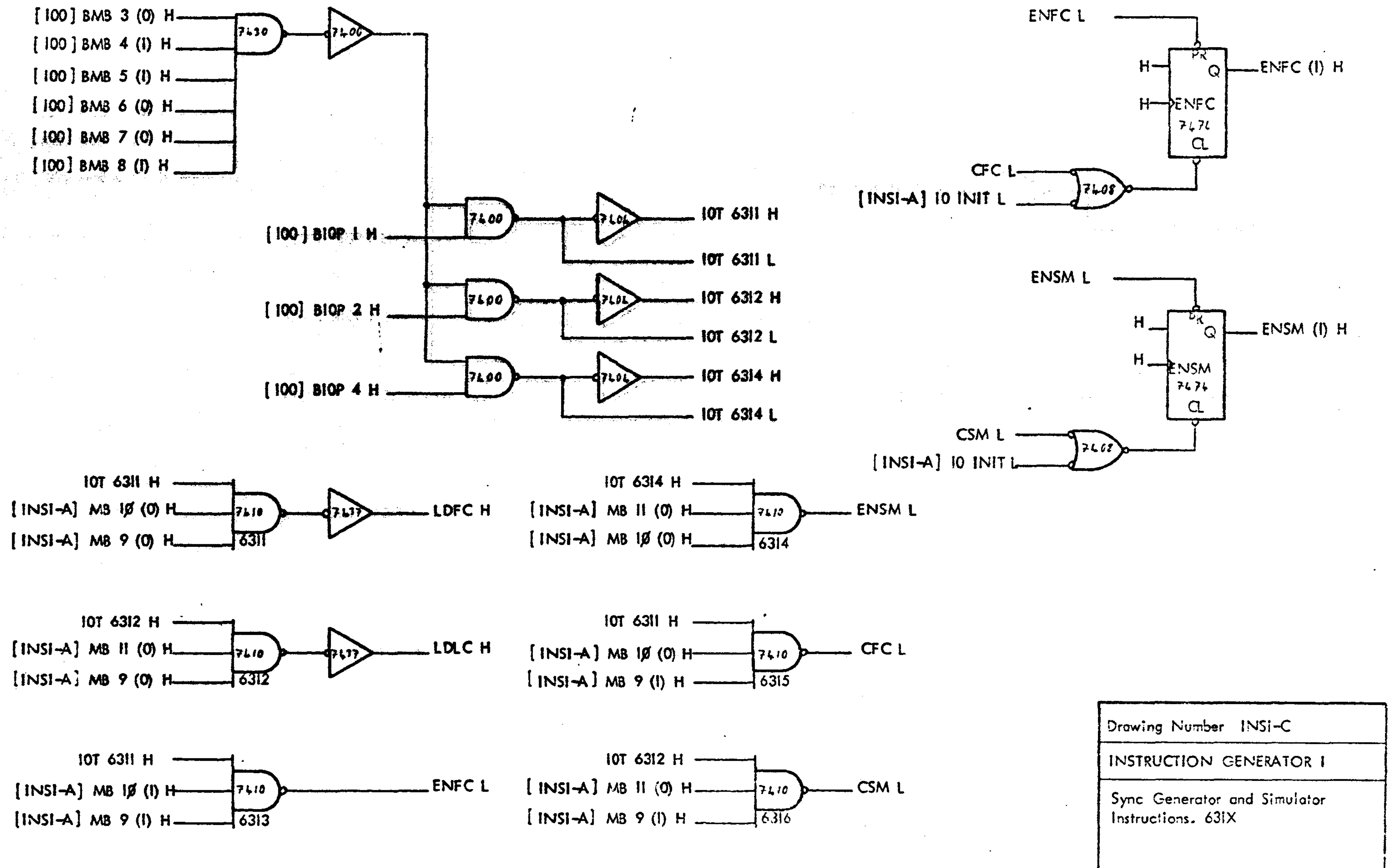
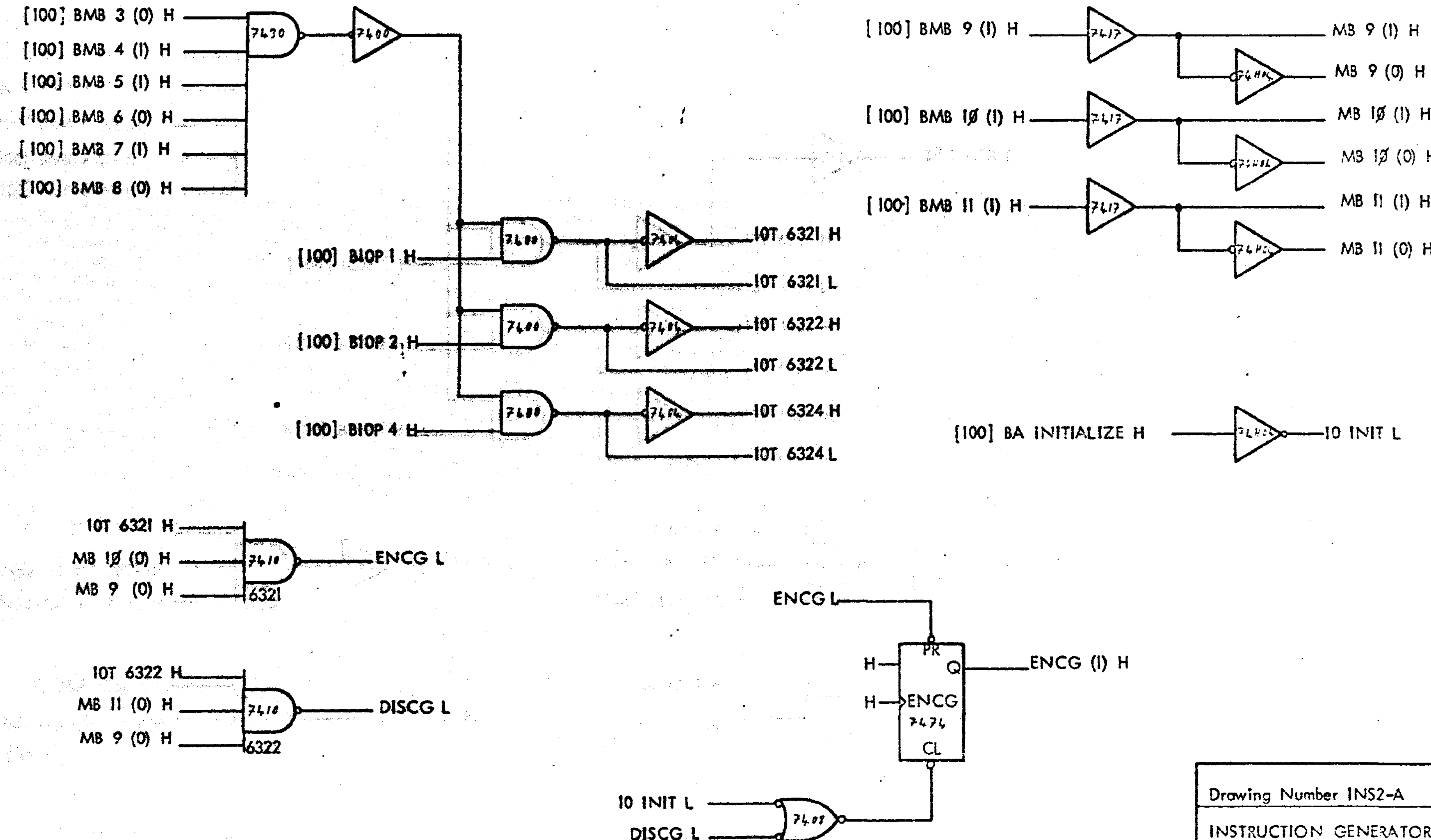


Figure 4.20 INSI-C. Instruction generator I - sync generator and simulator instructions 631X.



Drawing Number INS2-A

INSTRUCTION GENERATOR 2

Co-ordinate Generator Instructions. 632X

Figure 4.21 INS2-A. Instruction generator 2 - co-ordinate generator instructions 632X.

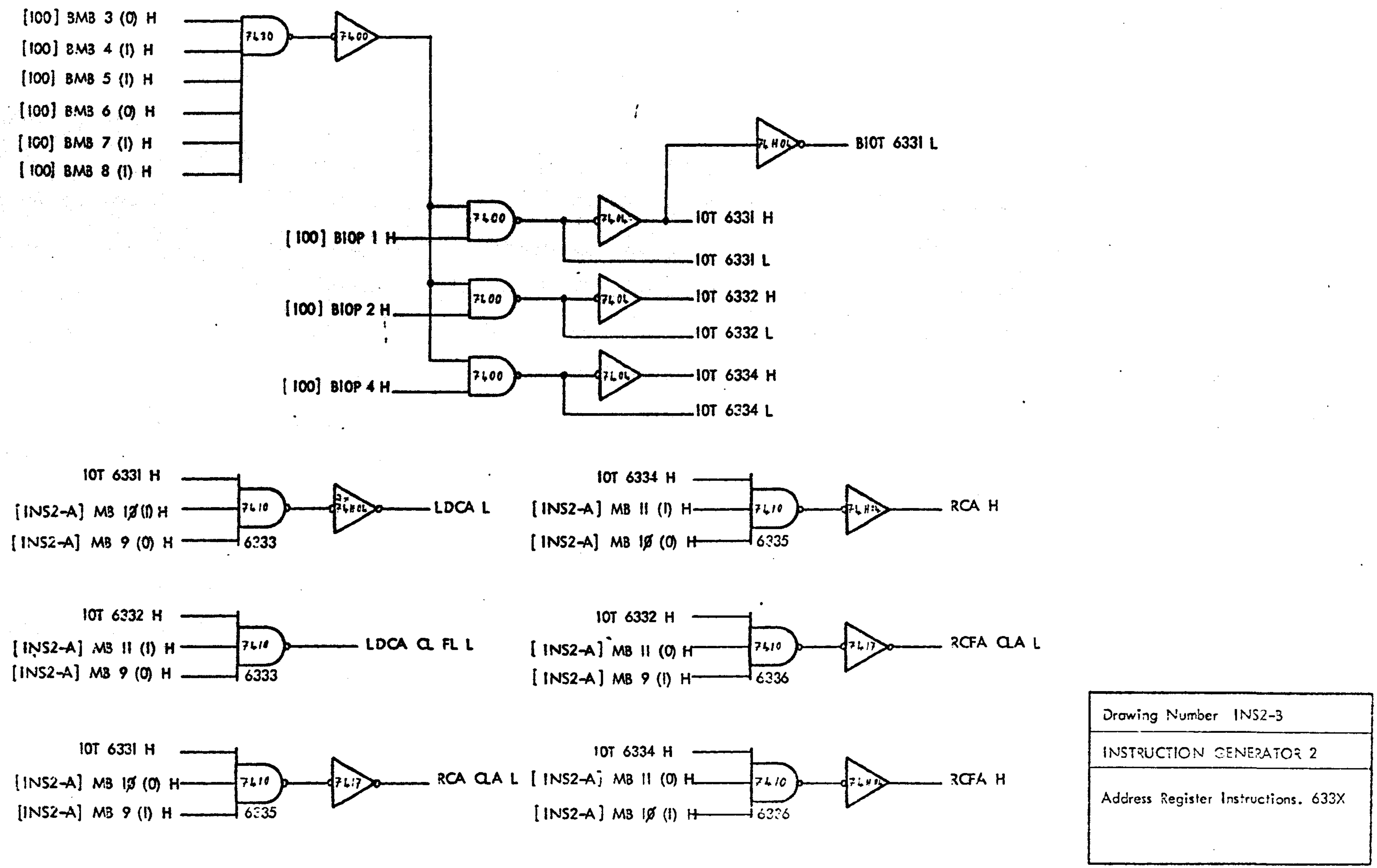


Figure 4.21 INS2-3. Instruction generator 2 – address register instructions 633X.

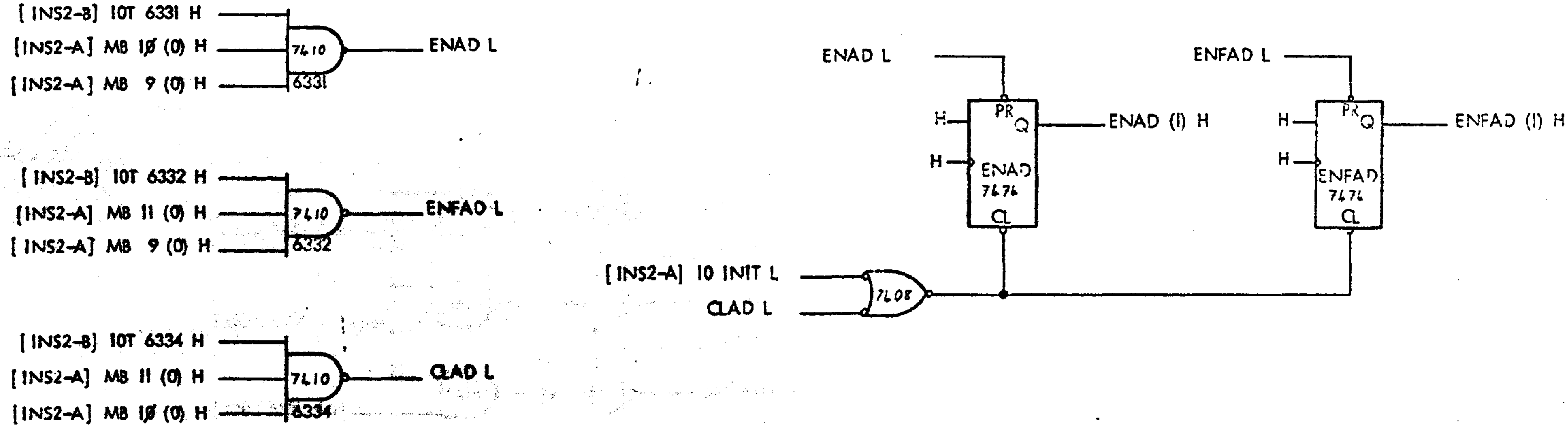
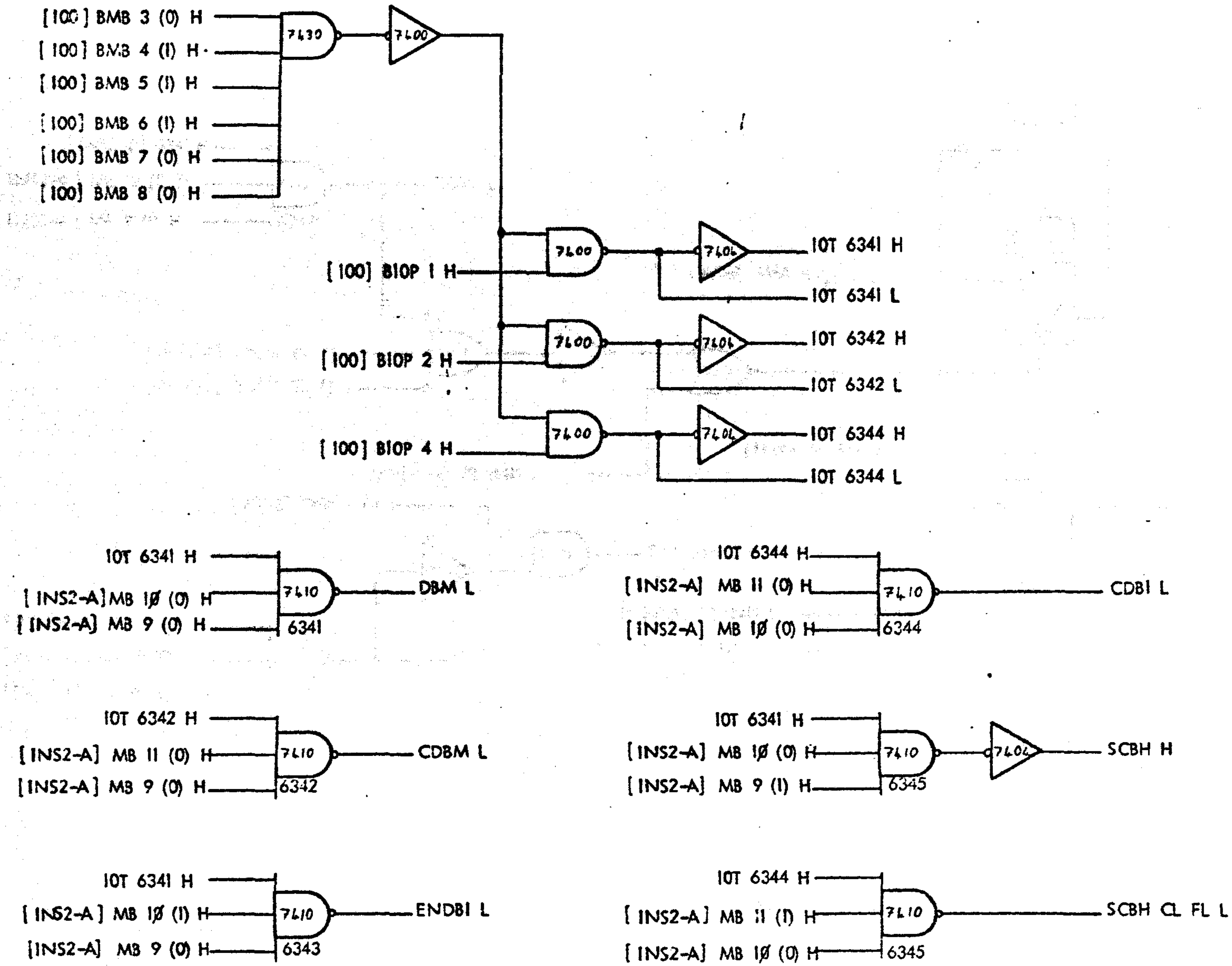


Figure 4.21 INS2-C. Instruction generator 2 - address register instructions 633X (continued).

Drawing Number INS2-C
INSTRUCTION GENERATOR 2
Address Register Instructions 633X (continued)



Drawing Number INS2-D
INSTRUCTION GENERATOR 2
Address Register Instructions. 634X

Figure 4.21 INS2-D. Instruction generator 2 - Address Register Instructions 634X.

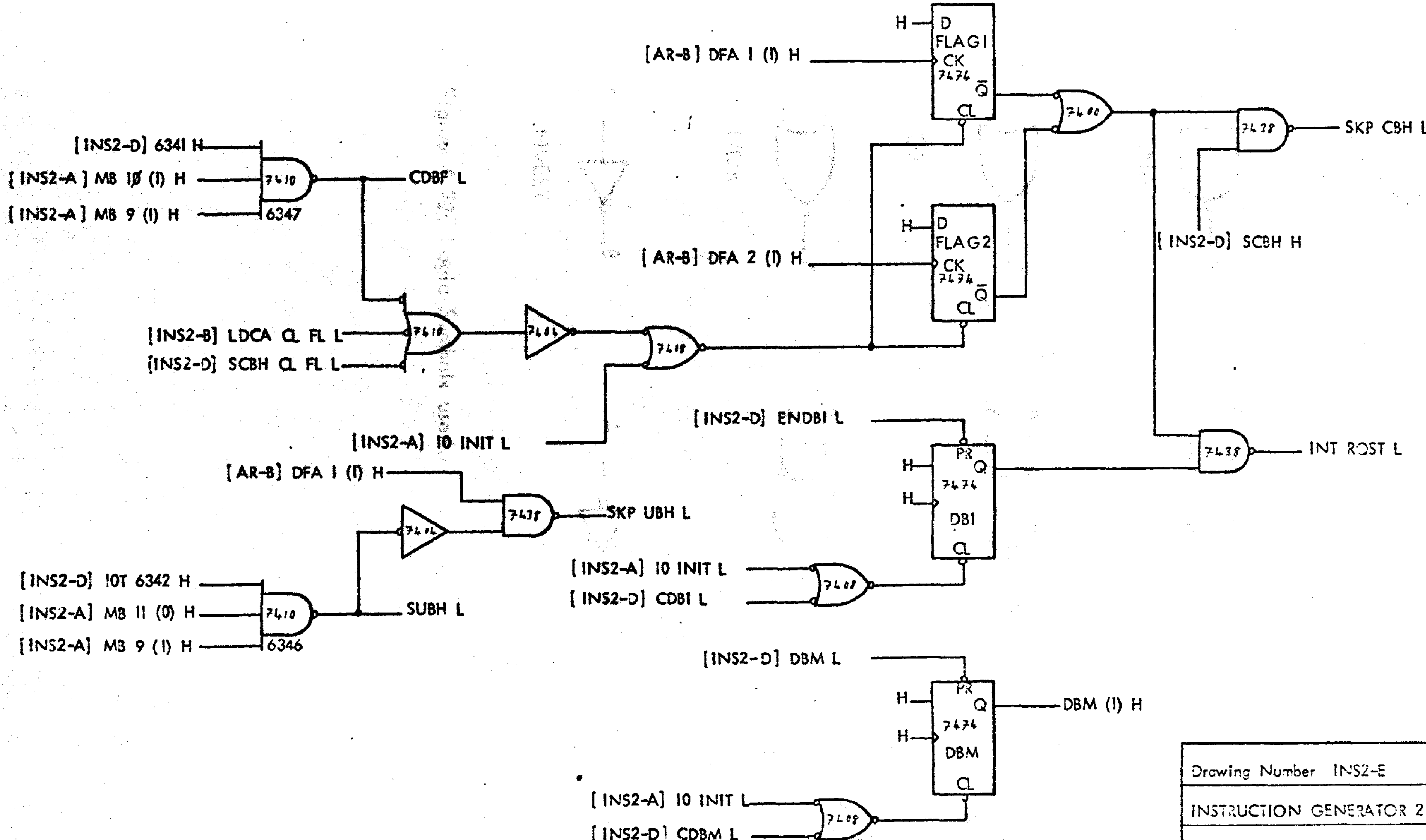
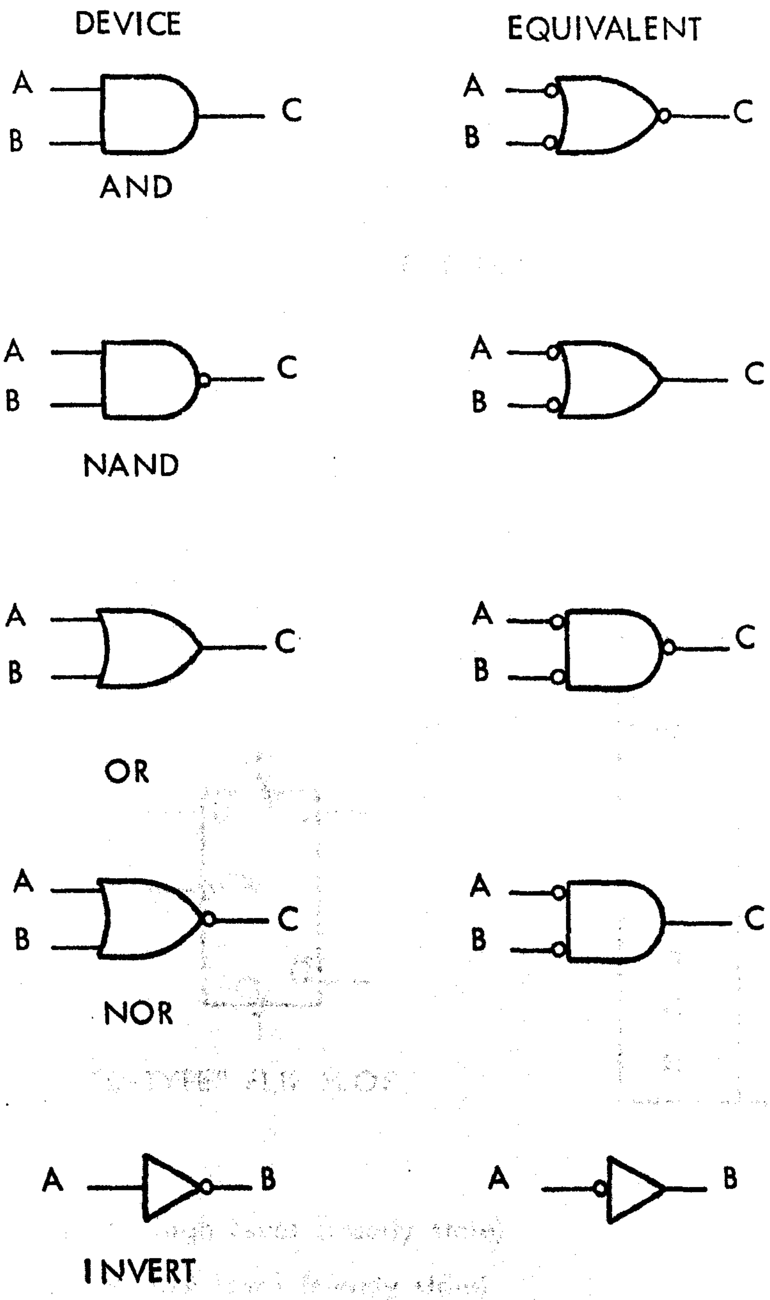


Figure 4.21 INS2-E. Instruction generator 2 – address register instructions 634X (continued).

Drawing Number INS2-E
INSTRUCTION GENERATOR 2
Address Register Instructions 634X (continued)



A	B	C
Ø	Ø	Ø
Ø	1	Ø
1	Ø	Ø
1	1	1

A	B	C
Ø	Ø	1
Ø	1	1
1	Ø	1
1	1	Ø

A	B	C
Ø	Ø	Ø
Ø	1	1
1	Ø	1
1	1	1

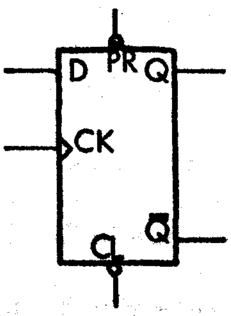
A	B	C
Ø	Ø	1
Ø	1	Ø
1	Ø	Ø
1	1	Ø

A	B
Ø	1
1	Ø

Figure 4.22. Logic Symbols used.

EXCLUSIVE OR

A	B	C
Ø	Ø	Ø
Ø	1	1
1	Ø	1
1	1	Ø



"D-TYPE" FLIP FLOP

Inputs				Outputs	
Preset	Clear	Clock	D	Q	$\overline{Q}$
L	H	X	X	H	L
H	L	X	X	L	H
L	L	X	X	H*	H*
H	H	↑	H	H	L
H	H	↑	L	L	H
H	H	L	X	Q_o	$\overline{Q}_o$

H = high level (steady state)

L = low level (steady state)

↑ = transition, from low to high level

X = irrelevant

Q_o = the level of Q before the indicated input conditions were established

* = This configuration is non stable.

Figure 4.22 (Continued)

CHAPTER 5

PROGRAMMING

5.1 Introduction

The instruction set created to control the interface is described in this section. The object in providing these instructions was to allow flexible program control with the minimum of manual intervention. The description of the instruction set is followed by some programming examples. A method of decoding the co-ordinate data generated by the interface is shown and a summary of the software developed is given. Full details of this software will be found in Appendix A3.

5.2 Instruction Set

Machine language programs for the PDP 12 computer are assembled using the LAP6 - DIAL operating system, DEC (1970). To simplify the use of the interface Instruction Set, mnemonics have been created for each instruction by the program TVI MN, which is shown in Appendix A3.

In the description of the instructions the mnemonics for each instruction will be given, followed by the octal code, followed by the operation performed. These instructions are used directly in 8 mode, but must be preceded by the instruction IOB in linc mode programming.

5.2.1 Address Register Instructions

ENAD 6331 - Enable Address; the data address register of the interface is enabled onto the external address lines of the PDP 12 computer (12 bits) by setting the address enable flip flop.

ENFAD 6332 - Enable Field Address; the data field address register of the interface is enabled onto the external data extended address lines of the PDP 12 (3 bits) by setting the field address enable flip flop.

LDCA 6333 - Load Composite Address; the initial data address register of the interface is loaded with the contents of the accumulator. Bits Ø - 8 of the Data Address register are set to correspond to bits Ø - 8 of this initial address and the Data Field Address register is set to correspond to the remaining bits, 9, 1Ø and 11. Bits 9, 1Ø and 11 of the Data Address Register are set to zero. The contents of the accumulator remain undisturbed. This instruction also clears the 'change buffer half' flags of the double buffer mode, after the initial address has been set.

CLAD 6334 - Clear Address and Field Address Enable flip flops; the interface data address is taken off the external address lines of the PDP 12.

RCA 6335 - Read Current Address; the accumulator is cleared and the contents of the 12 bit Data Address Register of the interface are read into the accumulator. The previous contents of the accumulator are lost.

RCFA 6336 - Read Current Field Address; the accumulator is cleared and the contents of the 3 bit Data Field Address Register are read into bits, 9, 1Ø and 11 of the accumulator.

DBM 6341 - Set Double Buffer Mode; the address register is set into the double buffer mode of operation. When the 15 bit address reaches 27777_8 the next address will be that held in the initial data address register.

CDBM 6342 - Clear Double Buffer Mode; the address register is reset to the normal mode of operation.

ENDBI 6343 - Enable Double Buffer Mode Interrupt; if the computer interrupt is turned on (I ON instruction) then an interrupt request will be made when the data buffer changes halves. The data buffer changes halves when the 15 bit address changes from 17777_8 to $2ØØØØ_8$ or from 27777_8 to $1ØØØØ_8$.

CDBI 6344 - Clear Double Buffer Mode Interrupt; no interrupt request will be made when the buffer changes halves.

SCBH 6345 - Skip if Change Buffer Half flag is set; the next instruction in the program will be skipped if either of the change buffer half flags is set. The flags are then cleared.

SUBH 6346 - Skip if Upper Buffer Half is being filled; the next instruction in the program is skipped if the 15 bit address is $2ØØØØ_8$ or greater.

CDBF 6347 - Clear Flags; the change buffer half flags are cleared.

5.2.2 Co-ordinate Generator Instructions

ENCG 6321 - Enable Co-ordinate Generator; The marker detector inputs to the co-ordinate generator are enabled allowing co-ordinates to be generated and data transfer to take place via the single cycle data break facility.

DISCG 6322 - Disable Co-ordinate Generator; the inputs to the co-ordinate generator are disabled and the break request flag cannot be set, inhibiting any data transfer.

5.2.3 Sync Generator & Simulator Instructions

LDFC 6311 - Load Field Count Register; the 8 bit field count register is loaded with the contents of bits 4 to 11 of the accumulator. The contents of the accumulator are undisturbed.

LDLC 6312 - Load line Count Register; the 8 bit line count register is loaded with the contents of bits 4 - 11 of the accumulator. The contents of the accumulator are undisturbed.

ENFC 6313 - Enable Field Count; the field count function of the sync generator and simulator is enabled. The sampling rate of the co-ordinate generator will be controlled by the contents of the field count register.

ENSM 6314 - Enable Simulator; simulated marker pulses will be generated on every television scan line specified by the contents of the line count register.

CFC 6315 - Clear Field Count; the field count function is disabled and the co-ordinate generator will sample every television field. The contents of the field count register are undisturbed.

CSM 6316 - Clear Simulator; generation of simulated marker signals is disabled. The contents of the line count register are undisturbed.

5.2.4 Calibration Control Instructions

ENMON 6301 - Enable Monitor Output; this output provides a 1 volt signal at the scan time corresponding to the position of the window. The signal may be mixed with the video signal from the camera viewing the calibration grid.

LDCAM 6302 - Load Calibration Margin; bits Ø to 3 of the contents of the accumulator are loaded into the calibration right hand margin register. When the left hand co-ordinate of the calibration window exceeds the value held in this register the co-ordinate generator is disabled and the calibration complete flag is set.

CAG0 6303 - Calibration Go; the calibration control is set into operation. The co-ordinates of the window are set to the beginning of the television line scan and collection of data will start at the beginning of the next television field (line Ø). The calibration complete flag is cleared and the monitor output is enabled. The calibration mode flip flop is set which enables the interrupt. An interrupt will occur when calibration is completed if the interrupt facility in the PDP 12 has been switched on (ION).

CLCAL 6304 - Clear Calibration mode; all flags and mode flip flops in the calibration control are cleared.

CAGOFR 6305 - Calibration Go Free Run mode; the calibration control is set into operation as before except that the calibration complete flag is inhibited and the right hand margin becomes inoperative. The window will therefore operate continuously. This instruction is used for maintenance purposes.

CCAFL 6306 - Clear flag; the calibration complete flag is cleared.

SCAC 6307 - Skip if Calibration is Complete; the next instruction in the program is skipped if the calibration complete flag is set. The flag is then cleared.

5.3 Programming Examples

The first example program shows how the interface is initialised and set into operation to generate co-ordinate data. In this example sense switch Ø is used to start and stop data collection, and a limit is placed on the amount of data collected. If this limit is exceeded the program automatically stops data collection by disabling the co-ordinate generator, the program then enters a routine to process the collected data (not shown). The interface will start transfer of data at location $2ØØØ_8$ of memory field 1 as defined by the composite address. The address limit is location $4ØØØ_8$ of memory field 2 as defined by 'end memory address' and 'end field address'. This limit may be exceeded by a maximum of 31_{10} words allowed for by the instruction on lines 76 and 77. This example also demonstrates how a program may be run independently of data transfer. Interaction with the interface is provided by the subroutine (SAI) which monitors the locations in memory used by co-ordinate data.

The second example shows how a program may control some of the other parameters of the interface. In this example the Field Count Register is set to $ØØ5_8$ and the Field Count mode can be enabled if sense switch 1 on the computer is set. This will limit the sampling rate of the Co-ordinate Generator

```
                        *20
                        /EX1 - EXAMPLE PROGRAM 1
                        /
                        /9-1-76
                        /
                                LODSYM          /LOAD INTERFACE
                        /                        MNEMONICS
                                PMODE
                                *20
        0020    6002            IOF             /TURN INTERRUPT OFF
        0021    6322            DISCG           /DISABLE CO-ORDINATE
        0022    7300            CLA CLL         /GENERATOR
        0023    1055            TAD CAL         /SET UP INITIAL ADDR
        0024    6333            LDCA            /IN ADDRESS REGISTER
        0025    6331            ENAD            /ENABLE ADDRESS LINES
        0026    6332            ENFAD
        0027    6141            LINC
                                LMODE
        0030    0440            SNS 0           /ENABLE CG ?
        0031    6030            JMP .-1         /NO, WAIT
        0032    0500            IOB             /YES, ENABLE CG
        0033    6321            ENCG
        0034    6056            JMP SA1         /GO TO SUBROUTINE
        0035    0460            SNS I 0         /CONTINUE ?
        0036    6034            JMP .-2         /YES
        0037    0500            IOB             /NO, DISABLE CG
        0040    6322            DISCG
        0041    0500            IOB             /READ & SAVE CURRENT
        0042    6336            RCFA            /FIELD ADDRESS
        0043    4053            STC CFA
        0044    0500            IOB             /READ & SAVE CURRENT
        0045    6335            RCA             /MEMORY ADDRESS
        0046    4054            STC CA
        0047    1020            LDA I           /GENERATE I/O PRESET
        0050    0020            0020            /TO CLEAR ALL FLAGS
        0051    0004            ESF
        0052    6200            JMP PROC        /ENTER PROGRAM TO
                        /                        PROCESS DATA
                        /
                        /
                        /
        0053    0000    CFA,    0
        0054    0000    CA,     0
        0055    2001    CAL,    2001            /COMPOSITE ADDRESS
                        /
                        /
                        /
                        /SUBROUTINE TO READ CURRENT ADDRESS USED BY
                        /INTERFACE AND CHECK AGAINST PRESET ADDRESS
                        /LIMIT.
                        /
                                LMODE
        0056    1000    SA1,    LDA             /SAVE RETURN ADDRESS
        0057    0000            0
        0060    4101            STC SA10
        0061    0500            IOB             /READ CURRENT FIELD
        0062    6336            RCFA            /ADDRESS
        0063    1440            SAE             /=END FIELD ADDRESS ?
        0064    0102            EFA
        0065    6101            JMP SA10        /NO, RETURN
        0066    0500            IOB             /YES, READ CURRENT
        0067    6335            RCA             /MEMORY ADDRESS
```

```
0070  1560            RCL I        /SET 5 LEAST SIGNIF
0071  0037            0037         /BITS TO ZERO
0072  1440            SAF          /=END MEMORY ADDRESS
0073  0103            EMA
0074  6101            JMP SA10     /NO, RETURN
0075  1020            LDA I        /YES, ADD 2 TO RETURN
0076  0002            2            /ADDRESS
0077  1140            ADM
0100  0101            SA10
0101  6000    SA10,   JMP 0        /RETURN
              /
              /
0102  0002    EFA,    2            /END FIELD ADDRESS
0103  4000    EMA,    4000         /END MEMORY ADDRESS
              /
              /
              /
              /
              /PROGRAM TO PROCESS DATA
                      *200
0200  0016    PROC,   NOP

NO ERRORS

CA      0054
CAD     0055
CAGO    6303
CAGOER  6305
CCAFL   6306
CDPF    6347
CDPI    6344
CDPM    6342
CFA     0053
CFC     6315
CLAD    6334
CLCAL   6304
CSM     6316
DBM     6341
DISCG   6322
EFA     0102
EMA     0103
ENAD    6331
ENCG    6321
ENDPI   6343
ENFAD   6332
ENFC    6313
ENMON   6301
ENSM    6314
LDCA    6333
LDCAM   6302
LDFC    6311
LDLC    6312
PROC    0200
RCA     6335
RCFA    6336
SA1     0056
SA10    0101
SCAC    6307
SCPH    6345
SUBH    6346
```

```
                    *20
                    /EX2 - EXAMPLE PROGRAM 2
                    /
                    /12-1-76
                    /
                            LOLSYM          /LOAD INTERFACE
                    /                        MNEMONICS
                    /
                            PMODE
                            *20
        0020  6002          IOF             /TURN INTERRUPT OFF
        0021  6322          DISCG           /DISABLE CG
        0022  7300          CLA CLL
        0023  1062          TAD CAL         /SET UP INITIAL ADDR
        0024  6333          LDCA            /IN ADDRESS REGISTER
        0025  7200          CLA
        0026  1060          TAD SLCT        /SET UP LINE COUNT
        0027  6312          LDLC            /REGISTER
        0030  7200          CLA
        0031  1061          TAD SFCT        /SET UP FIELD COUNT
        0032  6311          LDFC            /REGISTER
        0033  6341          DBM             /SET DBL BUFFER MODE
        0034  6331          ENAD            /ENABLE INTERFACE
        0035  6332          ENFAD           /ADDRESS LINES
        0036  6141          LINC
                            LMODE
        0037  0441          SNS 1           /ENABLE FIELD COUNT?
        0040  6043          JMP .+3         /NO
        0041  0500          IOB             /YES
        0042  6313          ENFC
        0043  0442          SNS 2           /ENABLE SIMULATOR?
        0044  6047          JMP .+3         /NO
        0045  0500          IOB             /YES
        0046  6314          ENSM
        0047  0440          SNS 0           /ENABLE CG?
        0050  6047          JMP .-1         /NO, WAIT
        0051  0500          IOB             /YES
        0052  6321          ENCG
        0053  0460          SNS I 0         /CONTINUE SAMPLING?
        0054  6053          JMP .-1         /YES
        0055  0500          IOB             /NO, DISABLE CG
        0056  6322          DISCG
        0057  6200          JMP NP          /GO TO NEW PROGRAM
                    /
                    /
                    /
                    /
        0060  0177  SLCT,   0177            /LINE COUNT
        0061  0005  SFCT,   5               /FIELD COUNT
        0062  6002  CAL,    6002            /INITIAL ADDRESS 6002
                    /                        IN MEMORY FIELD 2
                    /
                    /
                    /
                            *200
        0200  0016  NP,     NOP
                    /
                    /

NO ERRORS

CAD     0062
```

CAGD	6303
CAGDFR	6305
CCAFL	6306
CDRF	6347
CDRI	6344
CDRM	6342
CFC	6315
CLAD	6334
CLCAL	6304
CSM	6316
DRM	6341
DISCG	6322
ENAD	6331
ENCG	6321
ENDRI	6343
ENFAD	6332
ENFC	6313
ENMON	6301
ENSM	6314
LDCA	6333
LDCAM	6302
LDFC	6311
LDLC	6312
NP	0200
RCA	6335
RCFA	6336
SCAC	6307
SCRH	6345
SFCT	0061
SLCT	0060
SURH	6346

such that co-ordinates will only be generated on every 5th television field (10 Hz). The Line Count Register is set to 177_8 and simulated marker pulses will be generated if the simulator is enabled (by setting sense switch 2). These simulated pulses will appear on two lines in each television field as defined by the contents of the Line Count Register; the combinations of pulses previously shown in Figure 3.9 will be available on each of these lines and may be used to provide inputs to the marker detectors. In this way co-ordinates of known values will be generated and may be used to test data processing programs, data displays etc. This program also shows how the Address Register can be used in the Double Buffer mode to provide a re-circulating data buffer in computer memory. The Initial Data Address register, in the interface is set to $6ØØ2_8$ which is translated by the interface into a 15 bit starting address for the Address Register - location 6ØØØ in memory field 2. When co-ordinate data is generated it will be transferred to computer memory starting at this location, and the Address Register will be incremented upwards. When location 7777_8 of memory field 2 has been filled the interface will automatically reset the Address Register to the starting address held in the Initial Data Address register. By using the Address Register in this way the area in memory which the interface may access can be limited, in this case to 1024_{10} locations. The use of the Double Buffer mode to "double buffer" incoming data (so that data may be transferred to mass storage as it is received) is discussed in the next chapter.

The Co-ordinate Generator is enabled by setting sense switch Ø on the computer console. As soon as this is done the interface will begin to generate the co-ordinates of any marker signals detected in the video channel inputs. Generation of co-ordinates will continue until sense switch Ø is reset. The program could easily be expanded from this point to process data and, for example, to display the trajectories of markers in real time.

5.4 A Method of Decoding

The order and format in which data is stored in computer memory by the interface has been described in relation to the hardware in Chapter 3 and an illustration was given in Figure 3.7. In order to explain a method of decoding the data, the data format will be described in relation to programming. In this section a "data block" refers to the data generated by the interface for one television line, and will therefore be of variable length (3 to 7 words). A "data record" is all the data generated by the interface during a particular test. The length of this record is limited by computer core memory size or, if data can be double buffered and transferred to disk storage, by available disk space.

Due to the way in which the Co-ordinate Generator operates the first word of any data block will always be a vertical co-ordinate, there may then be up to 5 horizontal co-ordinates followed by the shift register code word. This code word will always be followed by the vertical co-ordinate of the next data block, except for the last word in any data record. The address of this last word will, however, have been read and stored by the computer program using the appropriate interface instructions. This data format is illustrated in Figure 5.1.

The camera code for each Horizontal Co-ordinate (HC) is made up of 3 bits; two of which are in bits Ø and I of the HC word, and the least significant bit is contained in the Shift Register (SR) word. The bit format for a data block is shown in Figure 5.2. The position in the SR word of the additional code bit corresponding to each HC is clearly shown in this figure. To reconstruct the camera code for each HC the subroutine shown in Figure 5.3 and 5.4 may be used. This subroutine would be entered once for each horizontal co-ordinate, starting with HCI as shown in Figure 5.2. The reconstructed camera code is left in the Accumulator on exit from the subroutine.

The method shown here is just one of several possible ways of reconstructing the camera code. The details of this method may be changed to suit other parts of a program, as has been done in some of the programs shown in Appendix A3.

5.5 Software Summary

All programs for data acquisition and interface control have been written in assembly language as have programs for calibration and data display, as this was the most suitable method available at the time. Full details of the programs summarized in this section will be found in Appendix A3, in the form of listings and, where appropriate, flow charts.

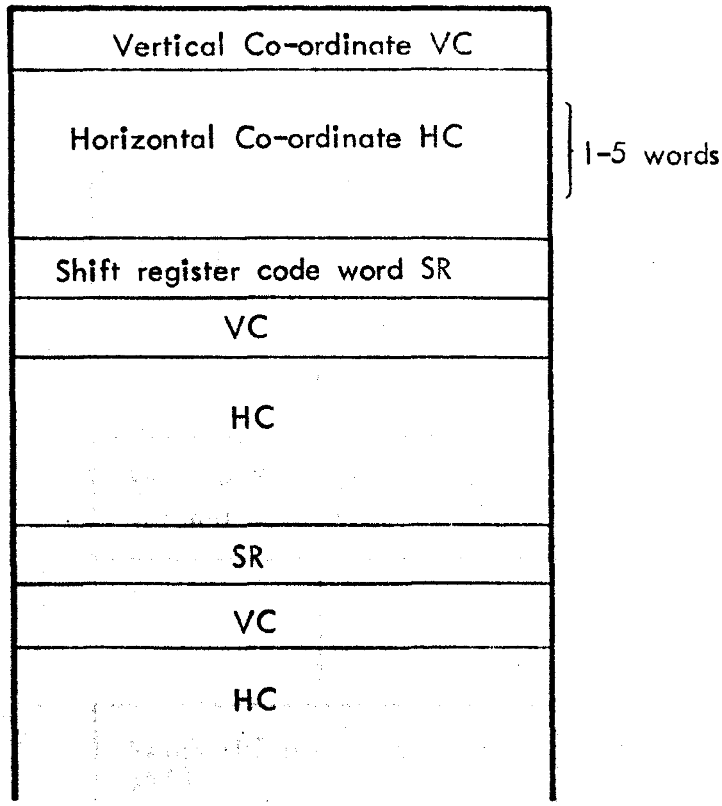


Figure 5.1. Data format for interface generated data.

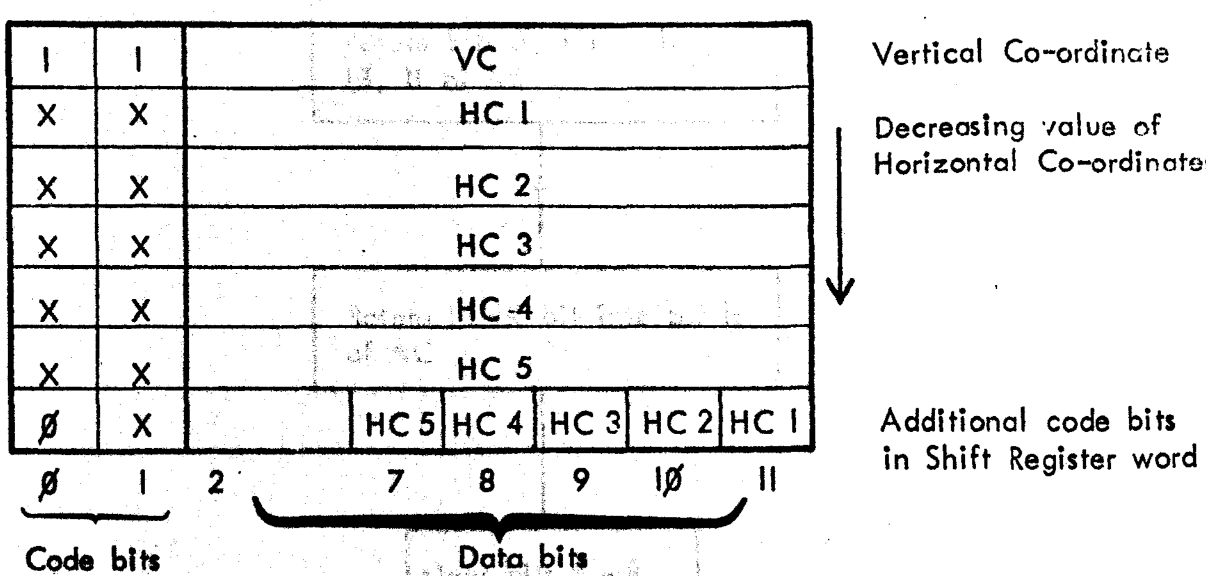


Figure 5.2. Data bits format for one data block of interface generated data.

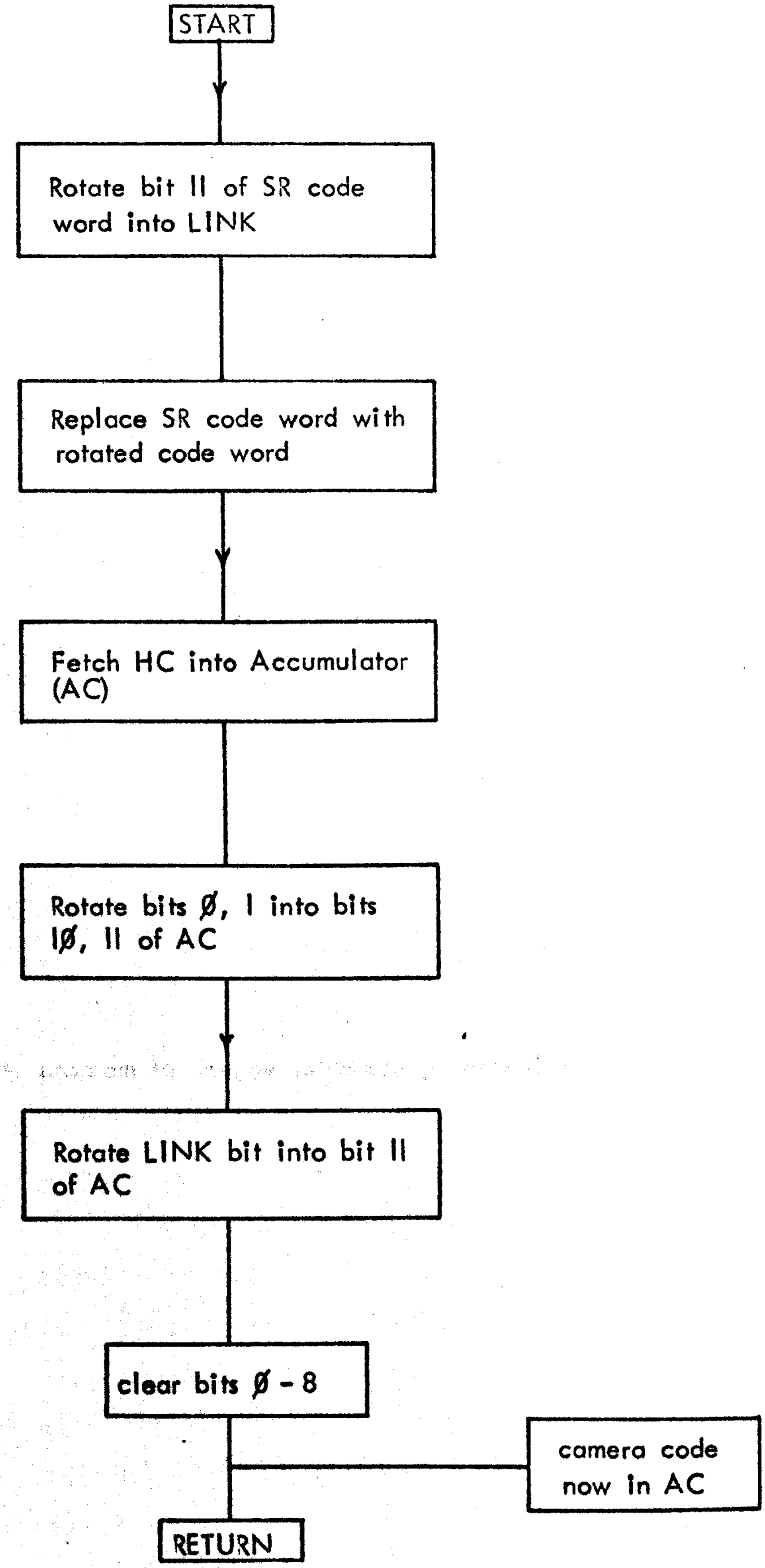


Figure 5.3. Flow chart for program of Figure 5.4. to obtain camera codes.

```
*20
        PMODE
SCODE,  0000            /RETURN ADDRESS
        LINC
        LMODE
        ROR I 1         /CODE BIT INTO LINK
        STC SR          /AND REPLACE SR
        ADD HC          /FETCH HC
        ROR 12          /CODE BITS INTO 10,11
        ROL I 1         /ADD THIRD CODE BIT
        BCL I           /CLEAR BITS 0-8
        7770
        PDP
        PMODE
        JMP I SCODE     /RETURN
```

Figure 5.4. Computer program to decode Interface generated data.

5.5.1 Real Time Display

The program DYDIS (Dynamic Display) provides a real time display of data generated by the interface. Co-ordinate data is transferred, by the interface, to a 1,000 word re-circulating buffer in computer memory. The program then decodes the data and stores it in one of six display buffers according to camera code. Any one of these buffers may be selected for display at any time during the running of the program. The camera code of the data currently being displayed is included in the display. The interface simulator can be controlled and may be used to provide simulated inputs to the marker detectors to generate co-ordinates for display. The Field Count mode may also be selected to reduce the sampling rate of the interface. Because the generated co-ordinates are displayed in real time the data rate is limited in order to avoid display flicker, this limit has been found to be approximately 4,000 words/sec. If it is desired to generate and display a large number of points in one television field and a reduction in sampling rate is acceptable then the Field Count mode can be used.

5.5.2 Data Acquisition

The main task of acquiring co-ordinate data and decoding it is accomplished by the program DP (Data Process). This program controls the acquisition of data from the interface, decodes it and stores the decoded data on magnetic tape. Six of the analogue channels of the PDP 12 may also be sampled on receipt of clock pulses generated by the interface, and this data will also be stored on magnetic tape. The sampling rate for this facility is controlled by the contents of the line count register. Processed co-ordinate data is stored in the format:- television field number (time co-ordinate), followed by the vertical co-ordinate, followed by the horizontal co-ordinate. These three co-ordinates are provided for every point detected in the video signals of each camera in the system. Data from each camera is stored in a separate sequence of tape blocks. The end of each sequence, or camera record, being indicated by at least three consecutive words of 7777_8. The camera (channel) number is indicated by bits 1, 2 and 3 of the time co-ordinate word; and bit Ø of this word, if set, indicates that the analogue channels of the computer were sampled.

Other facilities provided by the program include the ability to set a limit on the amount of memory used by the interface, the interface is disabled when this limit is reached. The sampling frequency of the interface may be controlled by entering the Field Count mode, and the simulator may also be used by this program. The various options are selected and their parameters are controlled from the computer console switches and by presetting registers in the program.

5.5.3 Calibration Data Acquisition

The acquisition of a matrix of calibration points from a grid of markers placed in the field of view of the camera is accomplished by the program CALMTX (Calibration Matrix acquisition). This program operates the calibration control of the interface, to generate the co-ordinates of the grid of markers. This data is then decoded and stored on tape in the format:- vertical co-ordinate followed by horizontal co-ordinate, for each point detected in the video signal. No time (field) co-ordinate or camera code is stored as these parameters will not change during data acquisition. Having acquired the grid co-ordinates the program then goes on to reduce this data, by simple averaging, to one co-ordinate pair per grid point. The results of this data reduction are displayed so that the success of the grid acquisition can be verified. If the program is allowed to continue then the reduced grid data is re-organised into a calibration matrix for use with the program CAL (Calibrate). This matrix consists of two arrays, one for the vertical co-ordinates and one for the horizontal co-ordinates. The positions of the co-ordinates in the arrays correspond to the positions of the markers on the grid. The results of this data reorganisation are displayed and if satisfactory may be stored on tape.

5.5.4 Calibration

The calibration program, CAL, is designed to implement the first method of calibration outlined in section 3.3.5. The locations on tape of the calibration matrix and the data to be calibrated are provided in response to questions displayed on the VDU (Video Display Unit). The starting block on tape to which calibrated data is to be written is also provided in this way. Once calibration of the data has been completed these questions are repeated and a new set of data may be calibrated. The program processes the data, television field by television field. First of all the data for one complete field is examined and co-ordinate pairs which meet a proximity criteria are averaged to provide one pair per marker. The subsequently reduced data is then calibrated against the calibration matrix. The flow chart and listing for this program in Appendix A3, show how this is done.

5.5.5 Data Display

A display program (DISC-CAL) provides a means of displaying calibrated data. 1024 co-ordinate pairs are read from tape into a display buffer, 512 of these pairs may be displayed at any one time. Selection of the starting point of the display is made by setting a potentiometer (analogue channel Ø) on the computer. The position in the display of a cursor is controlled by a second potentiometer (analogue channel 4), and the camera number, field number, and the values of the vertical and horizontal co-ordinates of the point indicated by this cursor are displayed in the top left corner. If the analogue channels were sampled this is indicated by the display of the letters FP (Force Plate). A typical display produced by this program is shown in Figure 5.5. A second version of this program (DISF-CAL) displays a cursor for every point in the field selected by the potentiometer setting of analogue channel 4. The field number is displayed in the top left corner as shown in Figure 5.6.

Three other programs based on the above display programs have been written. These versions allow uncalibrated data to be displayed on the VDU. The data is scaled to fit the grid dimensions of the VDU. The first version, DISC, displays co-ordinate data together with a read out of the co-ordinates and other information of the point in the display indicated by a cursor. The second version, DISF, is similar except that a cursor for every point in a selected field is shown on the display. The third version, DISG, is for

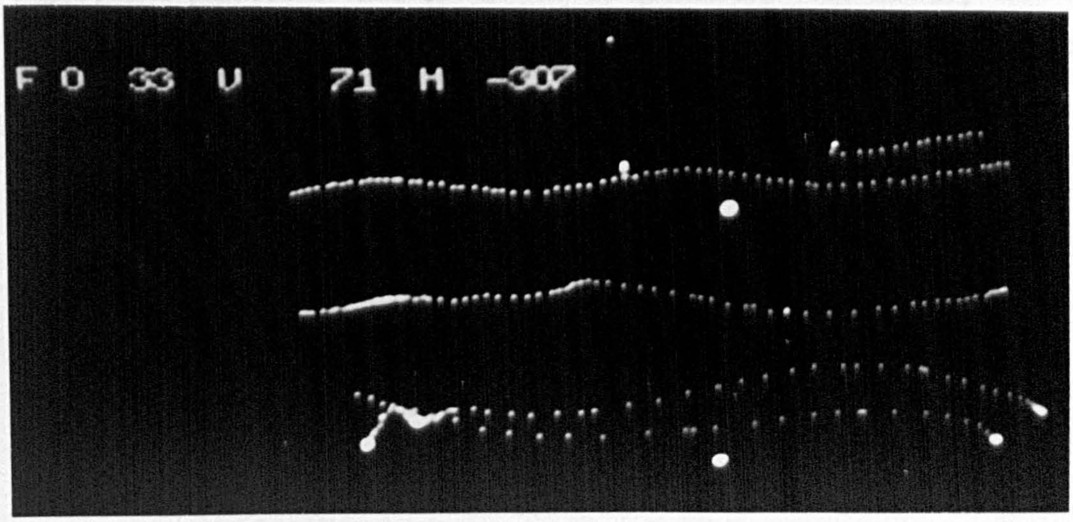


Figure 5.5. Computer generated display produced by the program DISC-CAL from marker trajectory data. The figures are a read out of co-ordinates and camera channel number for the point indicated by the cursor.

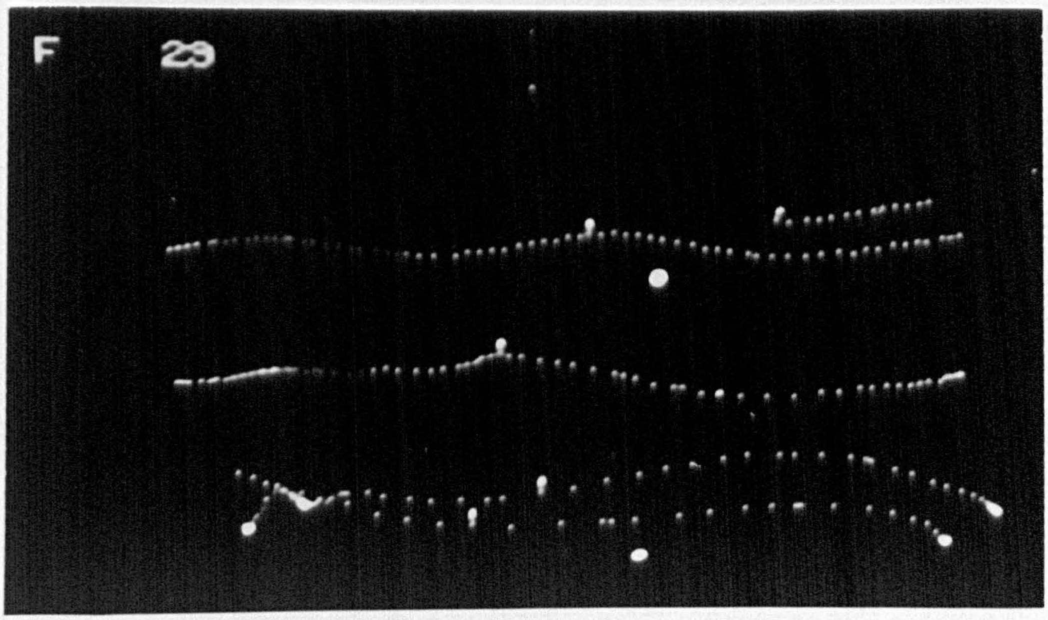


Figure 5.6. Computer generated display produced by the program DISF-CAL for the same data as in the previous figure. The cursors show the points generated during television field 29, the subject is walking from right to left.

displaying grid data acquired by the program CALMTX. This data is organised in horizontal and vertical co-ordinate pairs and does not include a field word. A cursor is provided to select individual points in the display and produce a read out of the co-ordinates. The memory location (with the beginning of the initial tape block considered as location zero) of the point is also indicated. This program would provide the basis of an editing facility to remove unwanted points from grid data.

CHAPTER 6

RESULTS AND DISCUSSION

6.1 Introduction

This chapter describes how the system was tested in all aspects of its design and in its suitability for human locomotion analysis. Measurement errors and methods of calibrating the data are discussed. The co-ordinates generated by the interface for the trajectories of markers placed on a walking subject are presented and a means of identifying markers from co-ordinate data is described. Some modifications to the basic design are suggested to give improved performance. The performance of the system is summarised and comparisons are made with other methods. The applications of the system are discussed and recommendations for future work are given. A photograph of the interface and its connecting cables to the PDP 12 is shown in Figure 6.1. A subject with markers in place is shown in Figure 6.2, the photograph was taken from behind the television camera light source in normal room lighting and gives an impression of the brightness of the markers compared with skin tones.

6.2 Interface Design

The efficacy of the interface design was evaluated using computer programs and the simulator. Initially programs similar to those shown in the examples of section 5.3 were used. These programs allowed the interface to operate under constant conditions, when the simulator was used to provide the marker detector inputs. It was thus possible to check that registers in the interface had been loaded with the correct data, that control logic was functioning correctly and that data transfers were taking place. Several important factors were revealed during the initial testing phase, which resulted in minor modifications to the original design.

The first modification was to terminate some of the signal lines from the PDP 12 computer. It was found that noise on the IOT pulses ([100] BIOP 1-4) and the initialise lines ([100] BA and BB INITIALIZE) could occasionally cause false operations. This problem was solved by terminating these lines with the circuit shown in Figure 6.3, as recommended in Digital (1972). The other signal lines from the PDP 12 were also extremely noisy, and although this did

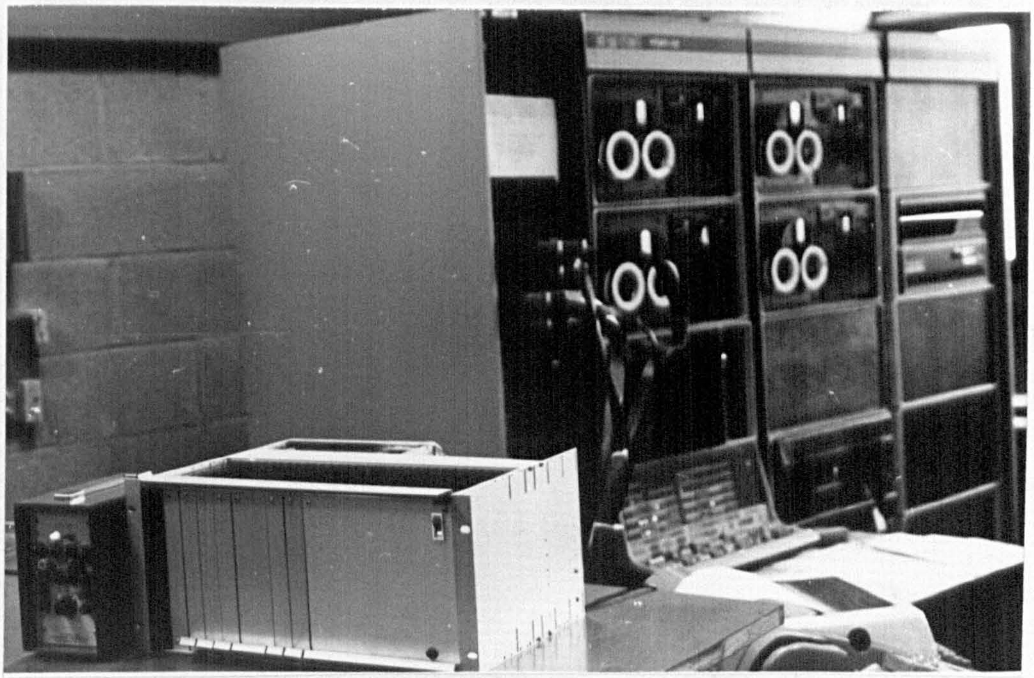


Figure 6.1. Television interface connected to the PDP 12.

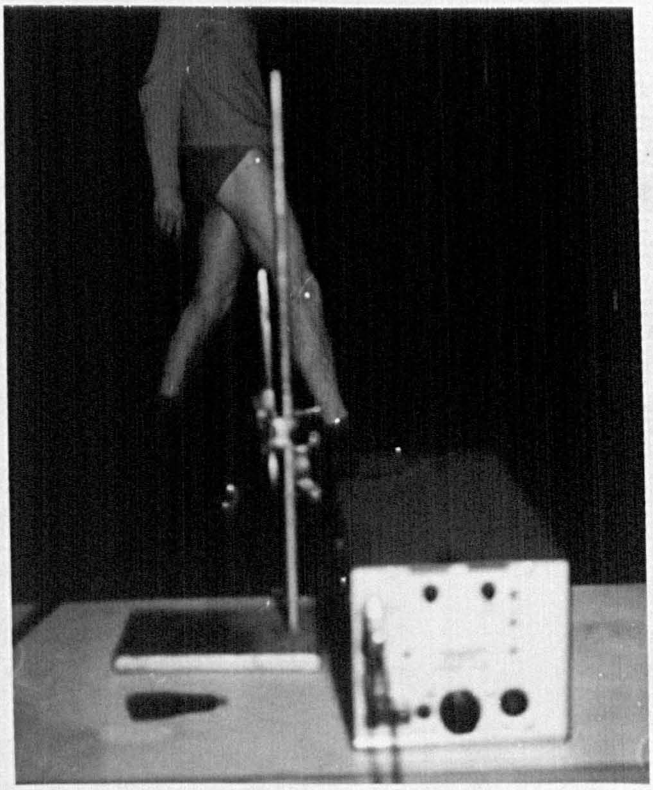


Figure 6.2. Subject with reflective markers on anatomical landmarks, the lighting is positioned to obtain maximum brightness from the markers as seen by the television camera.

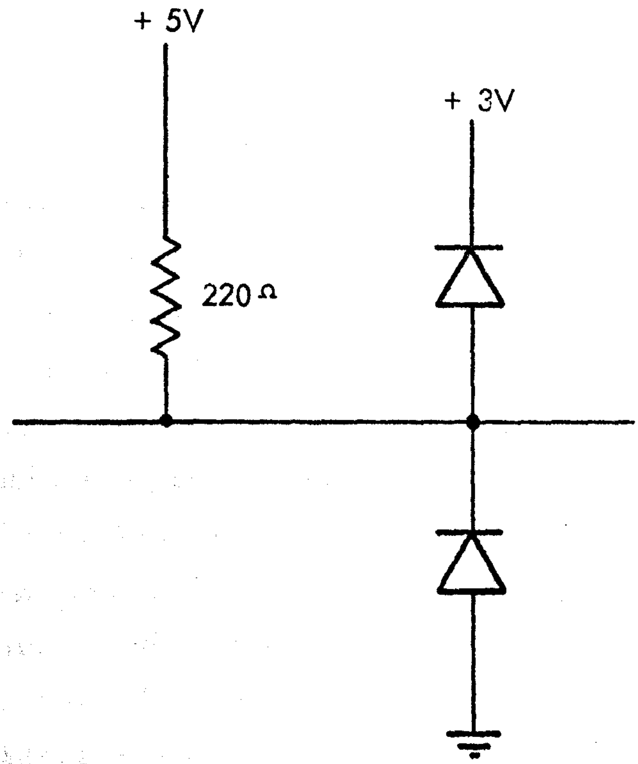


Figure 6.3. Terminating circuit for computer bus lines to reduce noise.

not appear to present any problem they were terminated with similar circuits as a precaution (Accumulator lines [100] BAC 0-11, Memory Buffer lines [100] BMB 0-11, Data Break control lines[100] BREAK and [100] ADD ACCEPTED). The signals on these lines were "cleaned up" considerably by terminating, and thus the chance of false generation of logic signals in the interface was reduced.

The second of these modifications concerned the timing of the data transfer to computer memory. Originally the address accepted signal ([100] ADD ACCEPTED (0) H) on the PDP 12 Data Break control lines was used to strobe co-ordinate data onto the IO bus data lines. The falling edge of this signal was also used to down count the address of the random access buffer memory in the Co-ordinate Generator, to access the next co-ordinate word in readiness for the next data transfer cycle. According to the "Single Cycle Data Break Input Transfer Timing Diagram", reproduced in Figure 6.4, this should have been satisfactory; however it was found that data was not being stored in computer memory. It will be seen from this timing diagram that data must be specified by time TP2 and will be strobed into a Central Processor register at TP3. The Address Accept pulse starts at TP1 and ends at TP3, and should therefore present the interface data on the IO bus at the correct times. Furthermore the internal computer logic signal in the Central Processor which ends the Address Accept pulse also causes the data presented on the IO bus to be stored. As there is a typical delay of 43 nS in the interface before the data is removed from the IO bus there should have been ample time for the data to be stored in the Central Processor (there would also be additional time caused by the connecting cable delays). Consultation with Digital Equipment Corporation engineers confirmed that this method of operation, although not normal practice, should have been satisfactory. The problem was avoided by using the logic described in section 4.4.5, which extended the duration of the Address Accepted pulse. An alternative solution, which provides all the necessary control signals required in the interface, is shown in Figure 6.5.

The final modification required was to the horizontal Co-ordinate Counter in the Co-ordinate Generator. Originally three SN 74161 binary counters

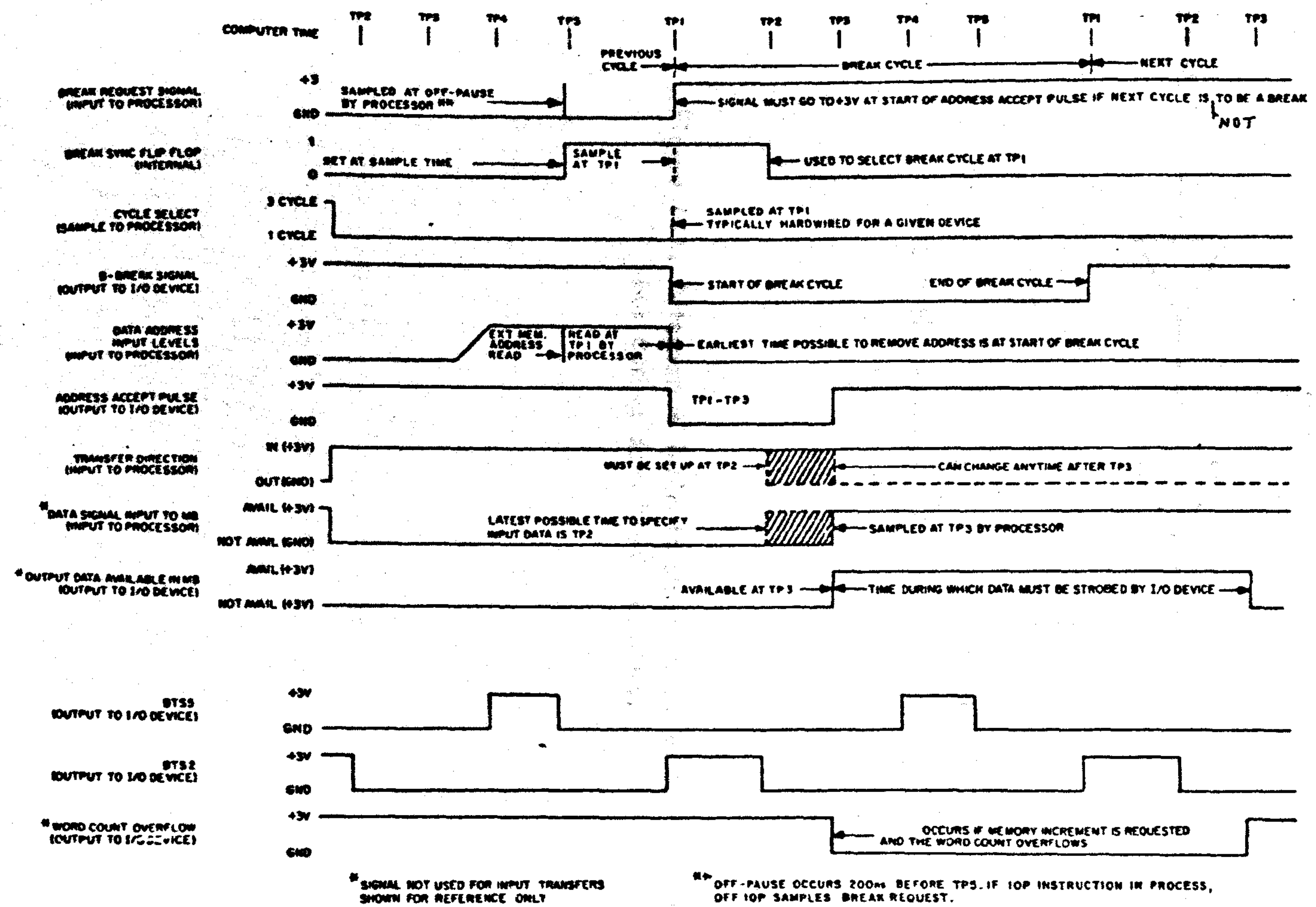


Figure 6.4. Single cycle data break input transfer timing diagram. (From Digital (1971)).

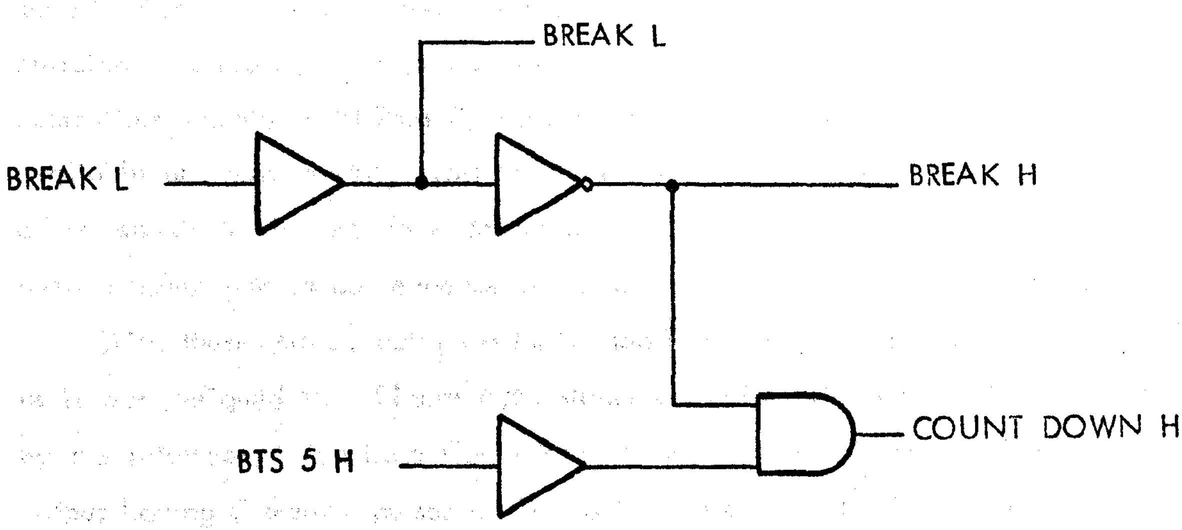


Figure 6.5. Alternative logic to strobe data on to computer bus during data break transfers.

were used in cascade. From the manufacturer's published characteristics for this device it was reasonable to expect them to operate at the design frequency of 20 MHz (Texas Instruments (1973a and 1973b), a typical maximum operating frequency of 25 MHz when used in cascade being quoted. However it was found that the devices would not operate at 20 MHz and a modification had to be made. This could have taken the form of "carry anticipate" circuitry as described in Texas Instruments (1973a) but a pin compatible counter (SN 74S163) with higher frequency capabilities became available and was directly substituted as described in section 4.4.3. In all other aspects of the interface design a "worst case" design approach had been adopted and in consequence no other problems of this nature occurred.

With these minor, but important, modifications the interface functioned as it was designed to. Figure 6.6. shows a partial print out of data generated by the interface. The Line Count Register was set to 37_8 and a simulator output having 7 marker pulses on it provided the input to the marker detector of channel Ø. The first column of the print out is the location in memory of the vertical co-ordinate which is shown in the next column. The next five columns are the horizontal co-ordinates of five marker pulses and the final column contains the Shift Register code word. The interface was generating co-ordinates on every television field, and the data generated over two fields is shown here. It can be seen that the horizontal co-ordinates remain almost constant as expected. The slight variations are due to one of two causes. Where there is only a 1 bit change then this could be due to the uncertainty caused by a marker pulse falling between two counts. Any greater change is most likely due to the fact that the simulated pulses are generated by monostable multivibrators with pulse durations of up to 42 μS, a slight variation in this time would produce such a change in co-ordinate value. Such variations are not critical and do not impair the usefulness of the simulator. The stability of the Co-ordinate Generator when used with camera inputs is discussed in the next section. It can also be seen from this print out that, although the simulator is set to generate pulses on every 37_8^{th} line, the first line in each television field on which co-ordinates appear is line 41_8. This

0541	6041	1113	0750	0461	0244	0041	1400
0550	6100	1114	0751	0462	0245	0042	1400
0557	6137	1114	0751	0462	0245	0042	1400
0566	6176	1113	0750	0461	0244	0041	1400
0575	6235	1114	0751	0462	0245	0042	1400
0604	6274	1113	0750	0461	0245	0041	1400
0613	6333	1113	0750	0461	0245	0041	1400
0622	6372	1114	0751	0462	0245	0042	1400
0631	6431	1114	0751	0462	0245	0042	1400
0640	6470	1113	0750	0461	0245	0041	1400
0647	6531	1114	0751	0462	0246	0042	1400
0656	6570	1113	0750	0461	0245	0041	1400
0665	6627	1114	0751	0462	0246	0042	1400
0674	6666	1113	0750	0461	0245	0041	1400
0703	6725	1113	0750	0461	0245	0041	1400
0712	6764	1113	0750	0461	0245	0041	1400
0721	7023	1114	0751	0462	0246	0042	1400
0730	7062	1113	0750	0461	0244	0041	1400
0737	7121	1114	0751	0462	0246	0042	1400
0746	7160	1114	0751	0462	0245	0042	1400
0755	6041	1113	0750	0461	0244	0041	1400
0764	6100	1114	0751	0462	0245	0042	1400
0773	6137	1114	0751	0462	0245	0042	1400
1002	6176	1113	0750	0461	0244	0041	1400
1011	6235	1114	0751	0462	0245	0042	1400
1020	6274	1113	0750	0461	0245	0041	1400
1027	6333	1113	0750	0461	0245	0041	1400
1036	6372	1114	0751	0462	0245	0042	1400
1045	6431	1114	0751	0462	0245	0042	1400
1054	6470	1113	0750	0461	0245	0041	1400
1063	6531	1114	0751	0462	0246	0042	1400
1072	6570	1113	0750	0461	0245	0041	1400
1101	6627	1116	0750	0451	0245	0041	1400
1110	6666	1113	0750	0461	0245	0041	1400
1117	6725	1113	0750	0461	0245	0041	1400
1126	6764	1113	0750	0461	0245	0041	1400
1135	7023	1113	0750	0461	0245	0041	1400
1144	7062	1113	0750	0461	0245	0041	1400
1153	7121	1114	0751	0462	0245	0042	1400
1162	7160	1113	0750	0461	0245	0041	1400

Figure 6.6. Print out of data generated by the system for simulated marker inputs. The first column shows the memory location of the vertical co-ordinate which is in the next column. The next five columns are the horizontal co-ordinates for five markers and these are followed by the shift register code word in the last column.

is due to the fact that the Line Counter is reset at the beginning of each field by the field sync. This print out also shows that further co-ordinate generation was inhibited on each line after five markers had been detected.

The program DYDIS is used extensively to check correct system operation, again by using the simulator to provide marker detector inputs. Figures 6.7 and 6.8 are photographs of the display produced while this program is running. Four simulated marker signals on each of 8 television lines in every field are being generated (data rate of 2400 words/sec). Three of the markers are on channel Ø and one marker is on channel 1 shown in Figures 6.7 and 6.8 respectively.

6.3 System Performance

The ability of the system to generate co-ordinates of markers and provide repeatable measurements is shown here. The material used for markers and the positioning of light sources has been discussed in section 2.2.1. The same degree of lighting has been used for all the tests reported here. This consisted of a single Malham SE23 lamp fitted with a 500W tungsten halogen bulb positioned as close as possible to the television camera lens. This configuration was used for each camera where two cameras were used. Normal room lighting was maintained.

6.3.1 Stability

To ascertain that the system could provide repeatable measurements a stability test was carried out. Stationary markers were used mounted on a board in the configuration shown in Figure 6.9. The distances between markers are also shown in this figure. The field of view covered by the camera in the plane of this board was 2.8 m by 2.1 m and the marker size required would be 7.7 mm calculated as shown in section 2.2.2. It was found, because there is a certain degree of flare, that a marker of 5 mm diameter could cover one or two television lines and this size of marker was used for the stability test. A thirty minute warm up time was allowed and then the co-ordinates of the stationary markers were generated by the interface. The interface was set to sample the spatial position of the markers once every 255th television field

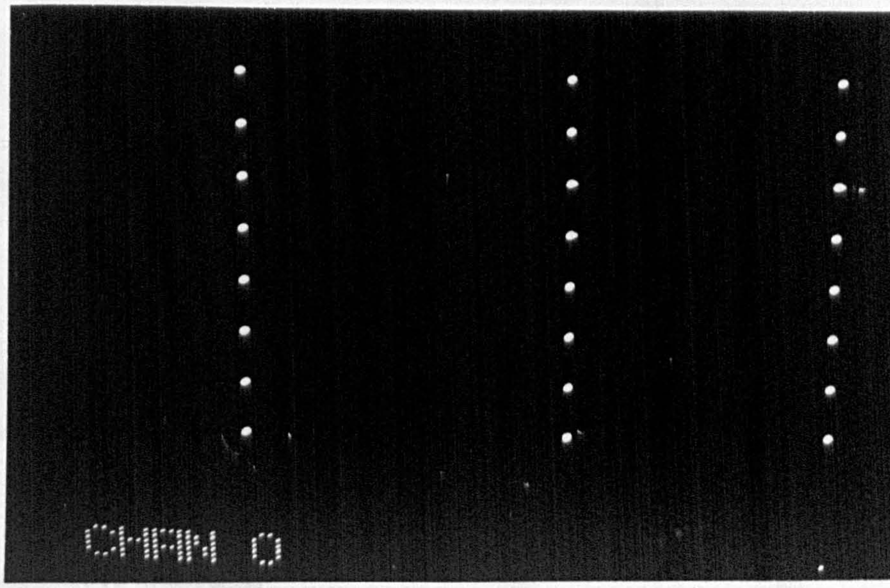


Figure 6.7. Real time computer display of data generated by the interface using the simulator. Channel Ø data.

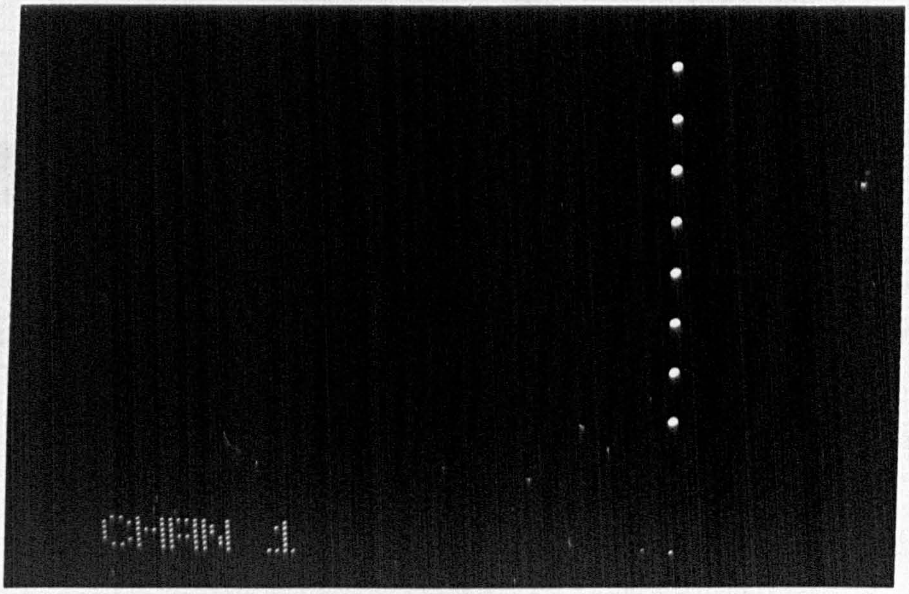


Figure 6.8. Data generated for channel 1 at the same time as that for channel Ø shown above.

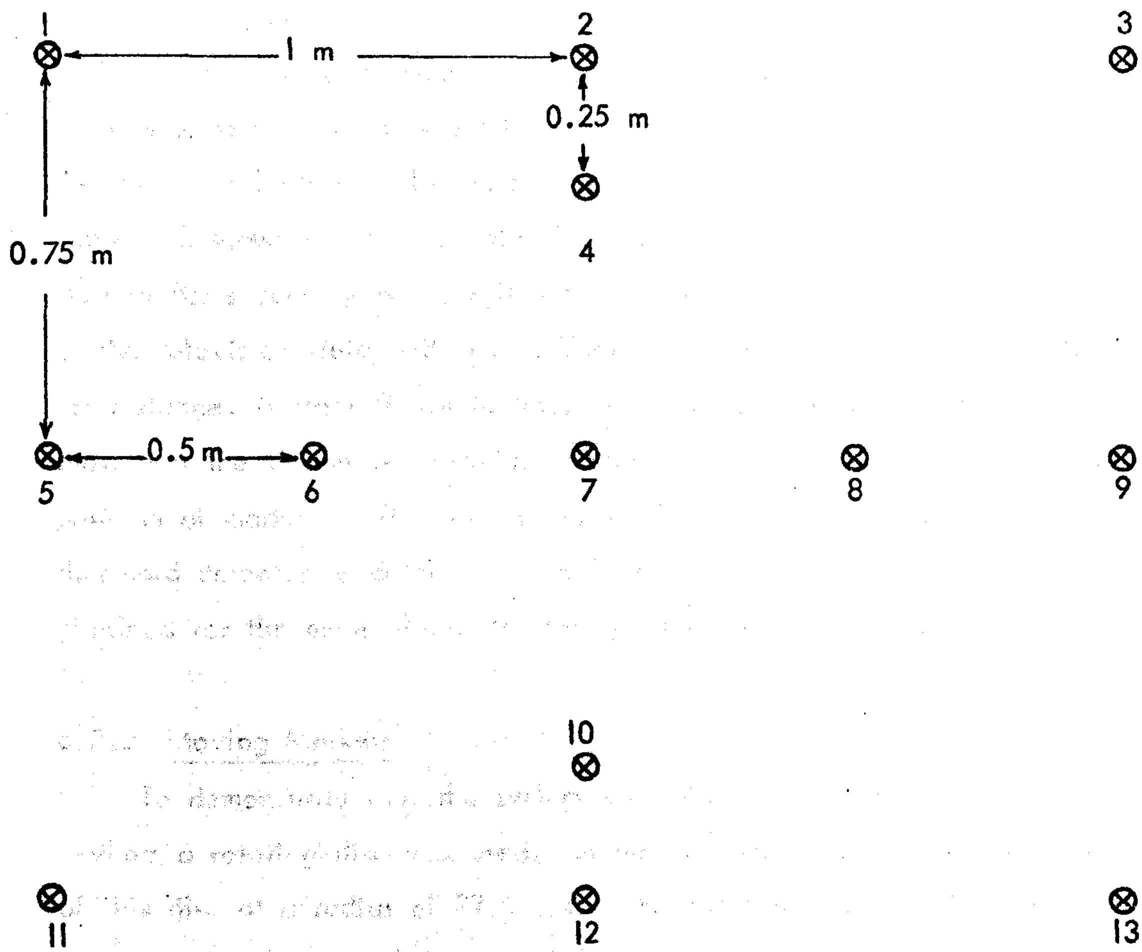


Figure 6.9. Configuration of markers used to test the stability of the system.

(5.1 sec). Sixteen sets of co-ordinates were obtained and then the system was left for two and a quarter hours after which time a further sixteen sets of co-ordinates were obtained. The co-ordinates generated for each marker were then compared. Almost perfect agreement was found between each set of data. The co-ordinates generated for markers 10, 11, 12 and 13 are shown in Tables 6.1 and 6.2, similar agreement was found between the repeated measurements for the other markers. Table 6.1 shows the co-ordinates for the "even" television field (vertical co-ordinates between 0 and 312) and Table 6.2 shows the co-ordinates for the "odd" fields. These particular markers have been chosen for illustration because they occur towards the end of the television field and any malfunction in the vertical co-ordinate counter, for instance, is more likely to have occurred by this time. These results show that the system can provide repeatable measurements of the spatial position of markers. The results shown above were obtained using a simple threshold detector to detect markers in the video signal. Similar results were obtained for the more elaborate marker detector described in section 2.2.4.

6.3.2 Moving Markers

To demonstrate that the system can generate the co-ordinates of moving markers a rotating disc was used. A marker was placed near the outer edge of this disc at a radius of 22.5 cm. The field of view of the camera in the plane of the disc was 3.2 m by 2.4 m and a marker size of 7 mm diameter was used. The disc was rotated by a synchronous electric motor through a variable reduction gearbox. Figure 6.10 is a plot of the co-ordinates generated by the interface for one complete revolution of the disc. The vertical co-ordinate has been scaled, the scaling factor being found from the diameter of the disc in horizontal co-ordinate units (142) and in vertical co-ordinate units (54) giving a scaling factor of 2.63. It can be seen that one complete revolution of the disc was made in 19 television fields or 380 mS (2.63 revs/sec). The marker will, therefore, reach a peak velocity in the x and in the y directions of 3.7 m/S and a peak acceleration of 61.4 m/S^2. It can be seen that at least one pair of co-ordinates was generated for the marker in every television field. The velocities and accelerations reached by the marker

TV Field	10		11		12		13	
0	239	504	275	150	273	504	270	860
2	239	504	275	150	273	504	270	860
4	239	504	275	150	273	504	270	860
6	239	504	275	150	273	504	270	860
8	239	504	275	150	273	504	270	860
10	239	504	275	150	273	504	270	860
12	239	504	275	150	273	504	270	860
14	239	504	275	150	273	504	270	860

Co-ordinates generated after 30 minute warm up period.

TV Field	10		11		12		13	
0	239	504	276	151	273	504	271	858
2	239	504	276	151	273	504	271	859
4	239	504	276	151	273	504	271	858
6	239	504	276	150	273	504	271	858
8	239	504	276	151	273	504	271	858
10	239	504	276	151	273	504	271	858
12	239	504	276	151	273	504	271	859
14	239	504	276	150	273	504	271	858

Co-ordinates generated 135 minutes later.

Table 6.1. Co-ordinates generated by the interface for markers 10, 11, 12 and 13 of Figure 6.9 during "even" television fields, showing the stability of the system. The interface was set to sample at a slow rate, one field every 5.1 secs.

TV Field	10		11		12		13	
1	551	504	587	151	585	503	583	860
3	551	504	587	151	585	503	583	860
5	551	504	587	151	585	503	583	860
7	551	504	587	151	585	503	583	860
9	551	504	587	151	585	503	583	860
11	551	504	587	151	585	503	583	860
13	551	504	587	151	585	503	583	860
15	551	504	587	151	585	503	583	860

Co-ordinates generated after 30 minute warm up period.

TV Field	10		11		12		13	
1	552	504	588	151	586	503	583	859
3	552	504	588	151	586	503	583	859
5	552	504	588	151	586	503	583	859
7	552	504	588	151	586	503	583	859
9	552	506	588	151	586	503	583	859
11	552	504	588	151	586	503	583	859
13	552	504	588	151	586	503	583	859
15	552	504	588	151	586	503	583	859

Co-ordinates generated 135 minutes later.

Table 6.2. Co-ordinates generated by the interface for markers 10, 11, 12 and 13 of Figure 6.9 during "odd" television fields, showing the stability of the system. The interface was set to sample at a slow rate, one field every 5.1 secs.

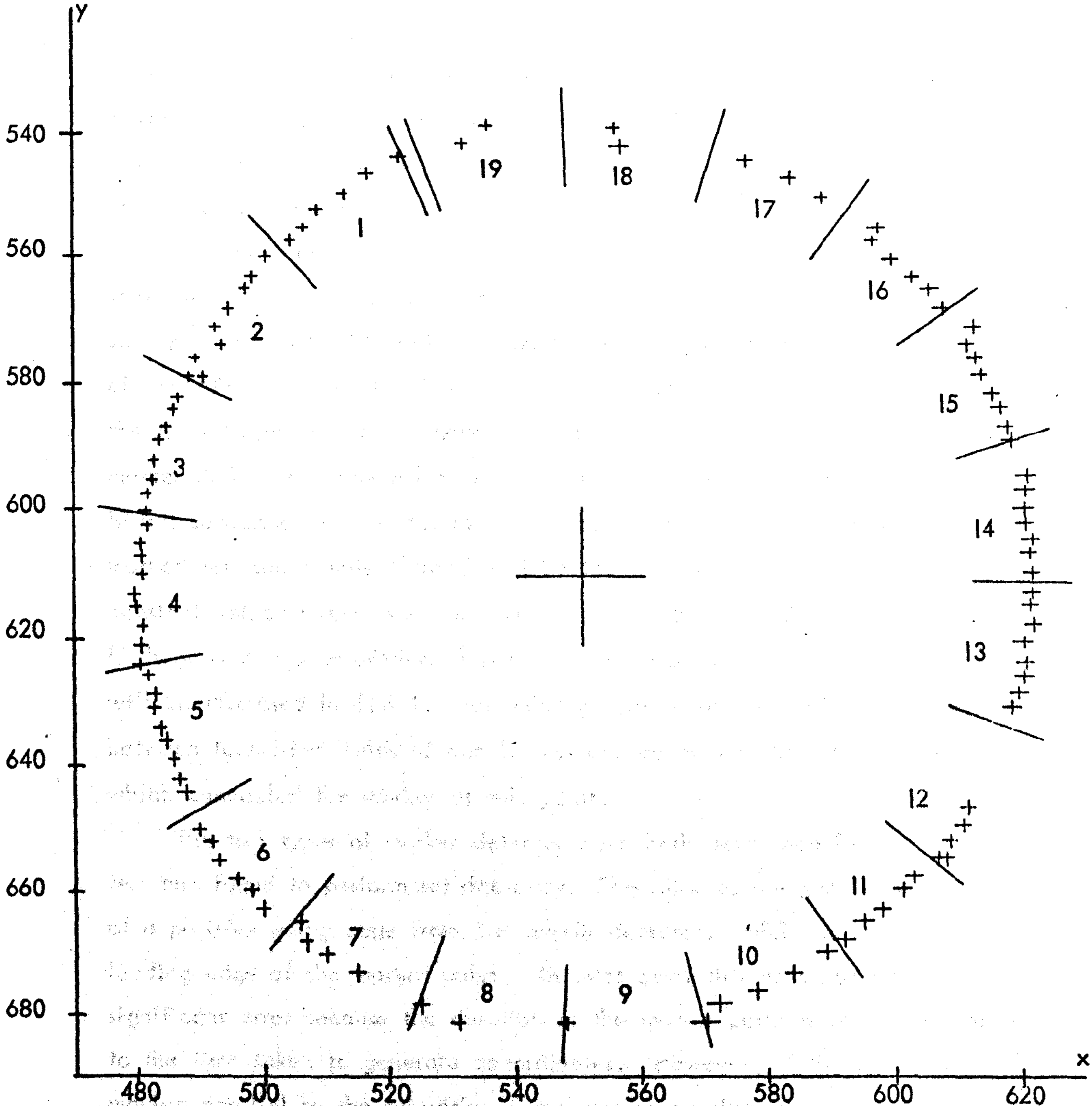


Figure 6.10. **Plot of data generated by the system for a marker on the periphery of a rotating disc. The vertical co-ordinates (y) have been scaled and the television field numbers, during which each part of the trajectory was formed, are indicated.**

compare favourably, as a realistic test for a locomotion measurement system, with the maximum velocities and accelerations reported by Winter (1974) and shown in Table 6.3. The fastest moving marker in this table is the heel marker (5) for fast walking (average cadence of 114 strides/min), which reaches average maximum vertical and horizontal velocities of 1.76 m/S and 3.78 m/S respectively.

The co-ordinate data generated by the interface for the rotating markers shows up an interesting characteristic of the television camera. This is the storage property of the pick up tube target. It can be seen that the sequence of co-ordinates generated for the marker in each television field is a part of the total trajectory of the marker. That is, it is the path traversed by the marker during the time taken to scan one complete television field (20 mS). If this sequence of co-ordinates is averaged then the average position of the marker between sample instants will be found. If the marker is moving with constant velocity then there will be no error caused by this averaging process. If there is any acceleration, however, then there will be an error, which will be discussed in 6.3.4. The missing portion of the marker trajectory between television fields 12 and 13 was caused by the disc mounting assembly which concealed the marker at this point.

The two types of marker detector have both been used in this type of test and found to perform satisfactorily. Co-ordinates are generated on receipt of a positive going edge from the marker detector, which corresponds to the leading edge of the marker pulse. In most cases this does not lead to any significant error because the duration of the marker pulse is short and similar to the time taken to generate co-ordinates. However, if the marker is moving parallel to the television camera scanning lines then co-ordinates will be generated for the leading edge of the trajectory only. In Figure 6.10 it can be seen that this has probably happened on some television fields (8 and 9 for example). This would be a source of measurement error, however the logic shown in Figure 6.11 could be used and then a series of horizontal co-ordinates would be generated for a trajectory lying parallel to the line scan.

6.3.3 Extraneous Light Sources

Co-ordinates will be generated for extraneous light sources of sufficient brightness in the field of view of the camera. Precautions can be taken to ensure that the number of such sources is minimised or eliminated by removing

Average cadences: Fast—114/min. Normal—93/min. Slow—82/min											
			Vertical. (Y)					Horizontal. (X)			
				Max. velocity (cm/sec)		Max. acceleration (cm/sec²)		Velocity (cm/sec)		Acceleration (cm/sec²)	
Marker No.	Speed of walk	No. of subjects	Displacement Range (cm)	Up	Down	Up	Down	Min.	Max.	Min.	Max.
1	Fast	8	5·9(1·2)	34(7)	32(10)	570(180)	500(190)	75(20)	154(35)	−480(190)	460(170)
	Normal	12	5·8(0·7)	31(4)	27(6)	530(120)	390(70)	66(16)	126(12)	−380(90)	360(60)
	Slow	8	4·9(0·7)	25(5)	19(5)	360(84)	280(50)	46(13)	104(15)	−400(90)	310(60)
2	Fast	8	8·9(1·8)	55(7)	41(11)	800(160)	820(340)	26(15)	235(52)	−980(530)	1270(430)
	Normal	12	8·1(1·9)	46(7)	36(10)	660(150)	620(100)	23(11)	201(15)	−760(250)	1050(210)
	Slow	8	7·0(1·2)	35(9)	25(7)	430(140)	410(100)	19(7)	156(30)	−630(170)	690(150)
3	Fast	8	7·4(1·2)	49(9)	34(14)	720(190)	690(310)	15(11)	244(57)	−940(440)	1380(560)
	Normal	12	6·6(0·9)	38(8)	31(9)	550(100)	490(100)	14(9)	204(17)	−770(230)	1060(120)
	Slow	8	6·2(1·1)	29(8)	22(7)	370(120)	370(60)	12(7)	167(26)	−600(150)	800(150)
4	Fast	8	17·3(1·0)	105(26)	120(33)	1280(480)	1920(880)	0(0)	346(82)	−3030(1390)	1590(610)
	Normal	12	16·8(1·5)	97(14)	99(9)	1320(610)	1490(210)	0(0)	294(27)	−1930(220)	1170(210)
	Slow	8	16·9(1·7)	81(21)	87(14)	800(220)	1300(290)	0(0)	239(34)	−1470(310)	830(180)
5	Fast	8	25·0(1·8)	170(46)	168(41)	1710(700)	2890(1200)	0(0)	378(93)	−3390(1460)	2000(870)
	Normal	12	24·4(1·7)	147(13)	143(10)	1350(200)	2250(270)	0(0)	323(28)	−2490(360)	1340(160)
	Slow	8	23·9(2·4)	125(19)	123(19)	1050(280)	1690(290)	0(0)	266(38)	−1870(390)	990(210)
6	Fast	8	11·9(1·2)	96(14)	91(13)	1690(510)	2010(580)	0(0)	408(103)	−3260(1590)	2540(530)
	Normal	12	11·8(1·6)	91(11)	77(8)	1230(200)	1640(200)	0(0)	338(29)	−2240(330)	2070(260)
	Slow	8	11·3(1·7)	85(19)	74(21)	980(210)	1250(250)	0(0)	277(42)	−1700(380)	1530(360)
7	Fast	8	11·9(1·7)	100(16)	106(23)	1550(430)	2690(570)	0(0)	425(108)	−3040(1360)	3660(1270)
	Normal	12	12·6(2·7)	98(18)	98(6)	1210(180)	2320(400)	0(0)	351(30)	−2100(210)	2800(280)
	Slow	8	12·9(2·3)	87(16)	78(21)	1070(280)	1930(510)	0(0)	286(42)	−1550(370)	2210(380)

Table 6.3. Linear trajectory data of anatomical landmarks during locomotion. Presented by Winter (1974).

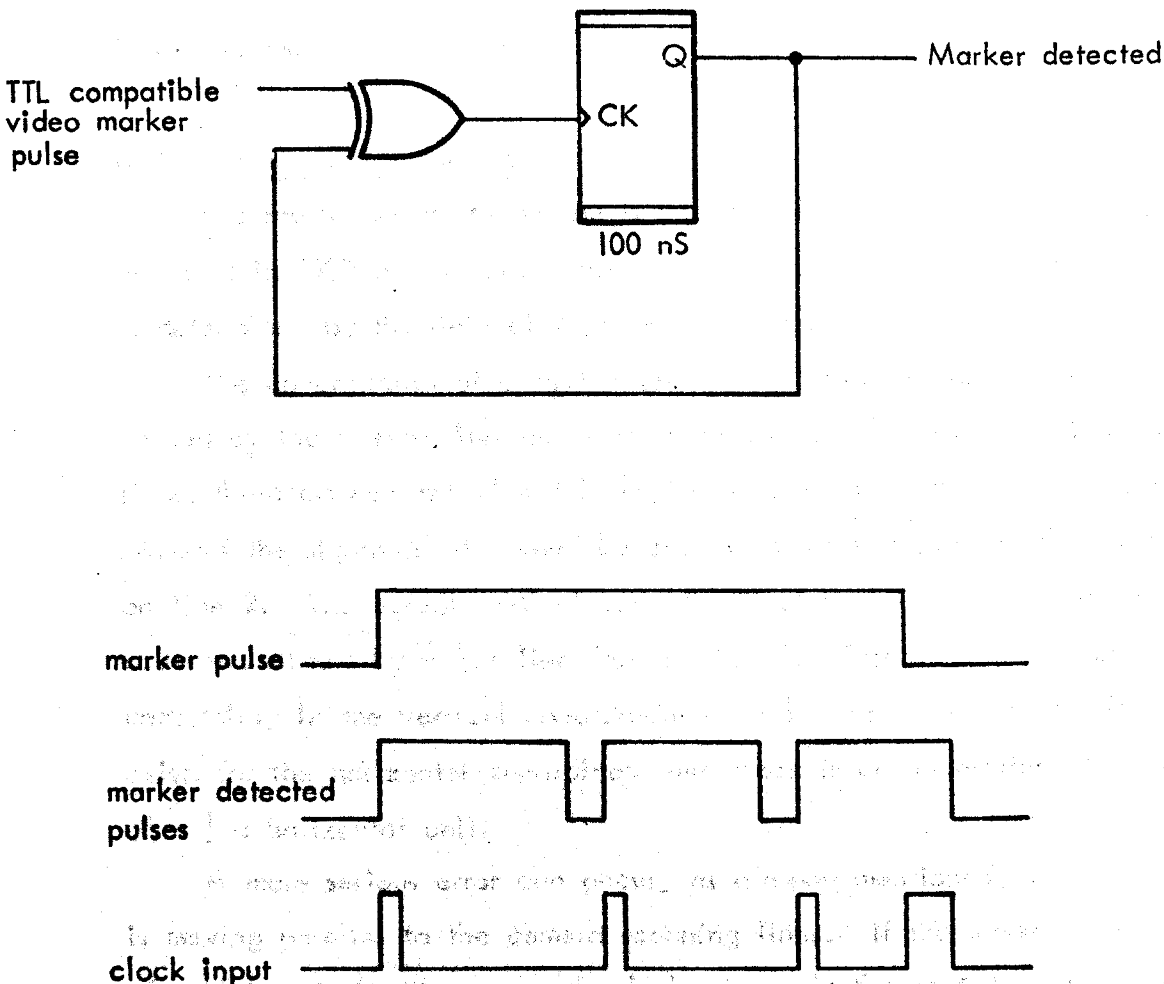


Figure 6.11. Logic and timing diagram to regenerate horizontal co-ordinates for long marker pulses.

shiny objects, and by the use of drapes. The camera lens aperture is set to obtain maximum contrast between markers and background. If co-ordinates of extraneous light sources are generated then they can be eliminated in subsequent data processing to be described in section 6.5, their only effect is to increase the data rate.

6.3.4 Errors and Resolution

The resolution of the system is one part in 292 in the vertical scan and one part in 1000 in the horizontal scan. The resolution in terms of distance is determined by the field of view of the camera.

The co-ordinates of a marker are generated when the video signal level caused by the marker rises above a pre-determined threshold. Figure 6.12 shows three markers all of which would be given the same vertical co-ordinate, because the signal level caused by each only rises above the threshold level on line 2. The actual vertical co-ordinate of the centres of markers 1 and 3, however, differs by $\pm \frac{1}{2}$ a line from marker 2. This difference represents an uncertainty in the vertical co-ordinate of $\pm \frac{1}{2}$ a line. A similar situation exists for the horizontal co-ordinate and there is an uncertainty in its position of $\pm \frac{1}{2}$ a horizontal unit.

A more serious error can occur, as already mentioned, when a marker is moving parallel to the camera scanning lines. If the marker is moving with high velocity then even the logic shown in Figure 6.11 would not provide enough co-ordinates to cover the entire trajectory. The magnitude of this error depends on the horizontal field of view of the camera and on the marker velocity. If co-ordinates are only generated at the beginning of the trajectory then the error in average position of a marker moving at 5 m/S horizontal velocity could be as high as 5 cm in a 20 mS period between samples. This error could be reduced by designing logic to generate the co-ordinates at the beginning and at the end of a trajectory. Alternatively, since in locomotion the highest components of velocity are in the horizontal direction (Winter (1974)), the camera could be turned on its side and high speed horizontal trajectories would then cross the scanning lines.

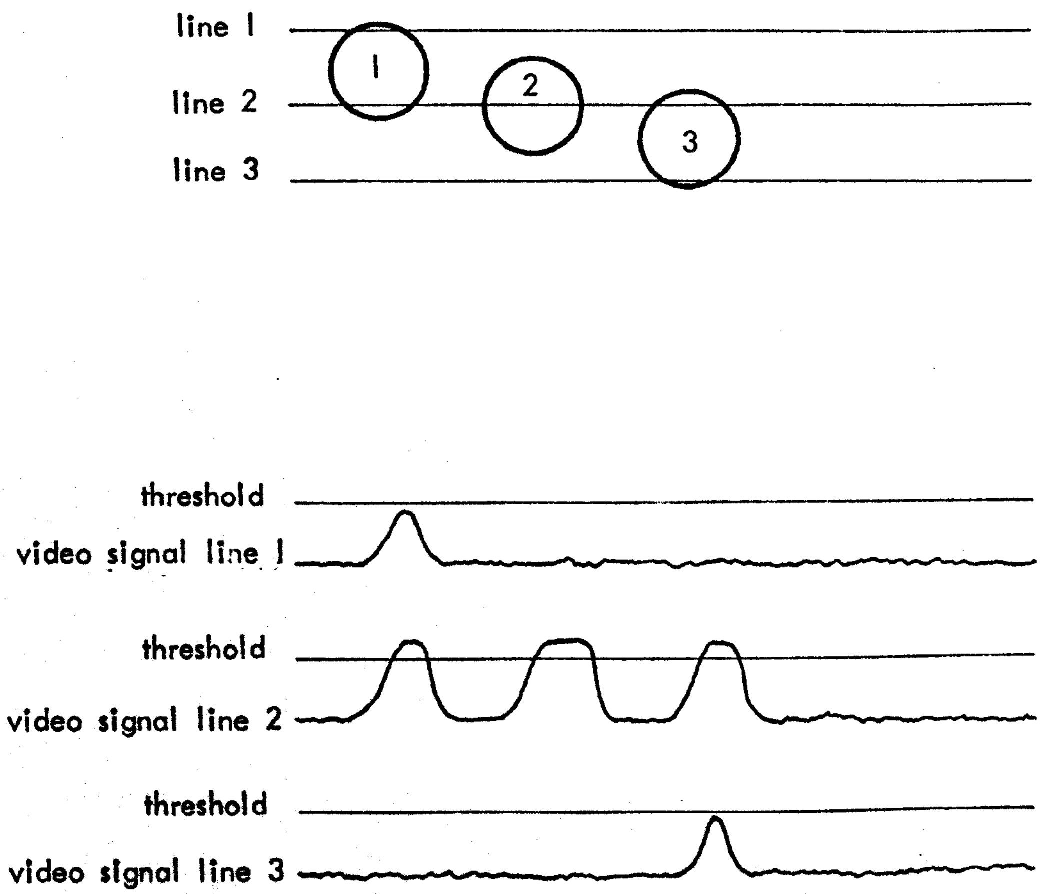


Figure 6.12. Three markers which would all be given the same vertical co-ordinate (line number).

The error caused by averaging a marker trajectory between sample instants is proportional to the acceleration of the marker during this interval and is given by $-1/8\ a\ t^2$ (for constant acceleration), where a is the acceleration and t is the time between sampling instants. For this system t is 20 mS so the error becomes $-0.05\ a.10^{-3}$. For an acceleration of 50 m/S^2 an error of 2.5 mm would arise from the averaging process. Since such high accelerations are only occasionally reached it would seem that averaging of marker trajectories is an acceptable procedure for most applications.

There is an inherent phase difference in sampling instants for different markers. This depends on their spatial relationship to each other with respect to the television camera scanning rastor. The position of a marker in mid field, for example, would be sampled some 10 mS later than a marker at the beginning of the field. The range of vertical movement of anatomical landmarks tends to be restricted in locomotion and there would, therefore, be little phase error between samples for the same marker. Corrections can be made for phase errors between markers because the position in the scanning rastor of a marker is related to time.

Phase errors and errors due to averaging of trajectories could be eliminated by the use of a rotating shutter. Such a method is used in the Dutch system Ingen Schenau (1973). The shutter consists of an opaque disc with a transparent window, it rotates in synchronism with the television field synchronising pulse so that the window is positioned over the camera lens during the field blanking period. The size of the window is chosen so that the camera is exposed to the field of view for approximately 1 mS. The light pattern picked up is stored on the camera target plate until it is scanned. The disadvantage with using this method is that a camera tube with a very rapid response is required in order to register the reduced light levels in the short exposure time. Such tubes tend to be much more expensive than the normal Vidicon tube.

The television camera scanning rastor is not perfectly linear and hence errors will arise due to these non-linearities. The manufacturer's specification quotes a maximum non-linearity of $\pm$ 1% in the line scan and $\pm$ ½% in the field scan, with the total error not occurring in less than half a line or half a field (KGM (1971)). A corresponding non-linearity will be introduced into the co-ordinates of markers detected in the video signal. Corrections can be made for this error by referring measurements to a calibration grid, either directly or by the use of equations as discussed in section 3.3.5.

Errors due to parallax can be corrected, if the system is used in a three dimensional configuration, by the same techniques that are used in cine film analysis (e.g. Paul (1967)).

6.4 Calibration

Data can be calibrated by generating the co-ordinates of the spatial position of markers at a known separation. This was effectively done to plot out the trajectory of the marker on the rotating disc of Figure 6.10, and it can be seen that the circle has been faithfully reproduced.

It has been possible to acquire the co-ordinates of a grid of markers using the Calibration Control, but it has been necessary to include a sloping row of markers at the top of the grid. The top row of markers is used to set the limits for the Calibration Control window referred to in section 3.3.5. For the control to function correctly markers must either slope downwards from left to right with respect to the television camera scan line or be horizontal to this line. If the markers slope upwards then the control will set the wrong window limits. This situation was catered for in the design by incorporating a "free run mode" and a monitor output. The control would be operated in this mode and the camera rotated until it could be seen on the monitor that the control was functioning correctly. It was found, however, that it is inconvenient to rotate the camera and that the control could operate successfully off a sloping row of markers. An example of a grid of points generated by the interface using this control is shown in Figure 6.13. A new design for a simplified Calibration Control is discussed in section 6.8.

The operation of the calibration program CAL was successful when a simulated calibration matrix was used to calibrate real data. Some 2000 co-ordinate pairs were reduced to one co-ordinate pair per marker in each

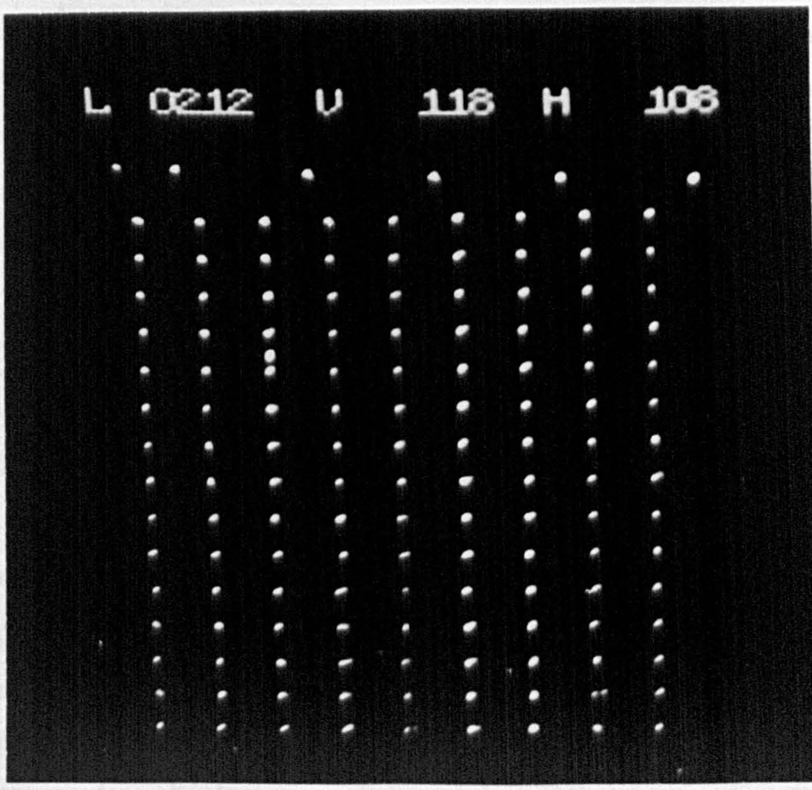


Figure 6.13. Data points generated by the interface for a grid of markers using the calibration control. The sloping row of markers used to set up the window limits can be seen at the top.

television field and calibrated against the calibration matrix in a matter of seconds. The part of the grid data acquisition program (CAL MTX) which organised the grid data generated by the interface into a calibration matrix was not however successful. One factor which occasionally caused malfunction of the program was that the number of co-ordinates collected for the grid markers was underestimated. The program had been written to cater for a maximum of 2000 co-ordinate pairs and this limit was sometimes exceeded. Also no facility was provided by this program to select out unwanted co-ordinates, such as those generated for the sloping row of markers, which would lead to errors in building the calibration matrix. Such a facility could be provided very effectively by utilising the visual display unit of the PDP 12.

6.5 Gait Data Acquisition and Marker Trajectory Identification

In the first example of gait data generated by the system data was collected simultaneously for two television channels and the force plate. One of the television channels was connected to a simulator output which generated a marker pulse half way down the television field (line 160). The second television channel was connected to a camera output to record the side view trajectories of markers placed on a subject's limb. Markers were placed over the hip, knee and ankle joints and on the foot. Some of the data generated for these markers is shown in Figure 6.14 the read out for the cursor showing that the force plate was also sampled during the television field indicated. This is a display produced on the PDP 12 visual display unit by the program DISC (Display with cursor). The number of points displayed is limited by the computer program to 512, this limitation being necessary to avoid display flicker. The co-ordinates shown are unprocessed in that they have not been averaged to produce one co-ordinate pair per marker in each television field. Data that has been processed in this way (by the program CAL) is shown in Figure 6.15; this data was also calibrated against a simulated calibration matrix. Here the complete trajectory is shown, and also a stationary marker that was positioned in the field of view of the camera to provide a check on the stability of the system during this test. No significant change was observed in the co-ordinates generated for this marker. At the same time that

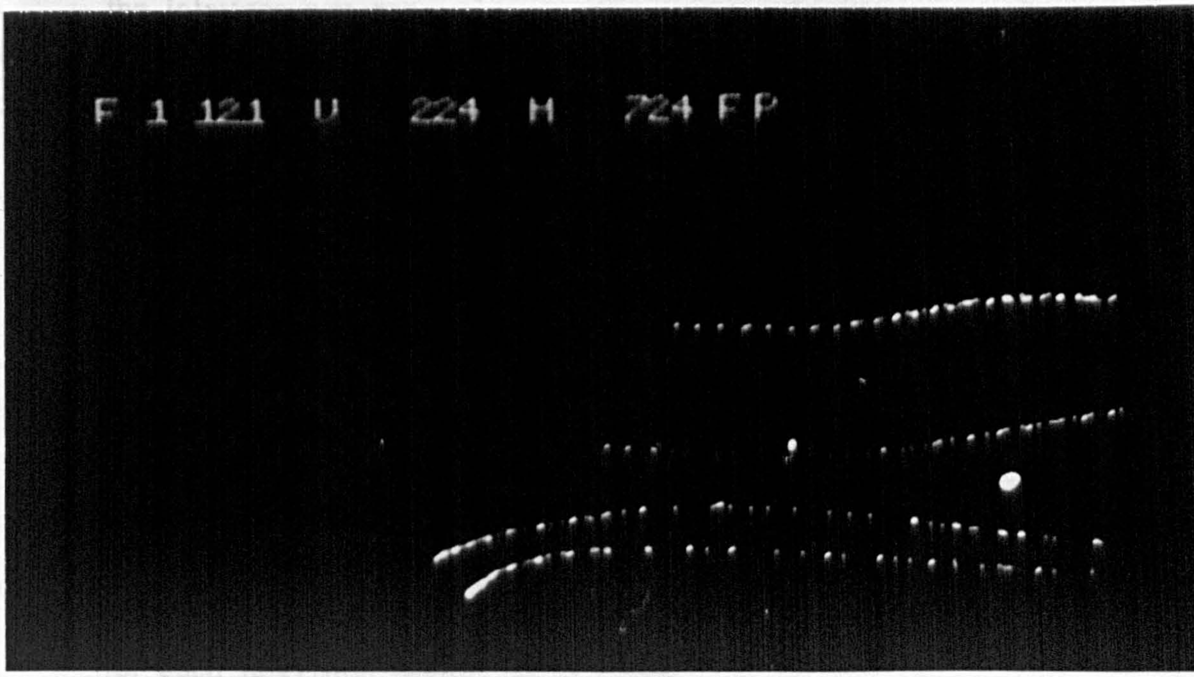


Figure 6.14. Computer display of unprocessed data showing part of the trajectories of markers placed on a subject's limb. Markers were placed on the hip, knee, ankle and foot.

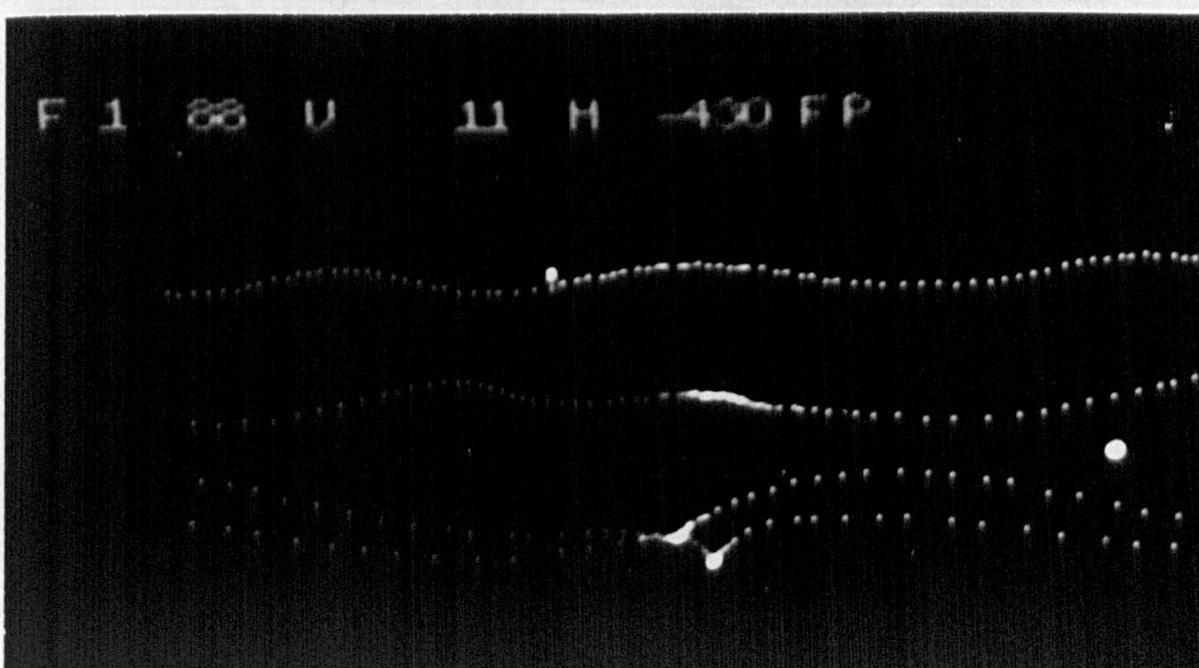


Figure 6.15. Data of Figure 6.14 averaged to produce one co-ordinate pair per marker per television field and calibrated against a simulated calibration matrix. The bright spot is a stationary marker placed in the field of view to check stability.

the interface was generating co-ordinate data the computer was sampling the six analogue channels of the force plate. This data is shown in Figure 6.16.

The combination of data inputs described above tested a number of aspects of the interface design. The internal logic signals which generate the simulated marker pulse also generate the clock pulses which are used to initiate analogue to digital conversions of the force plate transducer signals. This means that co-ordinate data is actually being generated and transferred to computer memory between analogue channel samples. This showed that even time critical computer programs can be successfully run during interface operation. Also the multi-channel capability of the interface is illustrated by this test.

The data generated by the interface consists of a set of co-ordinate pairs for each television field. Co-ordinates may occasionally be generated for extraneous light sources in the field of view of the camera, and trajectories of markers may cross, making marker identification difficult. Obviously it is necessary to define which co-ordinates belong to which markers so that the data can be analysed. Marker identification can be achieved by the application of a linear extrapolation routine such as that reported by Ingen Schenau (1973). With this method the first two points of a marker trajectory are identified and then the routine automatically locates the remaining points. This is done by making an estimate of the expected marker positions from the two previous positions, a boundary is placed around this estimate and a search is made for a co-ordinate pair within this area. The estimated x co-ordinate is found from

$$x_{t+2} = x_t + 2(x_{t+1} - x_t)$$

where t is the time co-ordinate.
The estimated y co-ordinate is found from a similar equation.

The process of extrapolation and search is illustrated in Figure 6.17. The extrapolation assumes that velocity of the marker is constant and accelerations are allowed for by the search boundary. The data from the test discussed above has been processed in this way, the trajectory for each marker being identified and stored separately. The resulting data was plotted on the

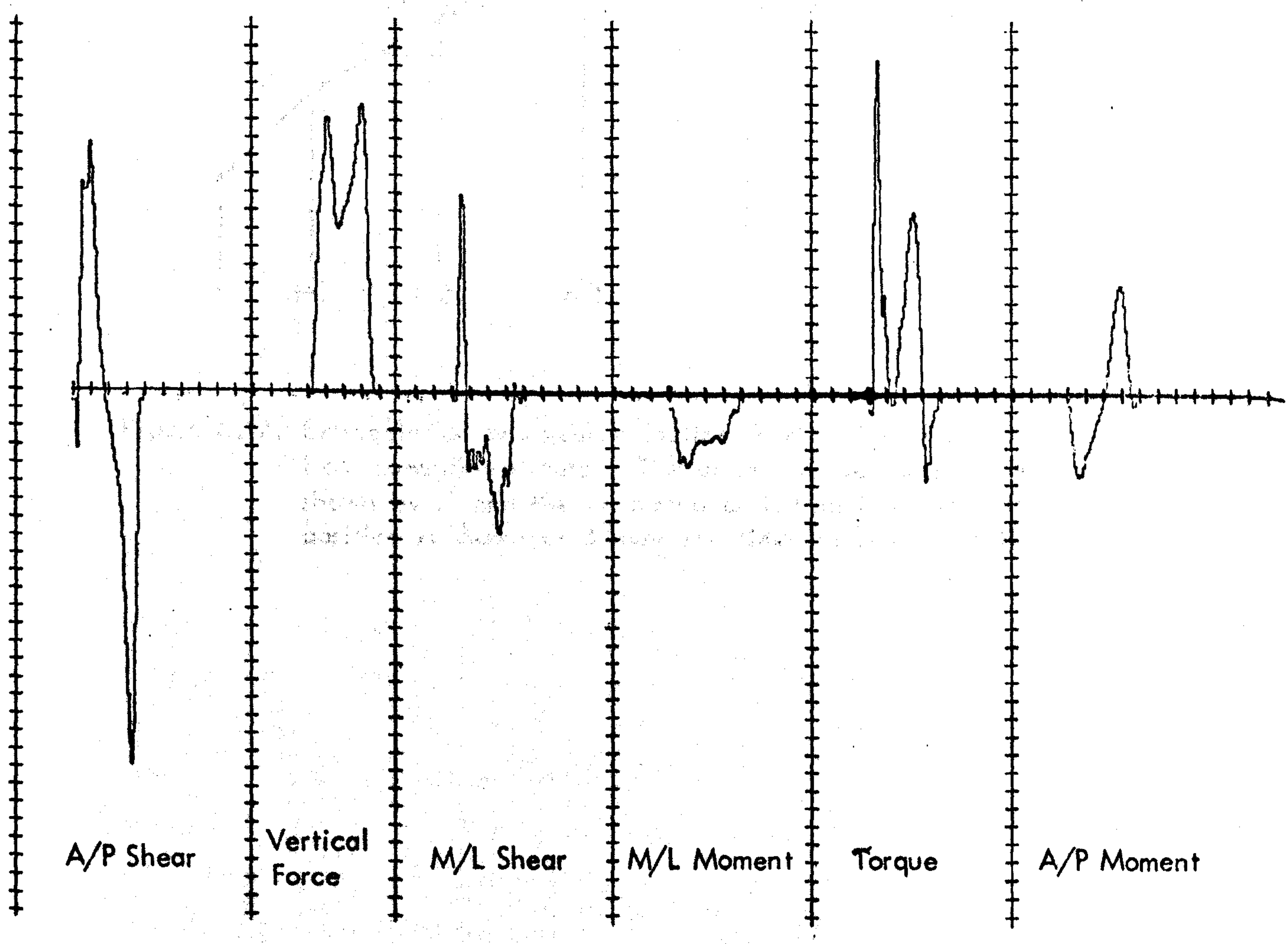


Figure 6.16. Ground reaction force data from the force plate acquired at the same time as the interface generated the co-ordinate data shown in Figure 6.15.

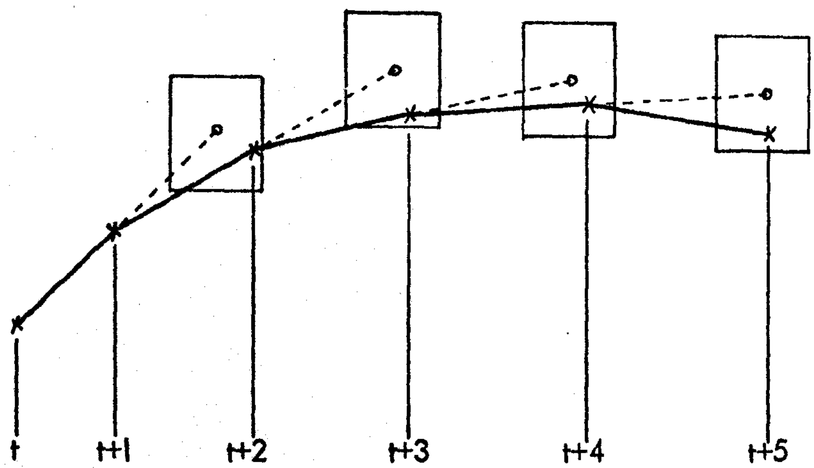


Figure 6.17. Extrapolation and search routine used to identify markers from co-ordinate data. The actual marker position is shown by X and the estimated or extrapolated marker position is shown at 0 over the time intervals t to t+5.

computer graph plotter and this plot is shown in Figure 6.18. The co-ordinates in every second television field have been joined together to show the relative instantaneous spatial position between markers. The stationary marker was filtered out by the extrapolation routine.

To successfully identify marker co-ordinates, using the procedure described above, care must be exercised in the marker configuration used on the subject. The co-ordinates shown in Figure 6.19 represent the side view data generated for a subject with a total of 10 markers. Markers were positioned over the hip, knee and ankle joints, on the pelvis and on the foot. Four of the markers were intended for the front view camera only and covered the pelvis, knee and ankle; as shown in Figure 6.20. It can be seen in Figure 6.19 that front view markers were occasionally picked up by the side view camera (as indicated by the cursors). At certain phases of the gait, marker identification, by the simple routine described above, for the ankle marker was impossible. Identification of the knee marker was satisfactorily accomplished despite similar pick up of the front view marker. It might be possible to develop a more sophisticated trajectory identification routine to solve this problem, however a simple solution can be provided by suitable marker positioning. The ankle joint marker for the front view camera could be shifted up the shank to lie a constant distance above the joint, and then pick up by the side view camera would not present a problem. A similar solution would be to provide a single marker for the ankle joint which could be seen at all times by both front and side view cameras. The size of the search boundary in the marker identification routine is defined by the expected accelerations and velocities that can be reached in the x and y directions. The size of this boundary in turn defines how close markers can be placed to each other. Markers with high expected accelerations and velocities will require large search areas and this should be noted when positioning markers. Similarly care should be taken to ensure that markers are not hidden from view if at all possible. In the tests illustrated above the subject walked with arms folded across his chest to avoid obscuring hip and pelvis markers. If this is considered undesirable then it would be necessary to provide secondary markers to be used when the primary marker was obscured.

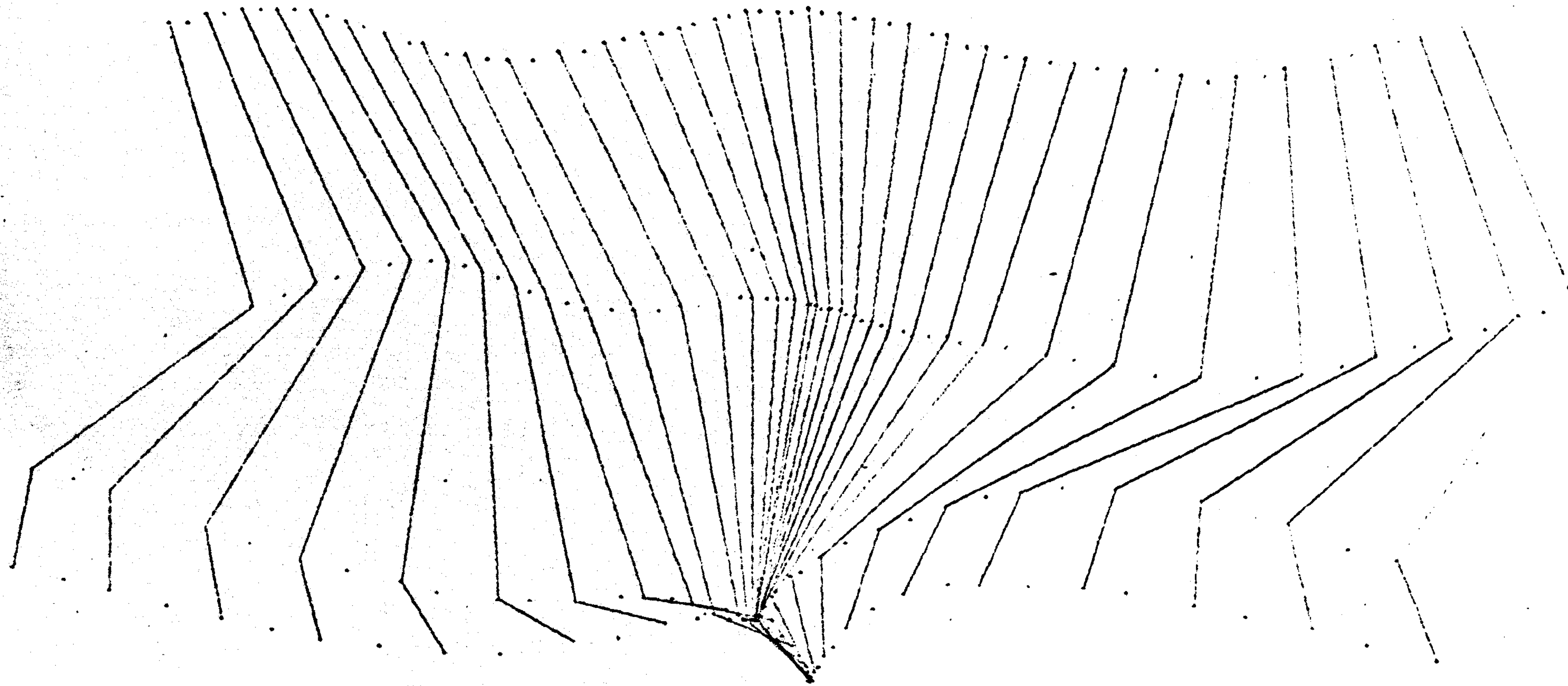


Figure 6.18. Computer plot of data generated by the system. Markers in every second television field are joined together.

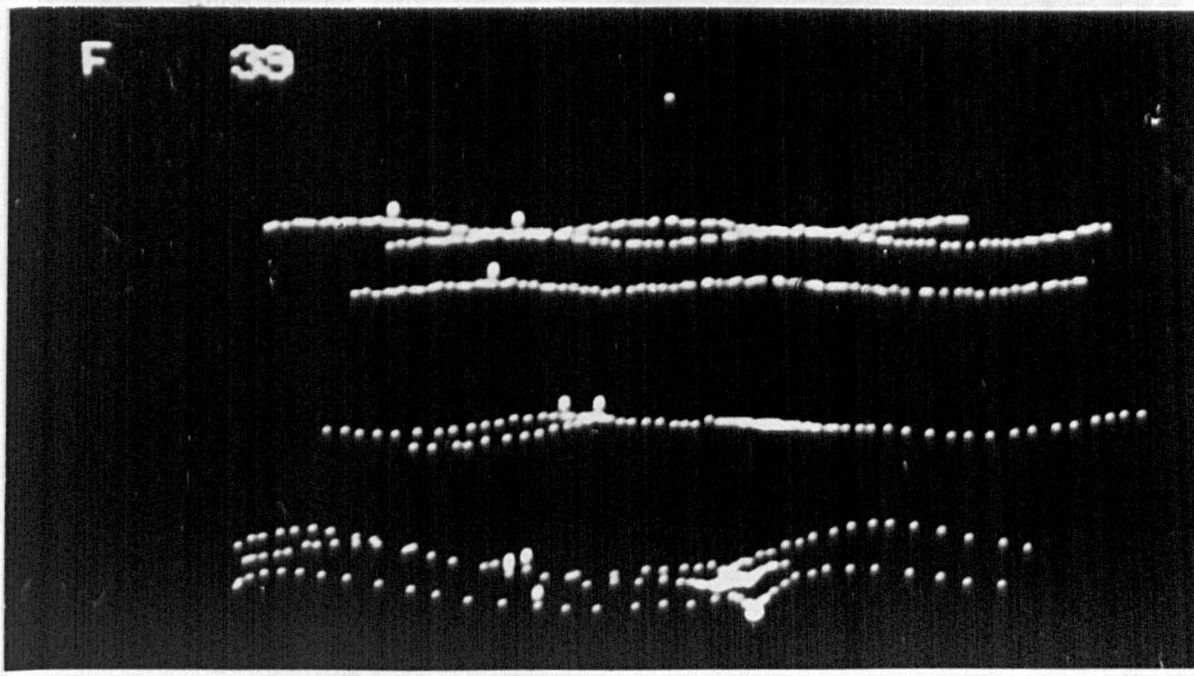


Figure 6.19. Side view data generated for a subject with front and side view markers. The cursors show that data has been generated by the side view camera for the front view markers during part of the trajectories.

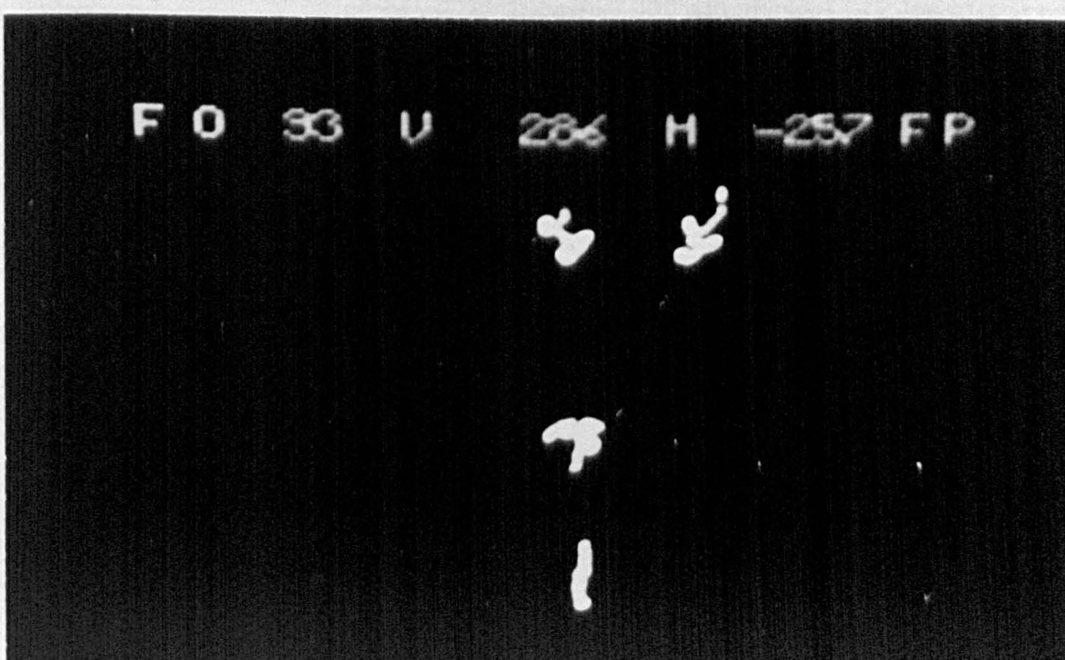


Figure 6.20. Front view data generated simultaneously with the data shown above. The subject had markers on the pelvis, knee and ankle. The side view ankle marker has also been picked up by the front view camera.

6.6 Simultaneous Data Processing and Data Rates

The ability of the system to run a program to acquire, simultaneously, data from other instrumentation while generating co-ordinate data has been shown above. The interface has been designed in such a way that the computer time required for the generation of co-ordinate data is minimised. This has made available a useful period of central processing time for running concurrent programs. The duration of this period is closely related to the data rate generated by the interface, which depends on the number of markers used, the number of lines on which markers are detected and the television field rate (which can be reduced if required by the interface). It is difficult to predict, exactly, data rates because the length of marker trajectories during each field are dependent on their average velocity during this period, however estimating that markers would be picked up on 5 lines then the data rate for 10 markers at the normal field frequency of 50 Hz would be 7500 words/second (3 words for each point - vertical and horizontal co-ordinates plus the code word).

The program DYDIS (Dynamic Display) has been used to assess simultaneous processing and data rates. The simulator was used to provide known inputs and the number of markers generated in each field was increased until display flicker was just noticeable, the data rate was then slightly reduced until there was no flicker. This was achieved when 3 markers were generated on each of 16 lines (5 words/line) at the normal field frequency of 50 Hz. This gave a data rate of 4000 words/sec; or, expressed in terms of markers, 2400 co-ordinate pairs/sec. The processing that is carried out by this program has been discussed in section 5.5.1.

For locomotion studies it will not usually be necessary to process data during a test run to any great extent. Also when a large number of markers is required the possibility of simultaneous processing is precluded because of the very high data rates involved. Even with 16K of core storage available, very little of which is required for the data acquisition program, the duration of a test would be severely limited. The use of the interface Address Register Double Buffer mode to extend the test duration was discussed in section 3.3.4.

The double buffer consists of two 4K areas in computer memory and 4K of data can be written onto one track of the PDP 12's RK05 magnetic disk. One track of data can be written onto disk in 40 mS so that, allowing time for data checking, re-writing, track access time, and possible recalibration of the disk address, data rates of 20 K words/sec should be quite feasible. The time required for data transfers from the television interface would be "invisible" to the disk data transfer program as will be discussed in the next section. The RK05 disk and its controller are described in Appendix A2.

6.7 Effect of Interface on Overall Computer Systems

The television interface uses the direct memory access facility of the PDP 12 (Single Cycle Data Break) for data transfers. Other peripherals, such as the disk, use the same method. The sharing of this facility is accomplished by a multiplexer (DM 12). This device examines data break requests on each cycle and allocates the facility to the peripheral with the highest priority, which can be allocated at installation time. Highest priority should be given to the device with the shortest latency time, where latency is defined by the maximum time which a device can wait for access to the computer memory before the data is lost. In the case of the television interface this time is the duration of the line blank time (12 μS) although it is preferable for the request to be granted almost immediately so that all data transfers can be completed within the line blank time. In the case of the disk there is a maximum latency time of 22.5 μS, because the disk has a 4 word data silo which can be emptied before data is lost. This silo is normally kept full during write operations. The television interface has therefore been given the highest priority. This interface is limited to transferring a maximum of 7 words during any one line blank period, there will then follow a period of at least 40 μS before there is likely to be another data break request from the interface. The time required to transfer the seven words would be 11.2 μS for a 1.6 μS cycle time; the disk data silo could therefore be half empty before a data break request by the interface, and still data would not be lost even if the interface transferred its maximum number of words.

Most of the PDP 12 instruction set can be used without any special consideration for the interface operation. However certain instructions should be avoided because of the short latency time of the interface. These instructions are those which use an extended cycle time such as the sample instruction SAM N when used in the normal mode (instruction time of 18.2 μS); this particular instruction can, however, be operated in a fast mode when it will only take 1.6 μS. Other instructions which should be avoided because of their long execution time are the Linc Tape instructions (unless the "No Pause" condition is enabled), and the relay buffer to accumulator instruction RTA. All other instructions, including all Input/Output instructions, can be used quite satisfactorily.

6.8 Recommended Modifications and Additions

One modification that should be made to the interface concerns the Address Register. Unless this is operating in the Double Buffer mode the register will address locations from the Initial Data Address (IDA) up to 32K (15 bits), and locations from zero upwards will be addressed as the register overflows. This only occurs under extreme or fault conditions (when excessively high data rates occur) when software protection may fail. Protection against this event occurring can be provided by hardware in one of two ways. Either the Co-ordinate Generator should be inhibited once the address limit of the computer is reached (16K at present) or it should be arranged to reset the Address Register to the contents of the IDA register on overflow.

The second modification concerns a re-designed calibration control to avoid the limitations discussed in section 6.4. The logic for this control is shown in Figure 6.21 and a timing diagram is in Figure 6.22. This logic simply enables the Co-ordinate Generator for 64 horizontal units at a time until the entire television field has been covered. Only five markers can be registered during any 64 unit period but only fault conditions are likely to cause this number of markers to occur during such a short period. The existing instruction set can still be used with this control, although a right hand margin cannot be set by software.

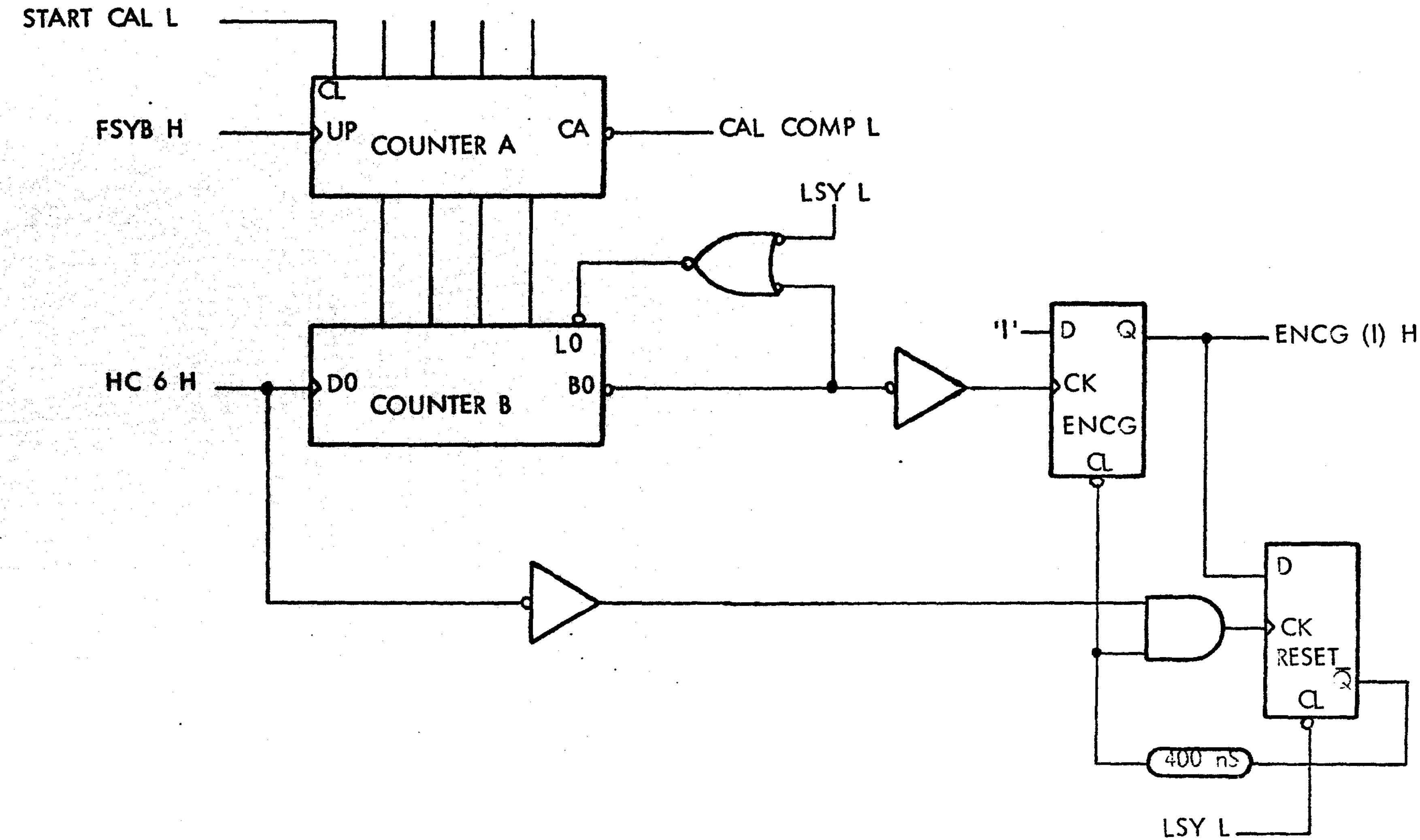


Figure 6.21. Calibration control logic.

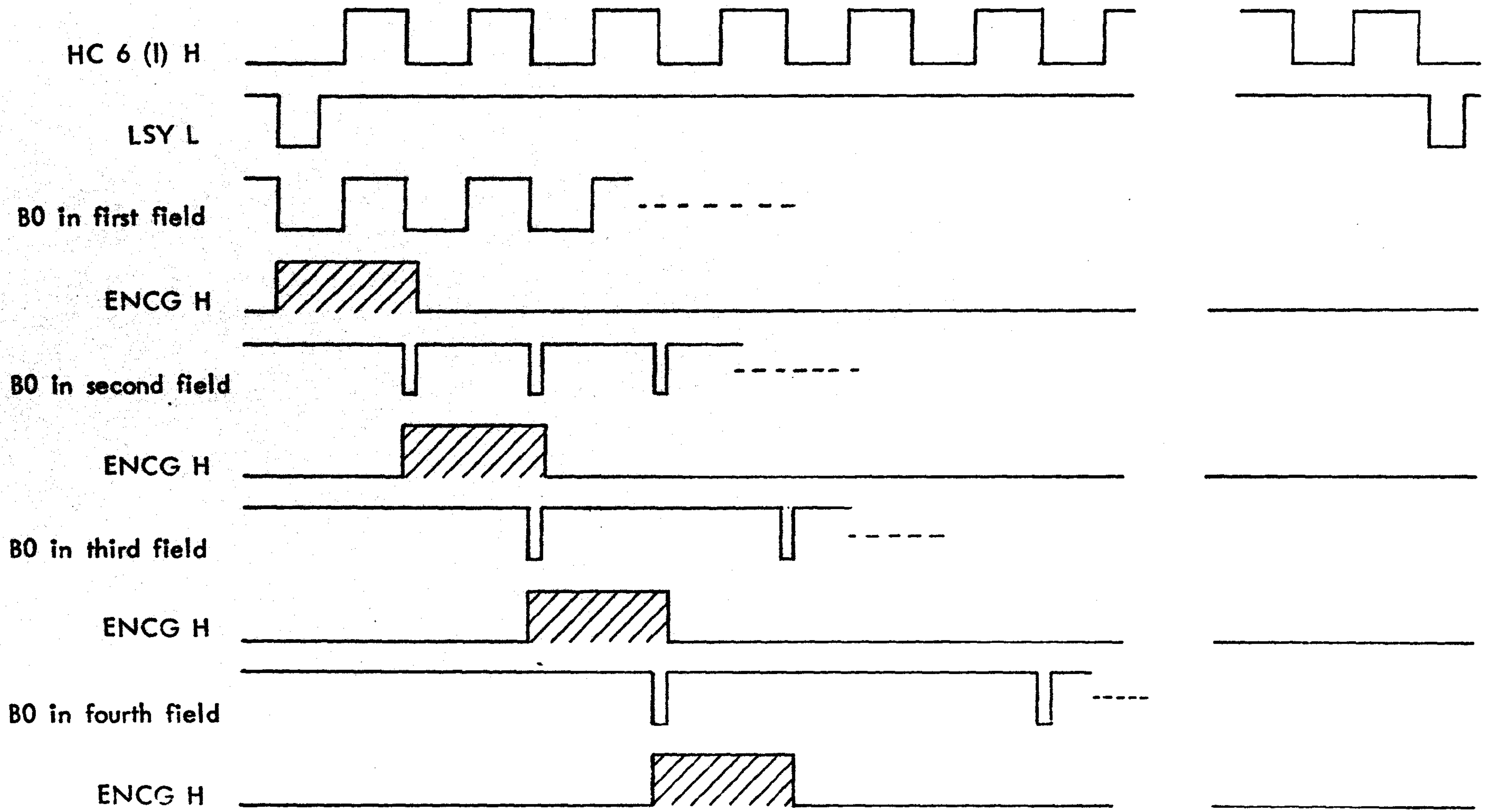


Figure 6.22. Timing diagram for calibration control of previous figure.

A recommended addition to the system is to use light activated switches (LAS's) to control data acquisition. These would be positioned at the start and end of the walk path (the area monitored by cameras), and just before the force plate to initiate data collection from this device. Switch inputs have been provided for this purpose in the interface and a noise immune switch such as that shown in Figure 6.23 could interface the LAS's to these inputs. Only a pulse of duration longer than 5 mS would give an output (SYNC H). The LAS marking the end of the walk path (which would inhibit the Co-ordinate Generator when activated) could also be used to generate an interrupt to the computer to signal the end of a test.

If this interface is to be implemented on other computers, or even on a PDP 12, it would be cheaper to use status and control registers for the hardware generation of software instructions. This method is discussed in Appendix A2.

6.9 Conclusions

The system that has been described here offers a means of automatically acquiring displacement/time measurements of human locomotion. Repeatable measurements can be obtained and it has been shown that co-ordinates can be generated for markers moving with relatively high velocities and accelerations, comparable with those reached during fast walking. The system is flexible in that up to six cameras can be used simultaneously in almost any position. Thus it is possible to obtain three dimensional measurements and cover several strides of the gait by appropriate positioning of the cameras. The only limitation in camera positioning is that the light source of a camera must not be in the field of view of any other camera. This is a limitation of the chosen marker system; if active light sources were used as markers then this limitation would not exist. Passive markers have been used throughout the testing procedures and found to perform adequately, this means that the test subject is not encumbered by connecting leads, power packs, or "strap on" markers. Normal room lighting can be left on during data acquisition. Markers can be positioned quite close to each other, although care must be taken where expected marker velocities and accelerations are high. The interface will generate synchronising pulses at a program selectable rate to control the

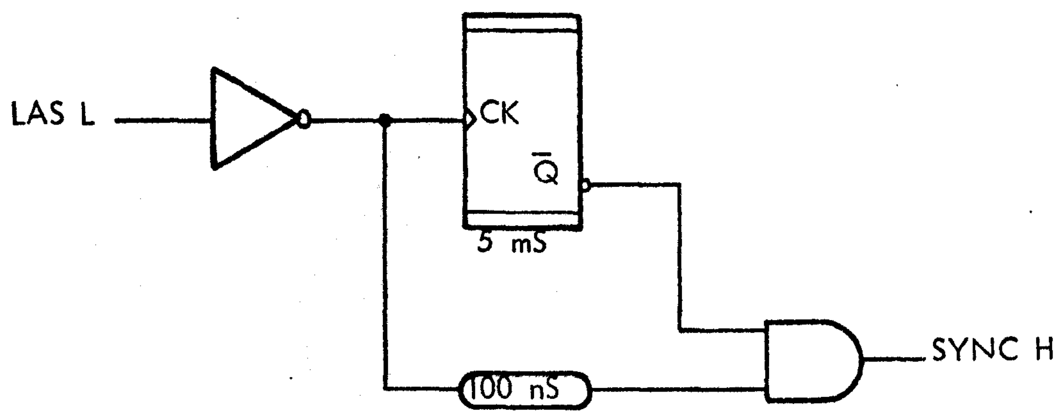


Figure 6.23. Logic for noise immune switch.

acquisition of data from other instrumentation, such as a force plate. A means of generating the co-ordinates of a calibration grid has been built in to the system. This will allow non-linearities to be corrected if the highest degree of accuracy is required. Measurement errors have been discussed and seen to be relatively small, the implications of these errors in biomechanical analyses are further discussed in Andrews (1976). The computation of other parameters from the displacement/time measurements, such as derivatives, is briefly discussed in Jarrett (1976) and more extensively in Andrews (1976).

The data rates generated by the system depend on the number of markers used and can be very high. This can be accommodated by double buffering the data onto disk storage; the facility to do this has been provided in the interface. Alternatively the data rate can be reduced by placing a rotating shutter in front of the camera lens to reduce the sampling period. This shutter also has the advantage of defining a consistent sampling instant, but requires the use of more expensive television cameras. The system can operate at lower sampling frequencies (down to 0.2 Hz), if this is acceptable for the motions being measured, which will reduce data rates considerably. The interface has been very reliable in use, no faults have arisen to date, but a built in marker pulse simulator will facilitate fault tracing. This simulator also allows a rapid check of system function and is useful in software development. It is clear that software must be designed on an interactive basis, preferably with extensive use of data display routines. Providing data rates are not too high it is possible to process incoming data in real time, the program DYDIS does this and produces a display of decoded data. Basic processing of the raw data can be adequately performed on a mini-computer such as a PDP 12. The identification of marker trajectories is made possible by the use of a simple linear extrapolation routine, manual intervention being required only to provide the first two data points.

All of the alternative systems have been extensively reviewed in Chapter I where their principal advantages and disadvantages were examined. Methods involving manual transcription of data, such as the use of cine film, are time consuming and prone to human error. Automated versions of these methods are costly, still require a lot of manual intervention and still suffer from the basic disadvantages of photographic media - such as slow turnaround from test to results. The systems of locomotion analysis which involve contact with the subject, such as goniometers, are generally undesirable because they may influence the gait. and their measurement ability is often limited. The other opto-electronic techniques such as SELSPOT (Selcom (1975)) and CODA (Mitchelson (1974 and 1975)) are powerful measurement systems. They can sample at higher frequencies than a television based system and, when fully developed, may offer higher resolving power. They can provide outputs in analogue form which is easy to store, or can be interfaced to a computer. Such interfacing would be similar in many respects to that required for the television system. However, these systems both require active light sources to indicate the anatomical landmarks and these sources must be switched on and off involving either trailing connecting wires or a telemetry link. Also the power of the presently available light sources which must be used (Light emitting diodes) is limited which puts constraints on the range of operation of the system.

The other television systems that have been developed are all limited in their performance capabilities in comparison with the system described here. At present none of them can use more than one camera simultaneously and their basic designs will make this extension difficult. None of the systems have been designed with the intention of collecting data from other measurement devices and consequently the ease with which this can be done is limited. The acquisition of the co-ordinates of a grid of calibration points has not been considered in any of the systems, except in the Dutch system (Ingen Schenau (1973)), but even this system was not purpose designed to take in the grid co-ordinates. The results of tests for stability and response to moving markers have been reported here but no similar tests have been reported for the other systems with which to make comparison.

The system will have applications both in the research laboratory and in the clinic. In the research situation it will be possible to conduct large numbers of tests with comparative ease. This has not been practicable in the past because of the time consuming manual interpretation that has been required to produce results for anything but the simplest of analyses (Jarrett (1974)). Also the research environment demands a system with some degree of flexibility, and especially the ability to acquire data from other transducers simultaneously. In the clinical situation the system offers a completely automated facility for data collection. The complexity of an analysis is variable - simple plots of change in segment angles may be derived, for instance, or data for a complete kinetic analysis could be collected. One of the most important advantages of this system in the clinical environment would be its non-contacting nature and also the complete silence of the system. Important areas of use in the clinic would be "before and after" studies of treatment regimes, identification of the "key" joint where several joints may be affected to varying degrees by a particular pathology, and in observing the different characteristics induced in the gait by an appliance.

6.10 Future Work

Research is currently in progress on methods of filtering co-ordinate data generated by systems such as the one described here, this research also includes investigations into digital differentiation schemes to derive velocities and accelerations (Andrews (1976)). This work will allow the data generated by this system to be used to provide a kinetic analysis of locomotion. The form of this analysis requires to be developed from existing work (Paul (1967), Morrison (1967), Poulson (1973)) to be compatible with suitable marker configurations for the television system. It will be advisable to structure this analysis in such a way that useful intermediate results can be obtained easily - to produce parallax corrected angle/angle diagrams for example. The incorporation of other measurement devices is seen as an important option to be built in to the analysis. These devices should include load measuring devices such as force plates (one or two), and pylon transducers; accelerometers; and possibly electromyograph recorders.

Presentation of data is an area which requires considerable investigation, the most promising direction would seem to be a graphically oriented one to make use of the outstanding pattern recognition abilities of the brain. Successful routine clinical use of a system, such as the one described here, will only be achieved when the resultant data can be presented in such a way that abnormalities in the gait can be easily and quickly recognised. If this is achieved then it may be possible to use a very basic model of mini-computer (with consequent economy) to collect and process data.

APPENDIX A.1.

BASIC PRINCIPLES OF TELEVISION

A1.1 Principles

In order to reproduce pictures which are acceptable to human vision television exploits a particular characteristic of the eye. This characteristic is known as "persistence of vision". The effect of this is that the eye perceives an image of a source for a certain period after the source has disappeared; a modulated source is, therefore, averaged by the eye. Experiment shows that it is necessary to project about 50 still shots of a moving scene, every second in order to allow the eye to average the pictures and reduce any flicker, due to changes, to an acceptable amount. It follows that a television system must scan the scene to be transmitted at least 50 times every second if flicker is to be acceptably low.

To represent a still picture in electrical form it is necessary that each level of brightness of the picture is specified by a unique and discrete electrical signal. This would require the picture to be broken up into an infinite number of elements each of which would have to be sampled, and allocated a value of electrical signal corresponding to its brightness. The whole array, for a moving scene, would have to be sampled 50 times every second to reproduce a picture acceptable to the eye. As usual a compromise is made and the picture is broken up into a finite number of elements which will produce a reasonably sharp picture at a bandwidth suitable for transmission. A modern, high definition, transmission system divides the picture into 300,000 to 400,000 picture elements and requires a bandwidth of several MegaHertz.

The signal levels corresponding to each element have to be transmitted sequentially. Practical television systems transmit the electrical signals corresponding to the picture elements starting at the top left hand corner of the picture. The signals corresponding to the top line of picture elements are first transmitted, then those comprising the next line, and so on until the whole picture has been transmitted; this process of transmitting a picture as a succession of horizontal lines is known as scanning. In conventional television systems scanning always starts from the left hand side of the scene, as viewed by the camera.

To convert the light signals into electrical signals a photosensitive surface is used. This surface, or target, varies in conductivity according to the intensity of light falling on it. The target is scanned by an electron beam which causes a current to flow in a signal plate, varying in magnitude according to the conductivity of the target. The current is passed through a signal resistor which develops a potential difference proportional to the current, this pd then being amplified. This system which applies to the vidicon and plumbicon pick up tubes is illustrated in Fig. AI.1. Other pick up systems exist, but they all work on similar principles.

AI.2 Scanning

The scanning of the electron beam is controlled by synchronising pulses. Deflection of the beam is accomplished by vertical and horizontal deflection coils which apply a magnetic field of varying strength across the path of the electron beam. As the electron beam passes through the magnetic field it is deflected at right angles to its direction of travel and to the direction of the field. The path followed by the electron beam in scanning the charge pattern on a camera target is shown in Figure AI.2. Starting at A the electron beam is made to travel horizontally at constant speed across the target to the right hand side; it then returns at a much greater speed and commences the next horizontal or line scan. The return traverse is known as the line flyback. Simultaneous to the line scan and flyback the electron beam is moved comparatively slowly and at constant speed downwards, the field scan. When the required number of lines has been scanned the electron beam is moved vertically back by the field flyback. Field synchronising pulses initiate field flyback and line synchronising pulses initiate line flyback.

To reduce the bandwidth required still further a system known as interlaced scanning is used. In this system the television camera transmits information in the same way as before, except that the complete picture is only scanned 25 times in every second. However to maintain the flicker below an obtrusive level each picture is scanned twice, the second scan taking place between the lines of the first scan. This technique is illustrated in Figure AI.3. Each complete scan is known as a field and there are thus

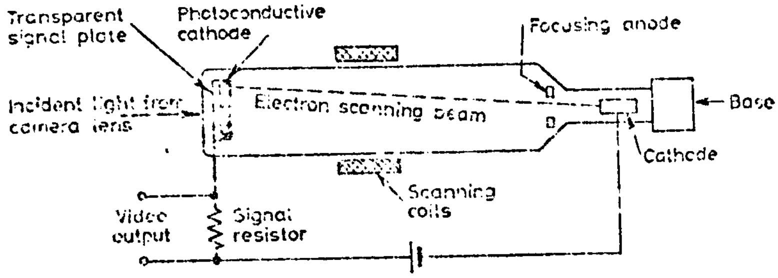


Figure A1.1. Camera pick up tube. (From Wharton (1967)).

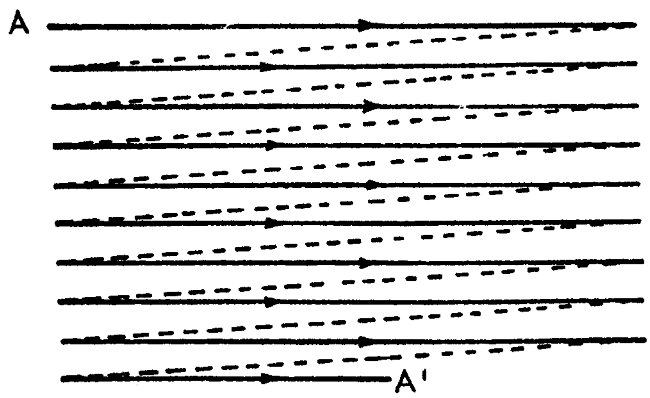


Figure A1.2. Scanning path

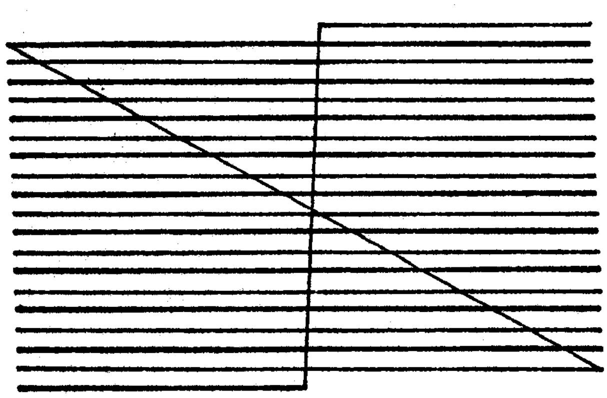


Figure A1.3. Interlaced scanning.

two types of field, "odd" and "even", interlaced to form a complete picture. The advantage of this system is that flicker, due to the succession of fields, is reduced by comparison with an equivalent sequentially scanned picture without an increase in bandwidth.

In the British system 625 lines are scanned in two fields. The number of active lines in each field is 292½, after accounting for those blanked during field flyback.

AI.3. Synchronisation

Field and line synchronising pulses are generated by a central sync pulse generator. They control the time characteristics of the camera scan, and the relationship between field and line syncs determines the interlace of odd and even fields. During line and field flyback the video signal is suppressed, an interval known as the blanking period. This means that a number of lines do not transmit video information between fields and that a certain portion of each line does not carry video information. The lines and proportion of each line which carry picture information are said to be "active".

The video output from the camera may also incorporate the synchronising pulses in which case it is referred to as "composite video". The composite waveform, showing details of the line sync pulses and line blanking is shown in Figure AI.4. The composite waveform showing details of the field syncs and blanking is shown in Figure AI.5. The equalizing pulses shown in the field sync waveform are not necessarily present in closed circuit systems. They are a refinement added to broadcast systems to reduce the effect of the half line which occurs at the end of alternate fields, just before the field sync pulse. This half line can impair the interlace of the receiver, by disturbing the field synchronisation. Also in closed circuit systems the field sync may be one pulse of about 160 μS duration, instead of five broad pulses.

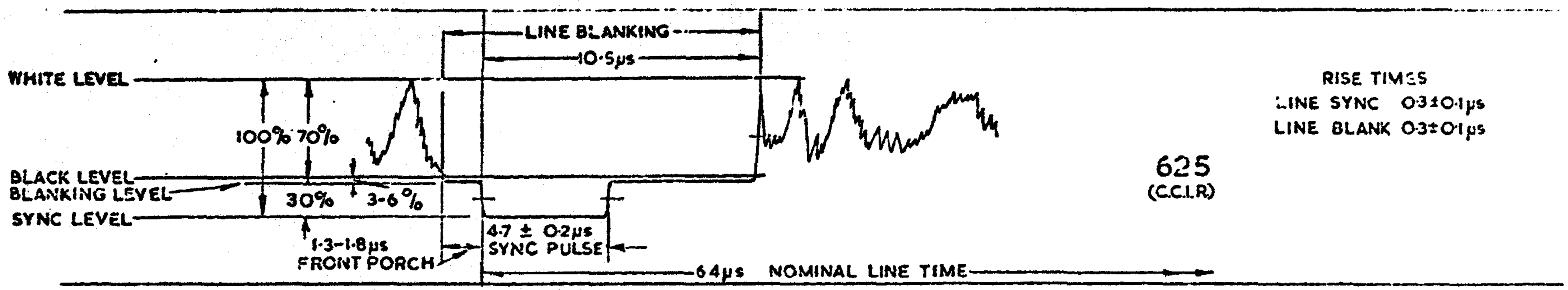


Figure A1.4. Line synchronisation waveform and blanking for the British 625 line television system (From Wharton (1967)).

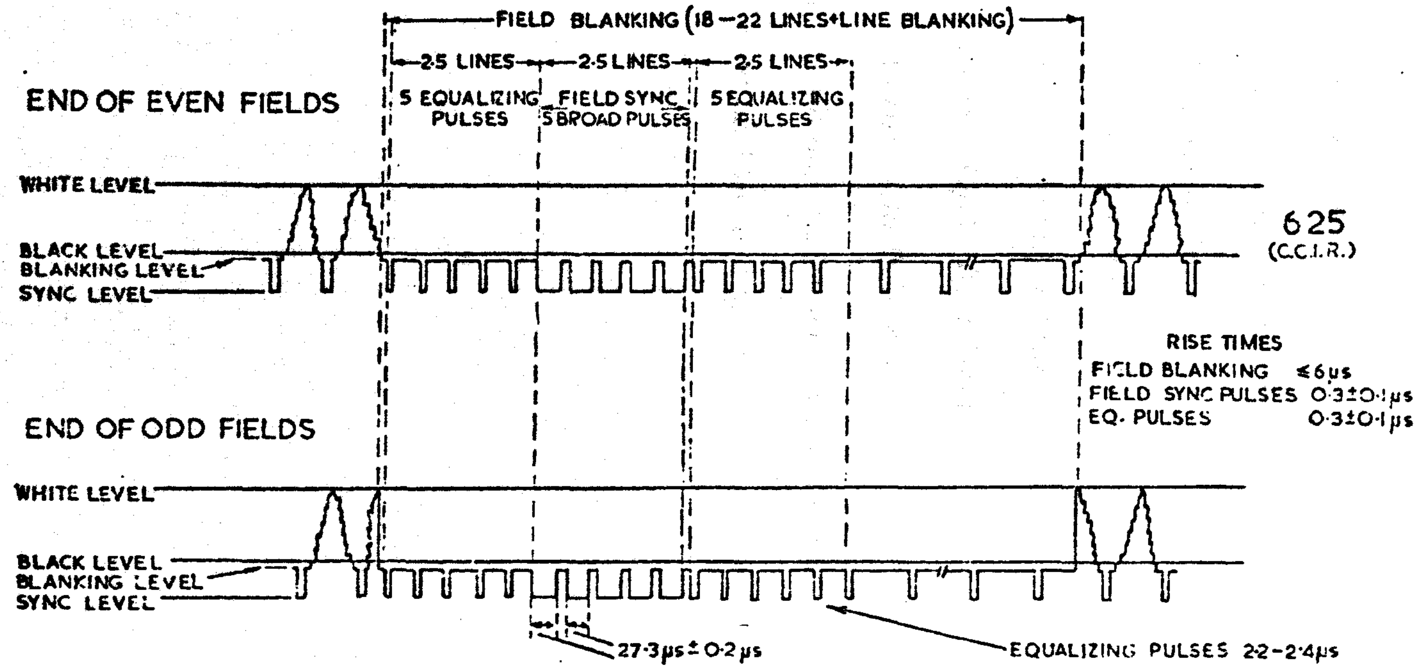


Figure AI.5. Field synchronisation pulses and blanking for the British 625 line television system (From Wharton (1967)).

APPENDIX A.2.

THE PDP 12 COMPUTER

A2.1 Introduction

The PDP 12 is a mini-computer designed for use in a laboratory environment. It is a 12 bit word length machine and can therefore basically address 4096 (4K) memory locations. An additional three address bits, the extended address, are provided to allow addressing of up to 32K of memory. The basic cycle time of the computer (the time taken to access and interpret one word from memory) is 1.6 μS, although certain instructions will extend this time. There is a 10 bit analogue to digital converter to which up to 32 channels can be multiplexed, and which is controlled by a programmable clock; eight of the channels are prewired to precision potentiometers. Magnetic tapes and disk provide the means of mass storage for data and programs. Six program controlled relays are also provided for control of external equipment. Communication with the computer is achieved via a teletype on the computer console switches. Data may be output on punched tape, on a graph plotter or displayed on a point plot visual display unit (grid dimensions 512 x 512 points).

Full details of the computer will be found in the reference and maintenance manuals (Digital (1970 and 1971)), however those aspects which directly concern the television interface will be briefly described here.

A2.2 Input/Output Transfer Instructions

The PDP 12 has two distinct modes of operation. LINC mode and PDP-8 mode, each of which has its own instruction set. The LINC mode instruction set includes instructions to control some peripheral devices such as LINC tape systems, the visual display unit, and the analogue to digital converter. Most peripherals and certainly any interface will be controlled by the Input/Output Transfer (IOT) class of instructions in the PDP-8 mode instruction set. A special LINC mode instruction, IOB, allows this class of instruction to be used in LINC mode programs without changing modes.

A2.2.1 Programmed Data Transfer

When an IOT class of instruction (6ØØØ) is decoded in the Central

Processor the computer enters a 4.25 μS expanded cycle, and enables the Input/Output Pulse (IOP) generator to produce time sequenced IOP pulses as determined by the three least significant bits of the instruction. A timing diagram for the IOP pulses is shown in Figure A2.1. These pulses are transmitted to all peripheral devices together with the contents of the Memory Buffer (MB) which holds the instruction. Figure A2.2 shows the function of each part of the IOT instruction. Bits 3-8 of the MB contents are transmitted to the peripheral devices in both (1) H and (0) H versions to simplify the logic required for decoding. This logic is shown in Figure A2.3 and gates the IOP pulses to the device when the appropriate code appears on the MB lines. The device code is assigned by wiring the appropriate MB lines to the inputs of the AND gate. In the example shown the device code is 31_8 ($11Ø1ØØ_2$). Any combination of the three IOP pulses can be generated depending on bits 9-11 of the instruction, therefore there can be up to 7 discrete instructions for any one device code. From one to three IOP pulses will be generated in each instruction; any device operation which requires a sequence of pulses can take advantage of this, and accomplish the sequence during one instruction. This type of operation can be used to advantage, for example, when loading a register with data may cause a flag to be set elsewhere in the interface; a second IOP pulse generated by the same instruction can be used to clear the flag without the need to resort to a second instruction.

Three other control lines are available for programmed data transfers. These are the Clear Accumulator, Skip and Interrupt Request lines (EXT AC CLEAR BUS L; EXT SKIP BUS L; and EXT INT RQST BUS L). The Clear Accumulator line is used when making data transfers from an interface to the accumulator. During each IOP data from the interface is strobed into the accumulator. This is done by making an inclusive "OR" of data already in the accumulator and data on the accumulator input lines. If there is no data from the interface or if the interface data is zero then the contents of the accumulator will remain unchanged. If it is desired to read the contents of an interface register then the accumulator must first be cleared. This

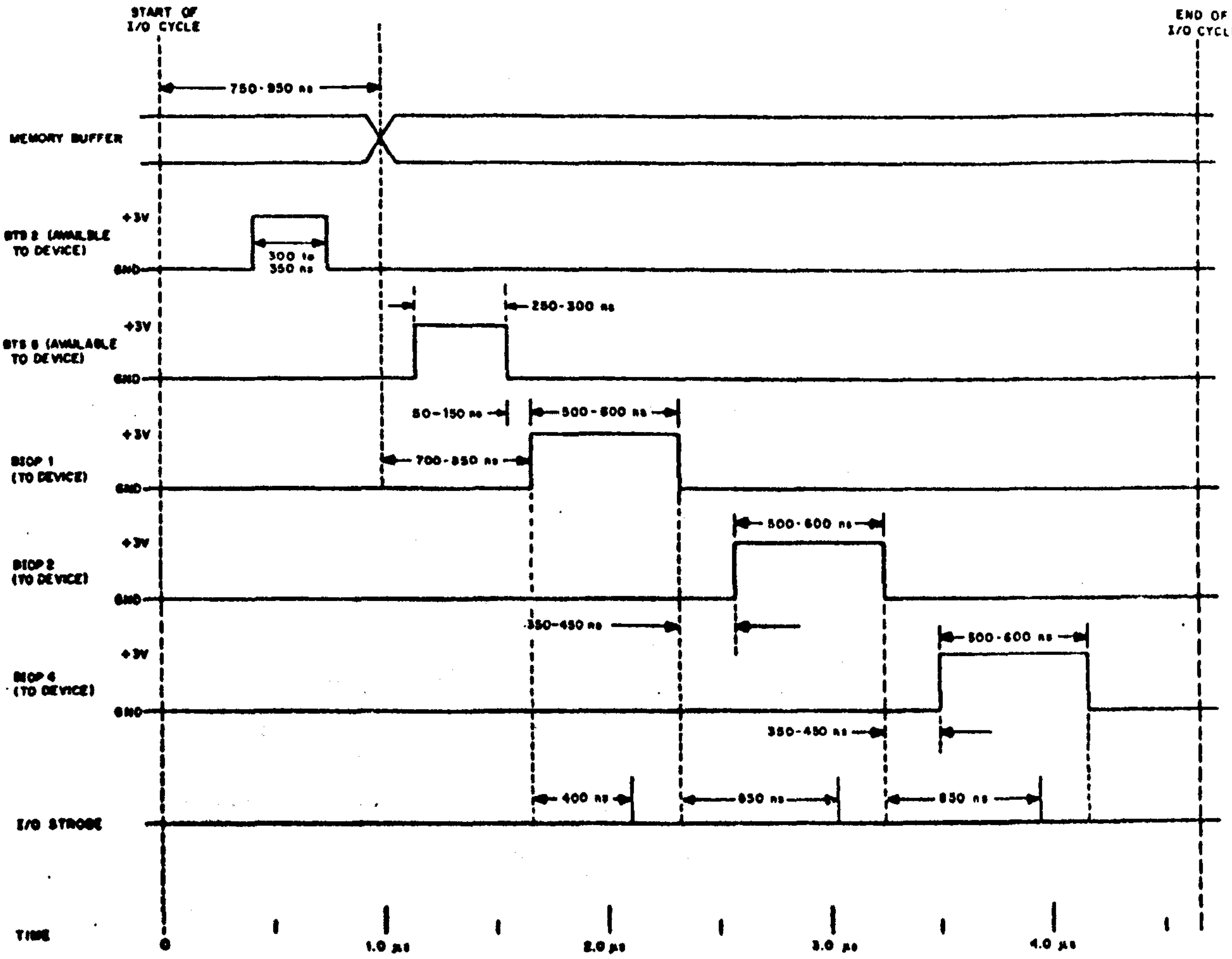


Figure A2.1. Programmed data transfer timing (from Digital (1970))

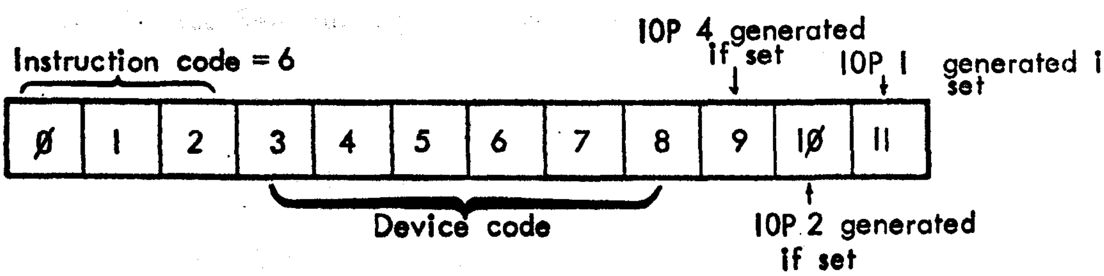


Figure A2.2. Bit functions for input/output transfer instructions.

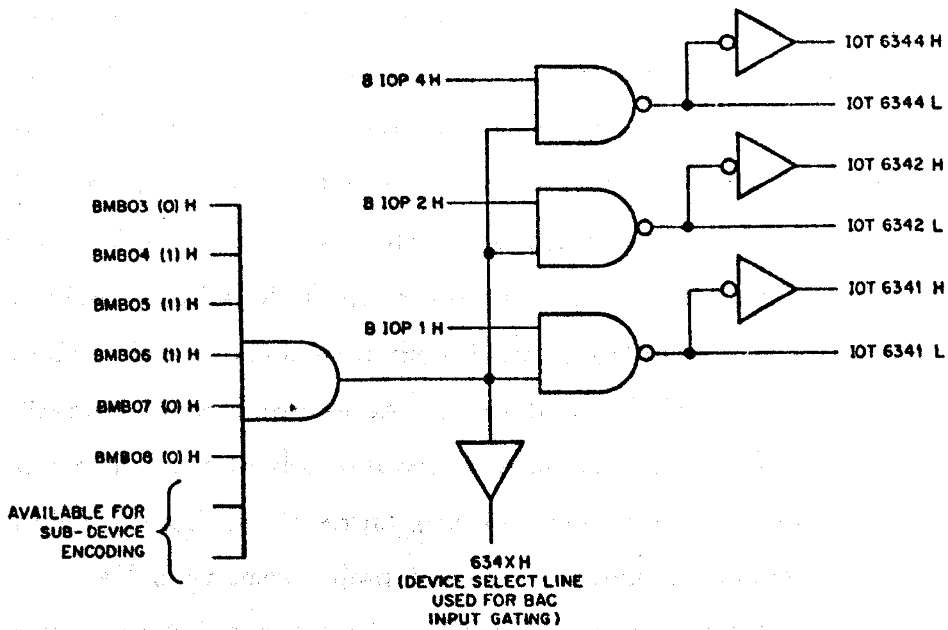


Figure A2.3. Device Selector logic. (From Digital (1971)).

can be done by the program, but it can also be done by using the clear accumulator line, which is preferable to avoid the possibility of programming errors. The Skip line allows the program to test the status of a flag in an interface. An IOP generated by an instruction will gate the status of the flag onto the Skip line, causing the next instruction in the program sequence to be skipped if the flag is set, (increments Program Counter). The Interrupt Request line will cause the current program to be interrupted if the interrupt facility of the computer is turned on (ION) and the interface pulls the line low. The computer will store the contents of the program counter in absolute memory location Ø if the processor is in PDP-8 mode or 4Ø if it is in LINC mode. The program will then jump to location 1 or 41, where it will be directed to an interrupt service routine. This routine will then test the status of flags in the external devices (using the Skip facility) to find out which caused the interrupt and will then take appropriate action.

All programmed data transfers between a device and the computer take place via the accumulator. Data in the accumulator is available on the [100] BAC Ø-11 lines; and data from a device is available to the accumulator on the [EXT] IO BUS Ø-11 lines. The initialize lines [100] BA and BB INITIALIZE H will be asserted whenever the computer power is switched on, the I/O Preset console switch is depressed, or when the I/O Preset Pulse is generated by program (Special Functions bit 6 set). The signal is used to clear all device flags and registers etcetera.

A2.2.2 Control and Status Registers

The methods of hardware instruction generation described above have been used in the television interface (see Chapter 4, Interface Logic - Instruction Generator I and Figure 4.22 for example). Usually each hardware operation is generated by a separate instruction; a great saving in components and the number of instructions used can be made by utilising status and control registers. Only two instructions are basically required; one to load the register and one to read it. The various status bits are set by the interface (such as "change buffer ½") and the control bits are set by data transfer from the computer (e.g. "Double Buffer mode"). Figure A2.4 shows how

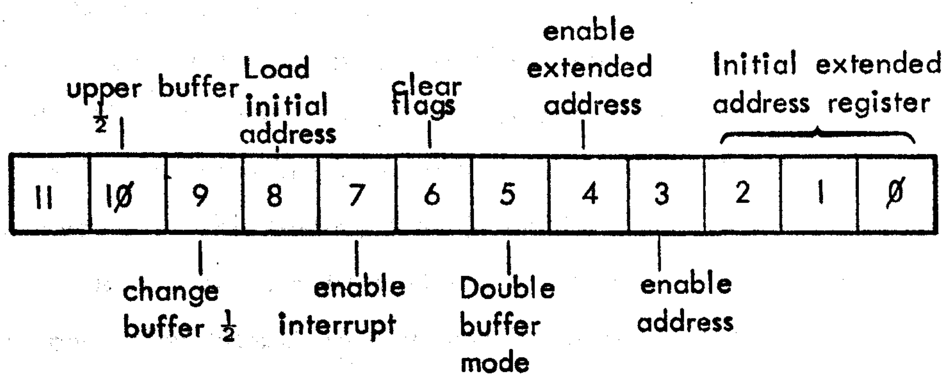


Figure A2.4. Status and control register for the address register instructions.

such a register might be used for some of the Address Register Instructions.

A2.3 Direct Memory Access

Direct memory access is provided in the PDP 12 on a cycle stealing basis by the Data Break Facility. When a break request is generated from an external device the computer completes the current instruction and then enters the "Break" state. The time required to enter this state is referred to as the latency of a break request and depends on the instruction currently being executed. This latency time is usually from 1.6 μS to 4.8 μS for three cycle instructions but can be anything up to 18.2 μS for some extended cycle instructions. The transfer of data can be either from or to the computer. To effect an input data break transfer the interface must specify the appropriate address in memory, provide the data word, indicate that transfer is to the computer, indicate whether 3 cycle or 1 cycle data break is required, and request a data break.

A2.3.1 Single Cycle Data Break

The timing diagram for input data transfers is shown in Figure A2.5. Data transfers to memory take place via the Memory Buffer to the location specified by the external data address lines. This address is provided by a 15 bit register in the interface and must be present on the address lines in anticipation of the data break cycle. When the address has been strobed into a central processor register the address accept pulse is generated and transmitted to the interface. This pulse is usually used to increment the interface address register in readiness for the next data transfer, and to clear the device break request flag if all data transfers will have been completed at the end of the current break cycle. If the break request flag is cleared before TP2 time of the cycle then the computer will return to normal programmed operation on completion of the data transfer. The B-BREAK signal is generated by the computer and remains low for the duration of data break transfers. The data to be transferred must be available on the external data lines by TP2 of the cycle and must not be removed until after TP3. The B-BREAK signal

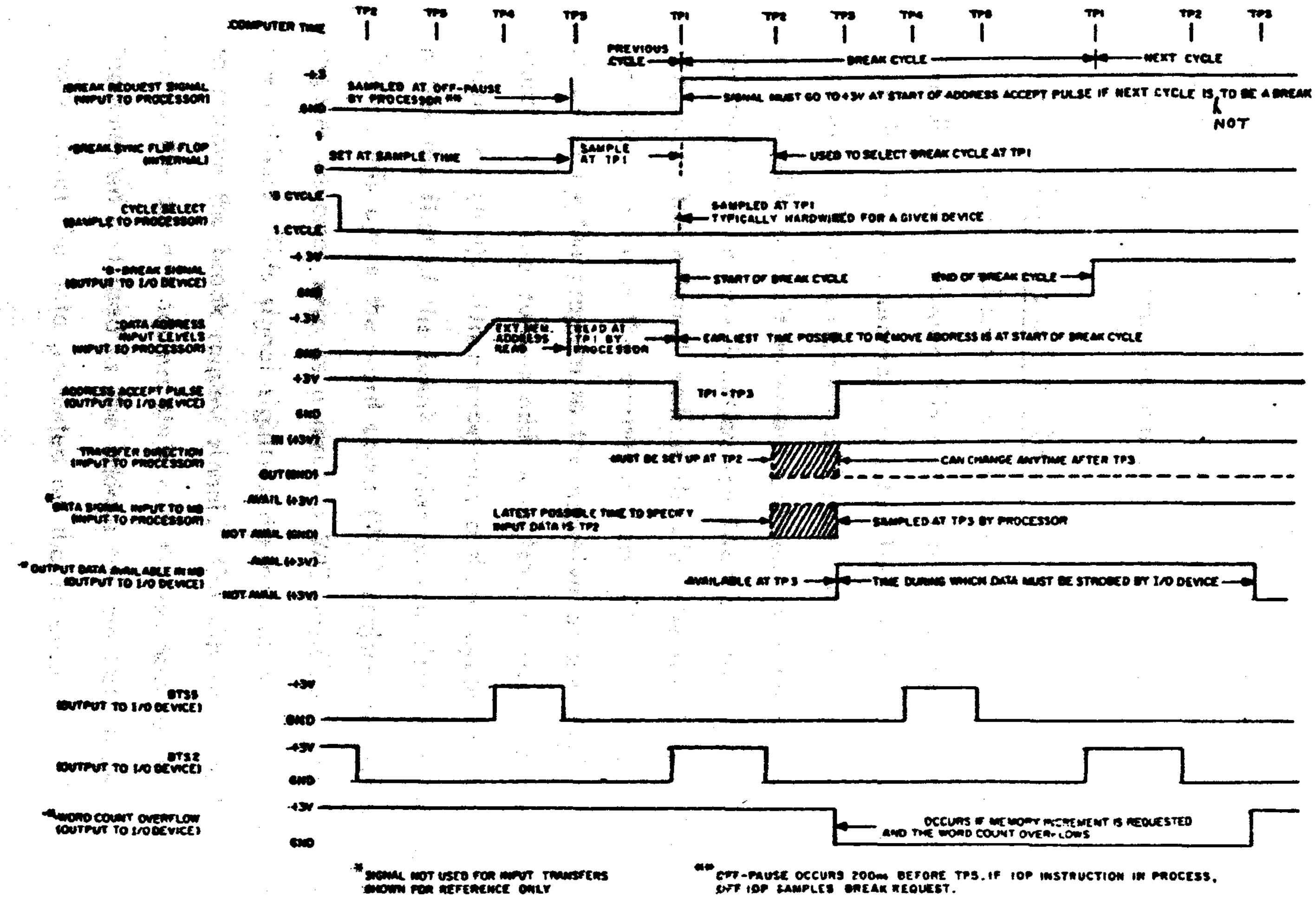


Figure A2.5. Single cycle data break input transfer timing diagram. (From Digital (1971)).

is useful as a data gating signal. BTS 5 and BTS 2 are "time state" signals generated by the computer, they are present on every cycle and must be gated with a data break control signal (e.g. B-BREAK) if they are to be used by the interface during data break cycles.

The initial conditions in the interface for single cycle data break transfers must be set up under program control. In the television interface the only conditions are the initial address for data transfers and the address register mode of operation. Usually an interface may also include a word count register which defines the number of data words to be transferred and is set up by program. In the television interface this register is set up automatically and depends on the number of markers detected.

A2.3.2 Three Cycle Data Break

The timing diagram for input or output transfers is shown in Figure A2.6. The difference between this method of data transfer and the previous one is that the computer provides registers for the current address and word count functions. If the extended addressing facility is to be used then the interface must provide a 3 bit extended address. The register used for the word count function is a memory location specified by the address (usually hard wired) placed on the external address lines by the interface. The next sequential memory location is the current address (CA) register. The word count register is preset by the program to the negative of the number of words to be transferred. The current address register is preset to the initial address minus one (A-l). Upon receiving a three cycle break request the computer enters the first of the break cycles on completion of the current instruction. During this cycle the word count (WC) register is incremented and if the register becomes zero as a result a WC overflow pulse is transmitted to the device. This signal signifies the end of a block transfer and is used to remove the break request signal. On the next break cycle the computer enters the current address state and the contents of the CA register are incremented and used as the address for the data transfer. The last break cycle stores the data presented on the external data lines by the interface

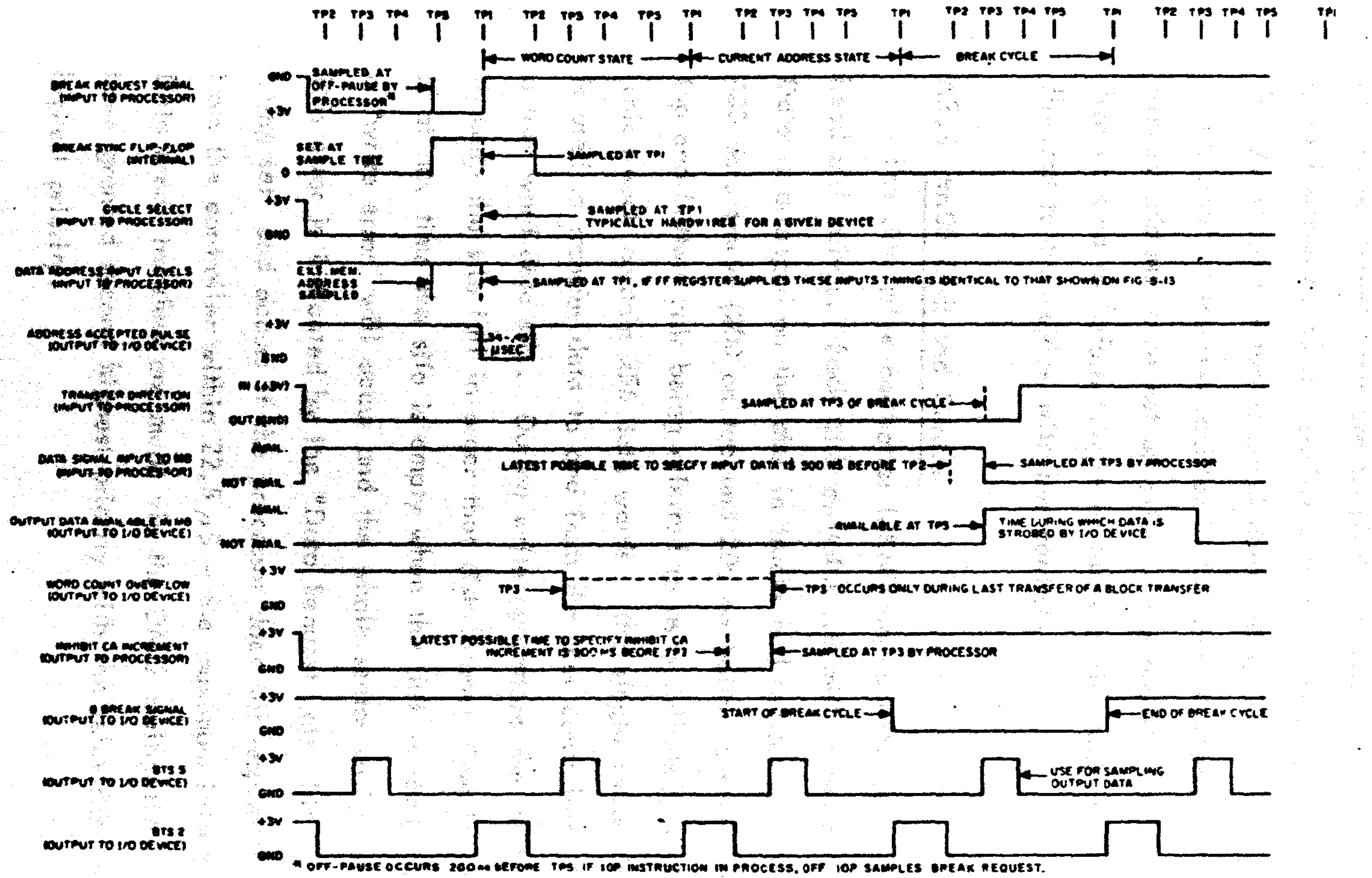


Figure A2.6. Three cycle data break timing diagram. (From Digital (1971)).

in the memory location specified by the CA register.

A2.3.3 Multiple use of the Data Break Facility

If more than one device requires the use of the data break facility then a multiplexer, the DM12, must be used. Separate cables are taken from the DM12 to each device for the data break control signals, the external data address, and the external data. Each device is allocated a priority and the break request lines are sampled, on every cycle, by the DM12 which gives bus control to the device with the highest priority requesting a break. On giving control the external data address lines of the device are gated to the Memory Address register in the central processor. This allows the memory address to be set up prior to the break cycle. The break cycle is then entered as before (single or three cycle) and all control signals are directed to the device with bus control.

A2.4 RK05 Disk and Control

The disk drive controller (RK8F) can control up to four RK05 moving head disk drives. Each disk contains 1.6 million words of data storage. Data is arranged on the disk in tracks and sectors of a track. There are 400 data tracks (200 on top and 200 on bottom surfaces of the disk, each top and bottom pair being referred to as a cylinder), divided into 16 sectors which each contain 256 data words. The single cycle data break facility is used to transfer data to and from the disk controller, in which there is a four word data silo. During write operations the controller endeavours to keep the silo full in order that disk latency time is kept at a maximum. If at any time the silo is empty when the disk is ready to accept data then a "write error" will occur and the whole sector will have to be re-written. This error is indicated by the "Data Request Late" bit in the status register being set, and occurs if the processor does not respond to a break request from the controller within 22.5 μS - the maximum latency time of the disk. Data break transfers are made via the DM12 multiplexer and the disk has been granted second highest priority with the television interface having the highest priority.

The transfer rate to or from disk is 8.32 μS per word, or 40 mS for a complete track of data (4096 words). Each sector of the disk contains, in addition to the data words, control sections and a header which provides a sector and cylinder address. Errors can arise in positioning the disk heads and this can be checked by comparing the disk cylinder address of a sector header with the cylinder address previously sent to the disk drive. If an address error is indicated then the disk heads must be returned to the home position (cylinder Ø) which is referred to as re-calibration, and the operation to find the required cylinder repeated.

In combining data transfers from the television interface and to the disk (double buffering) in order to obtain the maximum data rates it will be necessary to first of all position the disk heads on the required cylinder and then write 4096 data words (one track). On completion of this operation the disk heads will be moved to the next track (by the program) and a check of cylinder address carried out with re-calibration if required in readiness for the next 4096 word block transfer. Checking of data will be limited if the highest possible data rates are required.

The details of the RK05 disk and its controller given above are only meant to provide a pointer to combined operation with the television interface. Full details will be found for disk operation in the appropriate DEC manual.

APPENDIX A.3. COMPUTER PROGRAMS.

Interface Mnemonics

Real Time Display

Data Process

Calibration Data Acquisition

Calibration

Display Calibrated Data - DISC-CAL

DISF-CAL

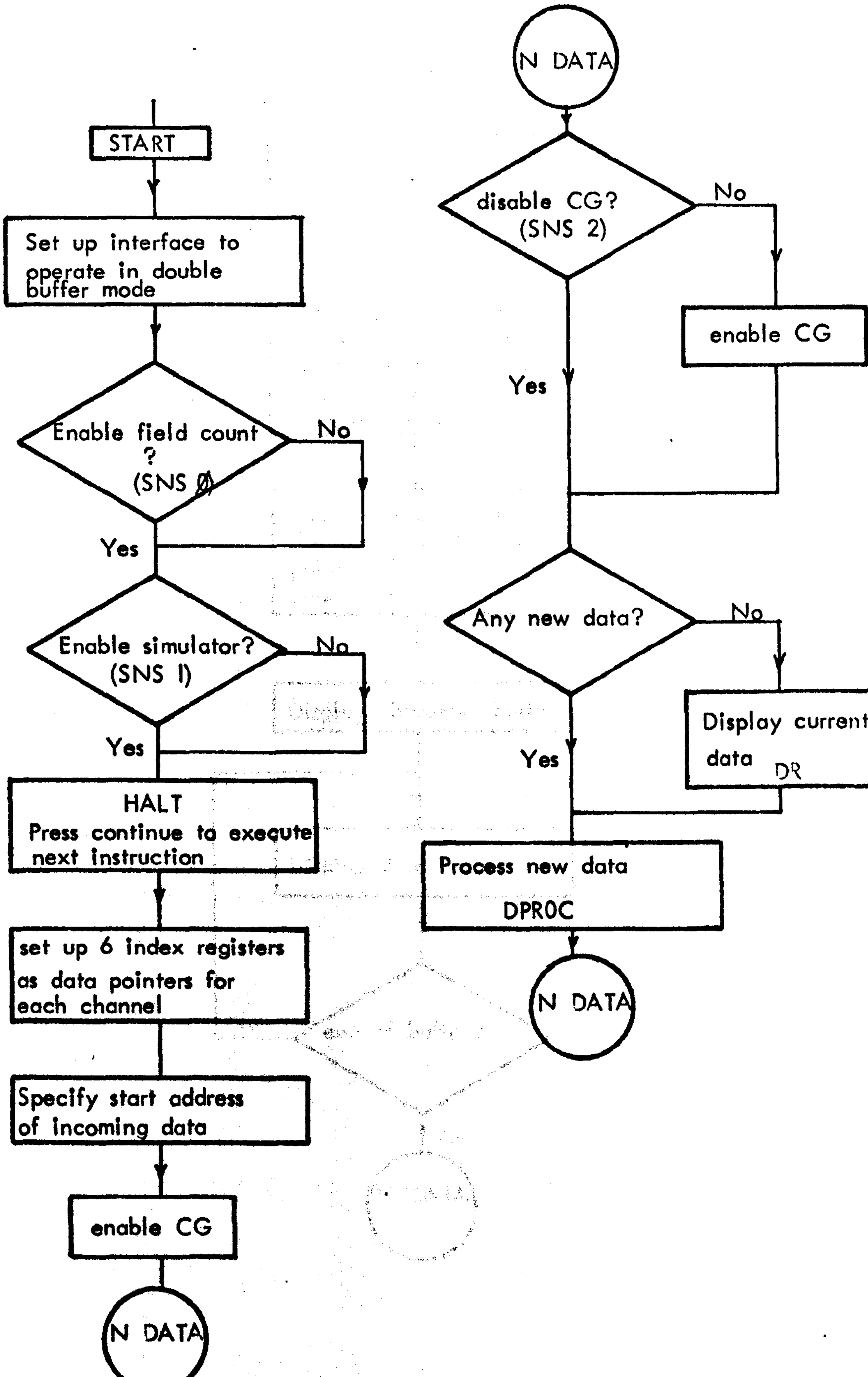
Display Interface Data - DISC

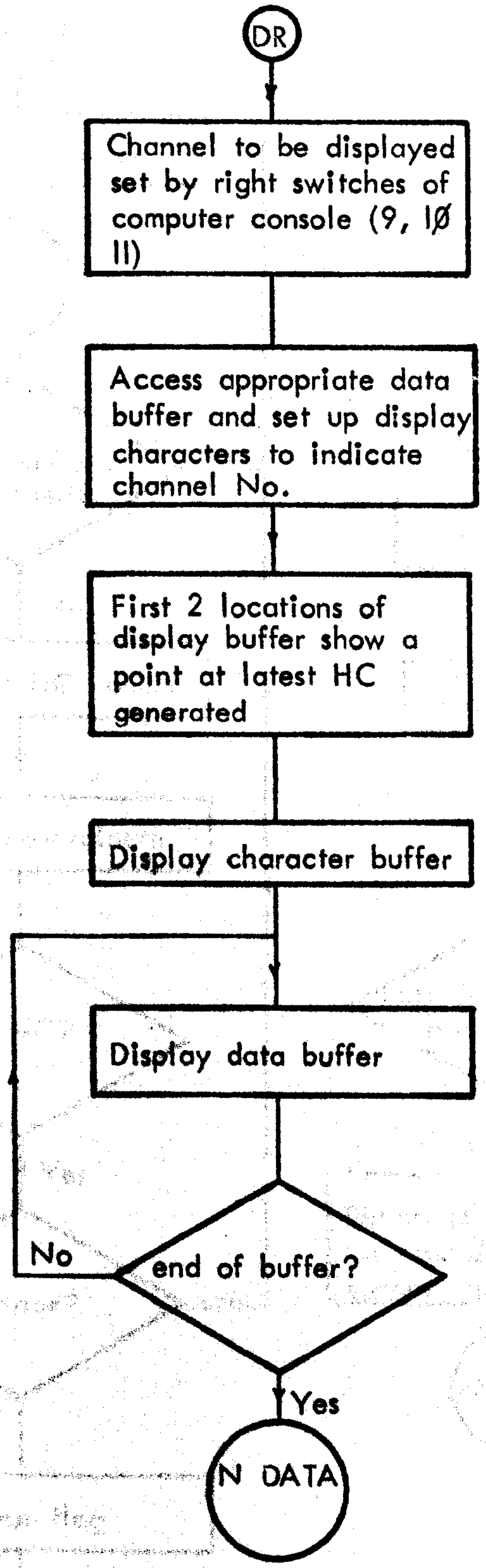
DISF

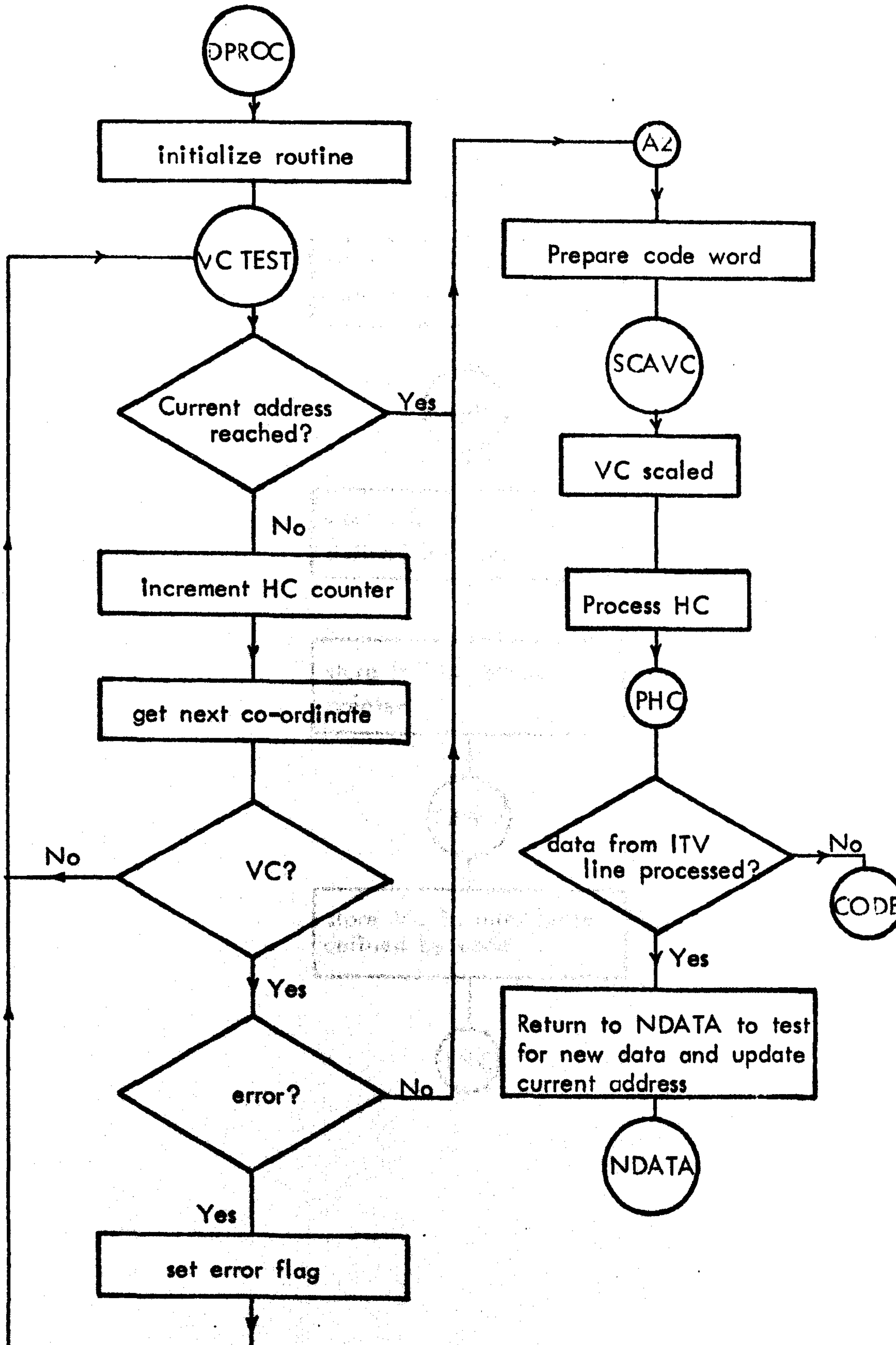
Display Grid Data - DISG

```
*20
/MNEMONICS FOR TV INTERFACE INSTRUCTIONS
/
/
/SOURCE VERSION IS CALLED "TVI-MN";IF SYMBOL
/TABLE IS LOST IT MAY BE REPLACED BY ADDING
/PROGRAM "TVI-MN" AND THEN ASSEMBLING,SYMBOL
/TABLE CONTAINING TVI MNEMONICS WILL THEN
/BE SAVED IN SAVSYM SYMBOL AREA ON TAPE ON
/UNIT 1.
/A TAPE CONTAINING THIS SAVED SYMBOL TABLE MUST
/BE USED IN CONJUNCTION WITH THE LODSYM
/COMMAND WHEN WRITING PROGRAMS CONTAINING
/TVI MNEMONICS.
/
/
/WHEN WRITING PROGRAMS USING THESE
/MNEMONICS A LODSYM PSEUDO-OPERATOR
/COMMAND IS USED AT THE BEGINNING OF
/THE PROGRAM TO BRING THEM INTO THE
/SYMBOL TABLE.
/
/
/
/CAL INSTRUCTIONS
        ENMON=6301      /SET MONITOR O/P FF
        LDCAM=6302      /LD BH MARGIN
        CAGO=6303       /CAL GO,CL FLAG,SET
/                       MONITOR O/P FF; SET
/                       CAL MODE FF.
        CLCAL=6304      /CLEAR ALL CAL FF.
        CAGOFR=6305     /CAL GO FREE RUN,SET
/                       MONITOR O/P FF, SET
/                       FREE RUN FF, CLR FLAG
        CCAFL=6306      /CLR CAL COMPLETE FLAG
        SCAC=6307       /SKIP IF CAL COMPLETE
/                       FLAG SET,CLR FLAG.
/
/
/SGS INSTRUCTIONS
        LDFC=6311       /LD FIELD COUNT
        LDLC=6312       /LD LINE COUNT
        ENFC=6313       /ENABLE FIELD CNT
        ENSM=6314       /ENABLE SIMULATOR
        CFC=6315        /CLEAR FIELD CNT
        CSM=6316        /CLEAR SIMULATOR
/
/
/CG INSTRUCTIONS
        ENCG=6321       /ENABLE CG
        DISCG=6322      /DISABLE CG
/
/
/ADDR INSTRUCTIONS
        ENAD=6331       /ENABLE MEMORY ADD
        ENFAD=6332      /ENABLE FIELD ADD
        LDCA=6333       /LD COMPOSITE ADDR
        CLAD=6334       /DISABLE ADD, FADD
        RCA=6335        /READ CURRENT MEMORY
/                       ADDRESS.
        RCFA=6336       /READ CURRENT FIELD
/                       ADDRESS.
/
/
/ADDR INSTRUCTIONS (CONT)
        DBM=6341        /DOUBLE BUFFER MODE
        CDBM=6342       /CLEAR DBFM
        ENDBI=6343      /ENABLE DBFM INT
        CDBI=6344       /DISABLE DBFM INT
        SCBH=6345       /SKIP IF CHANGE BUFFER
/                       HALF FLAG IS SET.
        SUBH=6346       /SKIP IF UPPER BUFFER
/                       HALF IS BEING FILLED
        CDBF=6347       /CLEAR UPPER HALF FLAG
/
/
/
/
/IO INIT CLEARS ALL FLAGS AND MODE FF,ALL
/INTERRUPTS ARE DISABLED
/
/
/4.8 US REQUIRED FOR EACH INSTRUCTION IN
/PMODE.
/
/
/
/
        SAVSYM 1

NO ERRORS, NO BINARY OUTPUT

CAGO    6303
CAGOFR  6305
CCAFL   6306
CDBF    6347
CDBI    6344
CDBM    6342
CFC     6315
CLAD    6334
CLCAL   6304
CSM     6316
DBM     6341
DISCG   6322
ENAD    6331
ENCG    6321
ENDBI   6343
ENFAD   6332
ENFC    6313
ENMON   6301
ENSM    6314
LDCA    6333
LDCAM   6302
LDFC    6311
LDLC    6312
RCA     6335
RCFA    6336
SCAC    6307
SCBH    6345
SUBH    6346
```

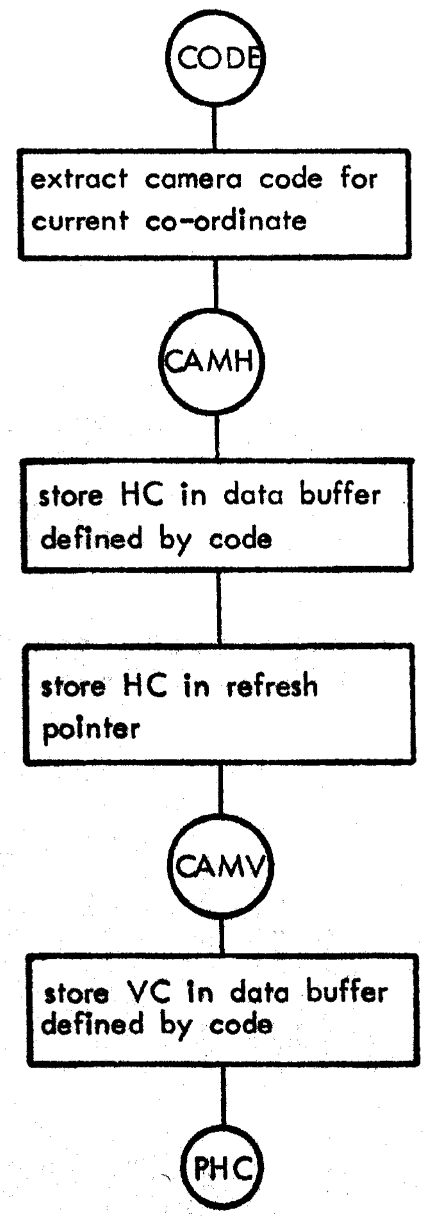
Flow chart for real time display program (DYDIS)




DR
Channel to be displayed set by right switches of computer console (9, 1Ø 11)
Access appropriate data buffer and set up display characters to indicate channel No.
First 2 locations of display buffer show a point at latest HC generated
Display character buffer
Display data buffer
end of buffer?
No
Yes
N DATA



DPROC
initialize routine
VC TEST
Current address reached?
Yes
No
Increment HC counter
get next co-ordinate
VC?
No
Yes
error?
No
Yes
set error flag
A2
Prepare code word
SCAVC
VC scaled
Process HC
PHC
data from ITV line processed?
No
CODE
Yes
Return to NDATA to test for new data and update current address
NDATA


CODE
extract camera code for current co-ordinate
CAMH
store HC in data buffer defined by code
store HC in refresh pointer
CAMV
store VC in data buffer defined by code
PHC

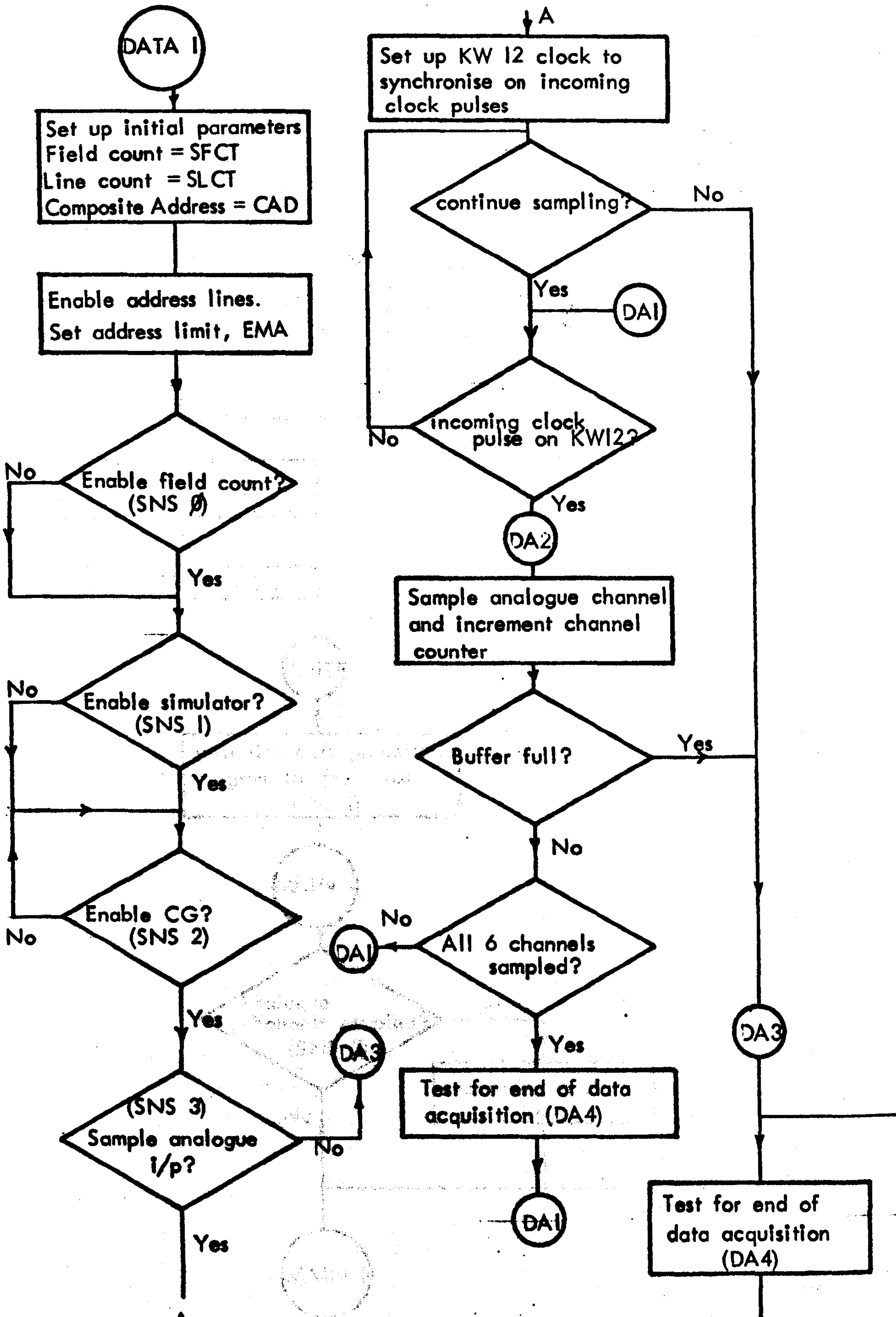
```
                        *20
                        /DYDIS - DYNAMIC DISPLAY.
                        /
                        /
                        /4-2-76
                        /
                        /
                        /M.O.JARRETT.
                        /
                        /
                        /DISPLAYS DATA AS IT IS RECEIVED FROM THE
                        /TV INTERFACE. ANY OF THE 6 CHANNELS MAY BE
                        /DISPLAYED.
                        /
                        /
                        /8-MODE, I/O PRESET, START 400.
                        /
                        /
                                LODSYM
                        /
                        /
                        /
                        /
                        /
                                PMODE
                                *400
0400  6002                      IOF
0401  6322                      DISCG
0402  7300                      CLA CLL
0403  3100                      DCA COUNT       /SET MEM COUNT=0
0404  7040                      CMA
0405  3013                      DCA AUTO        /SET ADDR=7777
0406  6211                      CDF 10          /DATA FIELD=1
0407  7240                      STA             /AC=7777
0410  3413                      DCA I AUTO      /FILL STORE 7777
0411  2100                      ISZ COUNT       /MEM FULL?
0412  5207                      JMP .-3         /NO
0413  7240                      STA             /YES
0414  3013                      DCA AUTO        /SET ADDR=7777
0415  6221                      CDF 20          /DATA FIELD=2
0416  7240                      STA
0417  3413                      DCA I AUTO
0420  2100                      ISZ COUNT       /MEM FULL?
0421  5216                      JMP .-3         /NO
0422  1104                      TAD CALDR
0423  6333                      LDCA            /COMPOSITE ADDR LOADE
                        D
0424  7200                      CLA
0425  1020                      TAD FCOUNT
0426  6311                      LDFC            /LOAD FIELD COUNT
0427  7200                      CLA
0430  1021                      TAD LCOUNT
0431  6312                      LDLC            /LOAD LINE COUNT
0432  6331                      ENAD            /ENABLE ADDR
0433  6332                      ENFAD           /ENABLE FIELD ADDR
0434  6341                      DBM             /DOUBLE BUFFER MODE
0435  6141                      LINC
                                LMODE
0436  0440                      SNS 0
0437  6442                      JMP .+3         /NO
0440  0500                      IOB             /YES
0441  6313                      ENFC            /ENABLE FIELD COUNT
0442  0441                      SNS 1
0443  6446                      JMP .+3         /NO
0444  0500                      IOB             /YES
0445  6314                      ENSM            /ENABLE SIMULATOR
0446  0000                      HLT
                        /
                        /
                        /
                        /
                        /
                        /
                        /
0447  0070                      SET I 10
0450  3777                      3777
0451  0071                      SET I 11
0452  3777                      3777
0453  0072                      SET I 12
0454  3777                      3777
0455  0073                      SET I 13
0456  3777                      3777
0457  0074                      SET I 14
0460  3777                      3777
0461  0075                      SET I 15
0462  3777                      3777
0463  1020                      LDA I
0464  6000                      6000
0465  4003                      STC BSTAD       /STORE START ADDR
0466  0500                      IOB
0467  6321                      ENCG            /ENABLE CG
0470  0653              NDATA,  LDF 13
0471  0442                      SNS 2
0472  6476                      JMP .+4
0473  0500                      IOB
0474  6322                      DISCG
0475  6500                      JMP .+3
0476  0540                      IOB
0477  6321                      ENCG
0500  0500                      IOB
0501  6335                      RCA             /READ CURRENT ADDR
0502  1620                      RSW I
0503  6000                      6000
0504  1040                      STA
0505  0105                      CAD
0506  0017                      COM
0507  2003                      ADD BSTAD
0510  0450                      AZE             /NEW DATA?
0511  6613                      JMP DPROC       /YES
0512  0011              DR,     CLR             /NO,ENTER DISPLAY ROU
                        TINE
0513  0516                      RSW             /WHICH CHANNEL?
0514  1560                      RCL I
0515  7770                      7770
0516  1040                      STA
0517  0546                      MARKD
0520  1120                      ADA I
0521  0643                      0643            /CREATES LDF N
0522  4542                      STC DFL
0523  1000                      LDA
0524  0546                      MARKD
0525  1120                      ADA I
0526  0220                      220
0527  1040                      STA
```

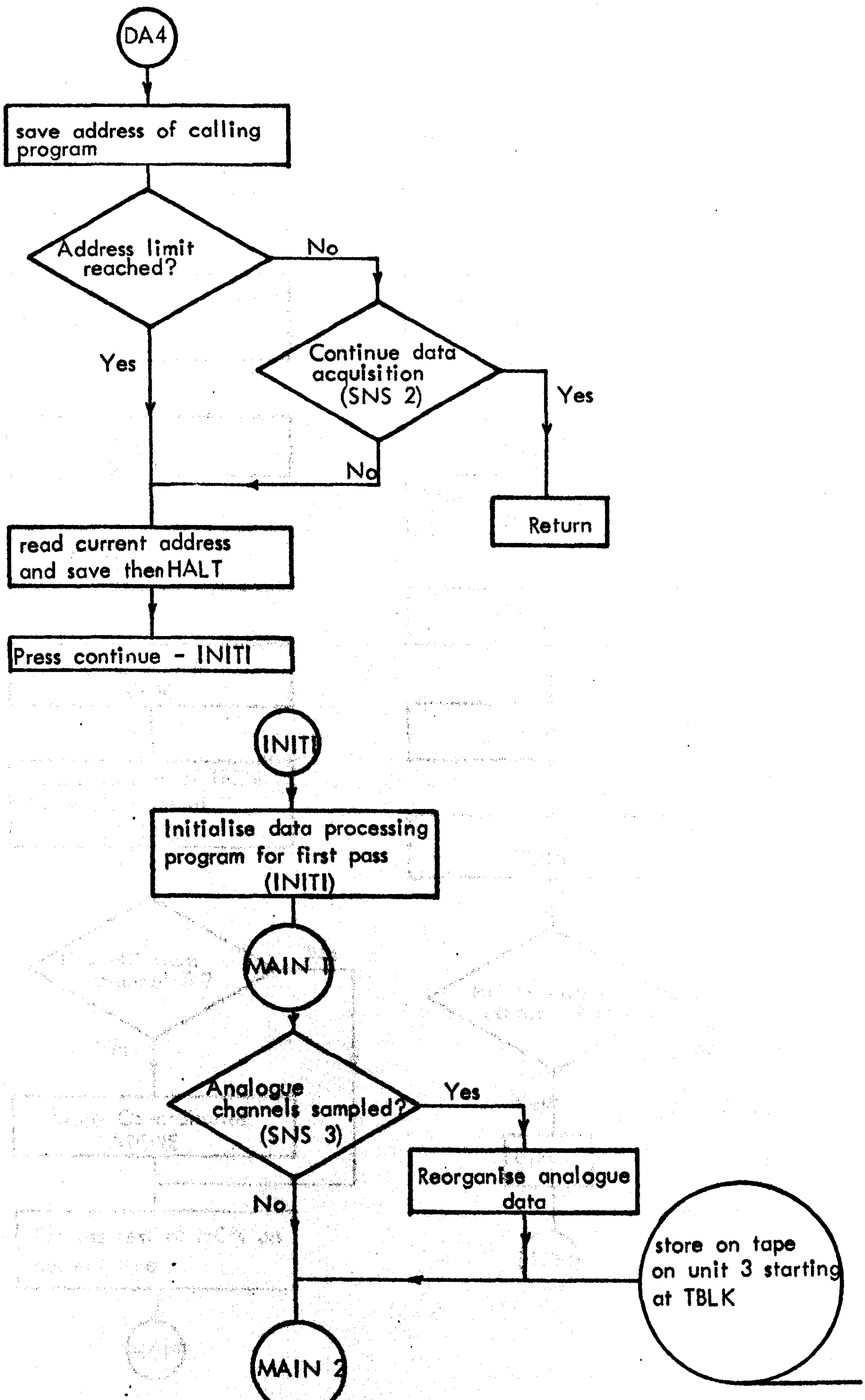
```
0530  0535            WORD1
0531  1120            ALA I
0532  0010            10
0533  4540            STC WORD2
0534  1000            LDA
0535  0000  WORD1,    0000
0536  4212            STC DW1
0537  1000            LDA
0540  0000  WORD2,    0000
0541  4213            STC DW2
0542  0644  DFD,      LDF 4              /LDF N
0543  1020            LDA I
0544  0023            23
0545  1120            ADA I
0546  0000  MARKD,    0000
0547  1040            STA
0550  0552            POINT
0551  1000            LDA
0552  0000  POINT,    0000
0553  1040            STA                /CURRENT HC TO FIRST
            LOC
0554  2000            2000
0555  0011            CLR
0556  1120            ADA I
0557  7400            -377
0560  1040            STA                /FIXED VC TO SECOND L
            OC
0561  2001            2001
0562  1020            LDA I
0563  3777            3777
0564  4036            STC DC
0565  0377            SET I 17
0566  0177            177
0567  0061            SET I 1
0570  0000            0
0571  0076            SET I 16
0572  7763            -14
0573  1020            LDA I
0574  7400            7400
0575  1777  CDIS,     DSC I 17
0576  0236            XSK I 16
0577  6575            JMP .-2
0600  1026  DISP,     LDA I DC
0601  0341            SCR 1
0602  1560            BCL I
0603  7000            7000
0604  4007            STC D
0605  0226            XSK I DC           /END OF BUFFER ?

0606  0456            SKP                /NO
0607  6470            JMP NDATA          /YES
0610  1006            LDA DC             /LOADS VC
0611  0147            DIS D
0612  6600            JMP DISP
            /
            /
            /
            /
            /
            /
            /
            /
0613  0653  DPROC,    LDF 13             /DATA FIELD=13
0614  0376            SET I 16
0615  0000            0
0616  1003            LDA BSTAD
0617  4101            STC VC             /VC STORED
0620  1000            LDA
0621  0003            BSTAD
0622  4002            STC B2             /START ADDR TO B2
0623  1000  VCTEST,   LDA
0624  0002            B2
0625  1440            SAE                /CURRENT ADDR?
0626  0105            CAD
0627  0456            SKP                /NO
0630  6655            JMP A2             /YES
0631  0236            XSK I 16
0632  1022            LDA I B2           /GET NEXT COORD
0633  1560            BCL I
0634  1777            1777
0635  1460            SAE I
0636  6000            6000               /VC?
0637  6623            JMP VCTEST         /NO
0640  1000            LDA                /YES
0641  0002            B2
0642  1120            ADA I
0643  7776            -1
0644  1620            BSE I
0645  6000            6000
0646  1440            SAE
0647  0003            BSTAD              /ERROR?
0650  6655            JMP A2
0651  1020            LDA I
0652  7000            7000
0653  4103            STC FLAG           /SET ERROR FLAG
0654  6623            JMP VCTEST
0655  1000  A2,       LDA
0656  0002            B2
0657  1120            ADA I
0660  7776            -1
0661  1620            BSE I
0662  6000            6000
0663  4004            STC BSR            /SR WORD ADDR
0664  2016            ADD 16
0665  0017            COM
0666  1120            ADA I
0667  0256            0256               /ROL N FORMED
0670  4672            STC .+2
0671  1004            LDA BSR
0672  0000            0000               /ROL N
0673  1044            STA BSR
0674  1000  SCAVC,    LDA
0675  0004            BSR
0676  4005            STC BHC            /HC ADDR+1
0677  1000            LDA
0700  0101            VC
0701  1560            BCL I
0702  6000            6000
0703  1120            ADA I
0704  7307            -470
0705  0471            APO I              /ODD OR EVEN FIELD?
0706  6711            JMP .+3
0707  1120            ADA I
0710  0470            470
0711  1120            ADA I
0712  7577            -200
```

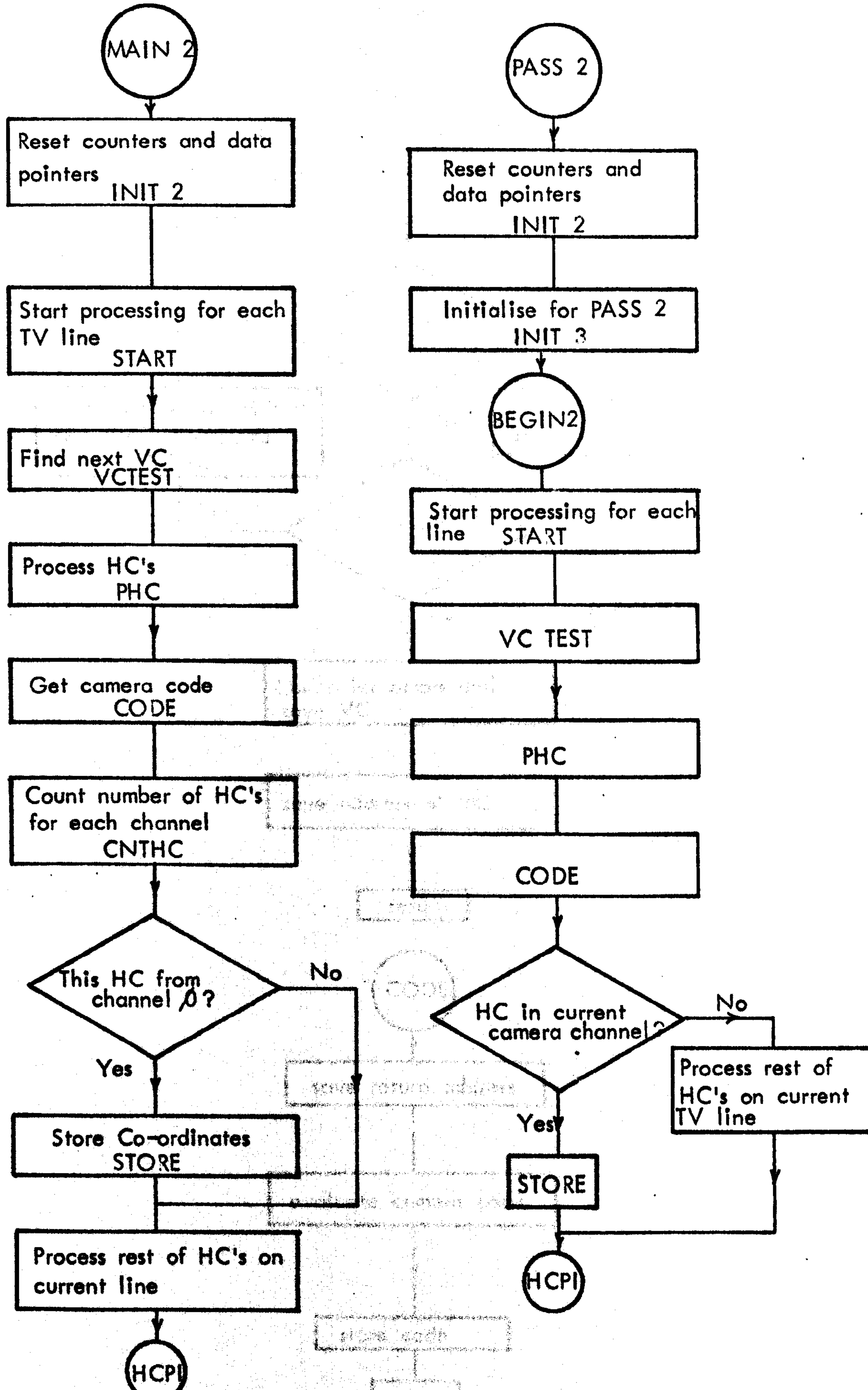
```
0713  0017            COM           /INVERT
0714  1560            RCL I
0715  7000            7000.
0716  1040            STA           /REPLACE SCALED VC
0717  0101            VC
0720  1000  PHC,      LDA           /PROCESS HC
0721  0305            BHC
0722  1120            ADA I
0723  7776            -1
0724  1620            BSE I
0725  6000            6000
0726  1040            STA
0727  0305            BHC           /HC ADDR
0730  1443            SAE
0731  0303            BSTAD         /BHC=BSTAD?
0732  6737            JMP CODE      /NO
0733  1000            LDA           /YES
0734  0302            B2
0735  4043            STC BSTAD     /UPDATE START ADDR
0736  6470            JMP NDATA
0737  1004  CODE,     LDA BSR       /SR WORD TO AC
0740  0261            ROL I 1
0741  1044            STA BSR       /REPLACE SR WORD
0742  1305            LDA BHC
0743  1040            STA
0744  0102            HC
0745  0312            ROR 12
0746  0261            ROL I 1
0747  1560            RCL I         /CAMERA CODE
0750  7770            7770
0751  1040            STA
0752  0762            CAMCO
0753  1040            STA
0754  0776            MARK
0755  1120            ADA I
0756  0643            0643          /CREATE LDF N
0757  4760            STC DF
0760  0647  DF,       LDF 7         /LDF N
0761  1120            ADA I
0762  0000  CAMCO,    0000
0763  1120            ADA I
0764  1070            1070          /CREATES STA I (USES
0765  1040            STA           /REGISTERS 10 TO 15)
0766  0772            CAMH
0767  5005            STC CAMV
0770  1000            LDA
0771  0102            HC
0772  0000  CAMH,     0000          /STORES HC IN CORRECT
0773  1020            LDA I         /FIELD)
0774  4023            4023
0775  1120            ADA I
0776  0000  MARK,     0000          /CREATES STC
0777  5002            STC INDI
1000  1000            LDA
1001  0102            HC
1002  0000  INDI,     0000          /SETS UP MARKER TO
1003  1000            LDA           /SHOW POSITION OF
1004  0101            VC            /REFRESH FOR EACH CH
1005  0000  CAMV,     0000          /STORES VC IN CORRECT
1006  0653            LDF 13        /FIELD
1007  6720            JMP PHC
                /
                /
                /
                /
                /
                /
                      *200
0200  4136            4136
0201  2241            2241          /C
0202  1077            1077
0203  7710            7710          /H
0204  4477            4477
0205  7744            7744          /A
0206  3077            3077
0207  7706            7706          /N
0210  0000            0000
0211  0000            0000
0212  0000  DW1,      0000
0213  0000  DW2,      0000          /0-7
                /
                /
                /
                      *220
0220  4136            4136          /0
0221  2101            2101          /1
0222  4523            4523          /2
0223  4122            4122          /3
0224  2414            2414          /4
0225  5172            5172          /5
0226  1506            1506          /6
0227  4443            4443          /7
                /
                /
                /
                      *230
0230  3641            3641          /0
0231  0177            0177          /1
0232  2151            2151          /2
0233  2651            2651          /3
0234  0477            0477          /4
0235  0651            0651          /5
0236  4225            4225          /6
0237  6050            6050          /7
                /
                /
                /
                /
                      *100
0100  0000  COUNT,    0
0101  0000  VC,       0
0102  0000  HC,       0
0103  0000  FLAG,     0
0104  6002  CALLR,    6002
0105  6000  CAL,      6000
                /
                /
                /
                      *20
0020  0001  FCOUNT,   1
0021  0177  LCOUNT,   0177
0022  6000  MODI,     6000
                /REFRESH POINTERS
0023  0000            0000
0024  0000            0000
0025  0000            0000
```

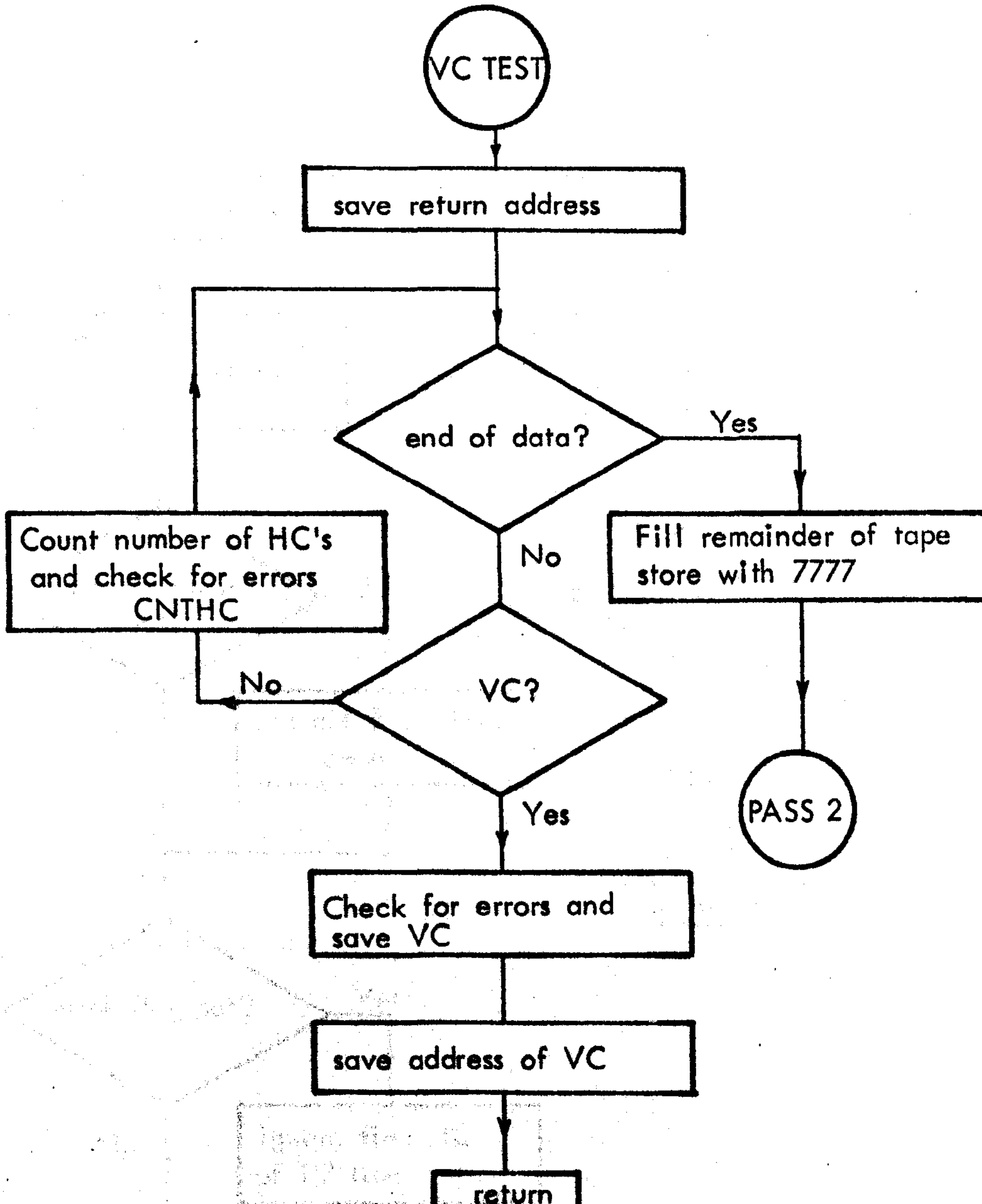
```
0026 0000          0000
0027 0000          0000
0030 0000          0000
0031 0000          0000
               /
               /
               /
                   *10
0010 3777          3777        /CAM1
0011 3777          3777        /CAM2
0012 3777          3777        /CAM3
0013 0000 AUTO,    0000        /CAM4
0014 3777          3777        /CAM5
0015 3777          3777        /CAM6
               /
               /
               /
               /
                   *2
0002 0000 P2,      0000
0003 0000 PSTAD,   0000
0004 0000 PSR,     0000
0005 0000 PHC,     0000
0006 0000 LC,      0000
0007 0000 D,       0000

NO ERRORS

AUTO    0013
A2      0655
PHC     0005
PSR     0004
PSTAD   0003
P2      0002
CAF     0105
CALDR   0134
CAGO    6303
CAGOFR  6305
CAKCO   0762
CAMI    0772
CARV    1105
CAAFL   6306
CDFP    6347
CDPI    6344
CDPM    6342
CDIS    0575
CFC     6315
CLAD    6334
CLCAL   6304
CODF    0737
COUNT   0103
CSM     6316
D       0007
DPM     6341
LC      0006
DF      0763
DFL     0540
DISCG   6322
DISP    0603
DPROC   0513
DE      0512
DE1     0212
DE2     0213
ENAD    6331
ENCG    6321
ENDPI   6343
ENFAD   6332
ENFC    6313
ENMON   6301
ENSM    6314
FCOUNT  0020
FLAG    0103
HC      0102
INDI.   1302
LCOUNT  0021
LDCA    6333
LDCAM   6302
LDFC    6311
LDLC    6312
MARK    0776
MARKD   0546
MODI    0022
NDATA   0470
PHC     0720
POINT   0552
RCA     6335
RCFA    6336
SCAC    6307
SCAVC   0674
SCPH    6345
SUPH    6346
VC      0101
VCTEST  0623
WORD1   0535
WORD2   0540
```

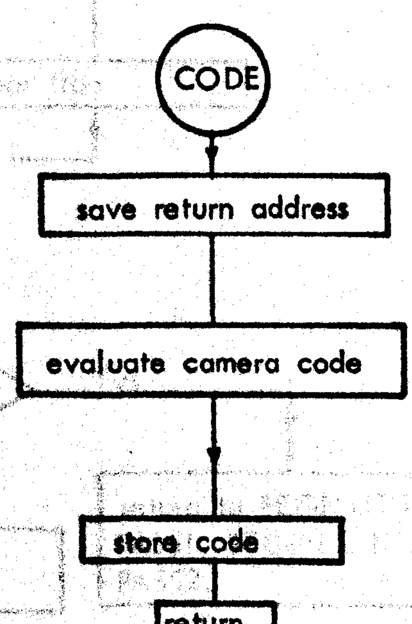
Flow Chart for data process program (DP).

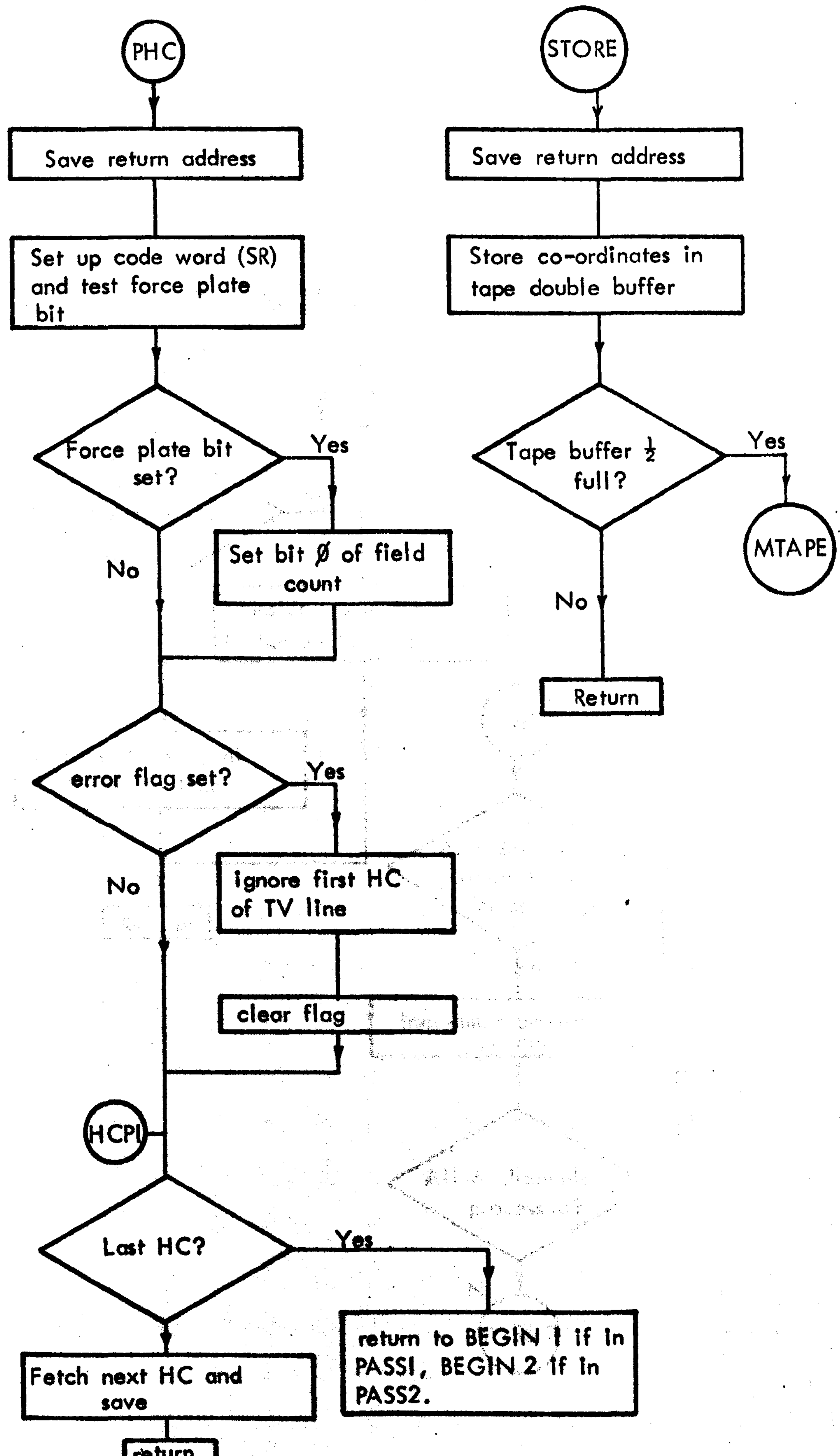


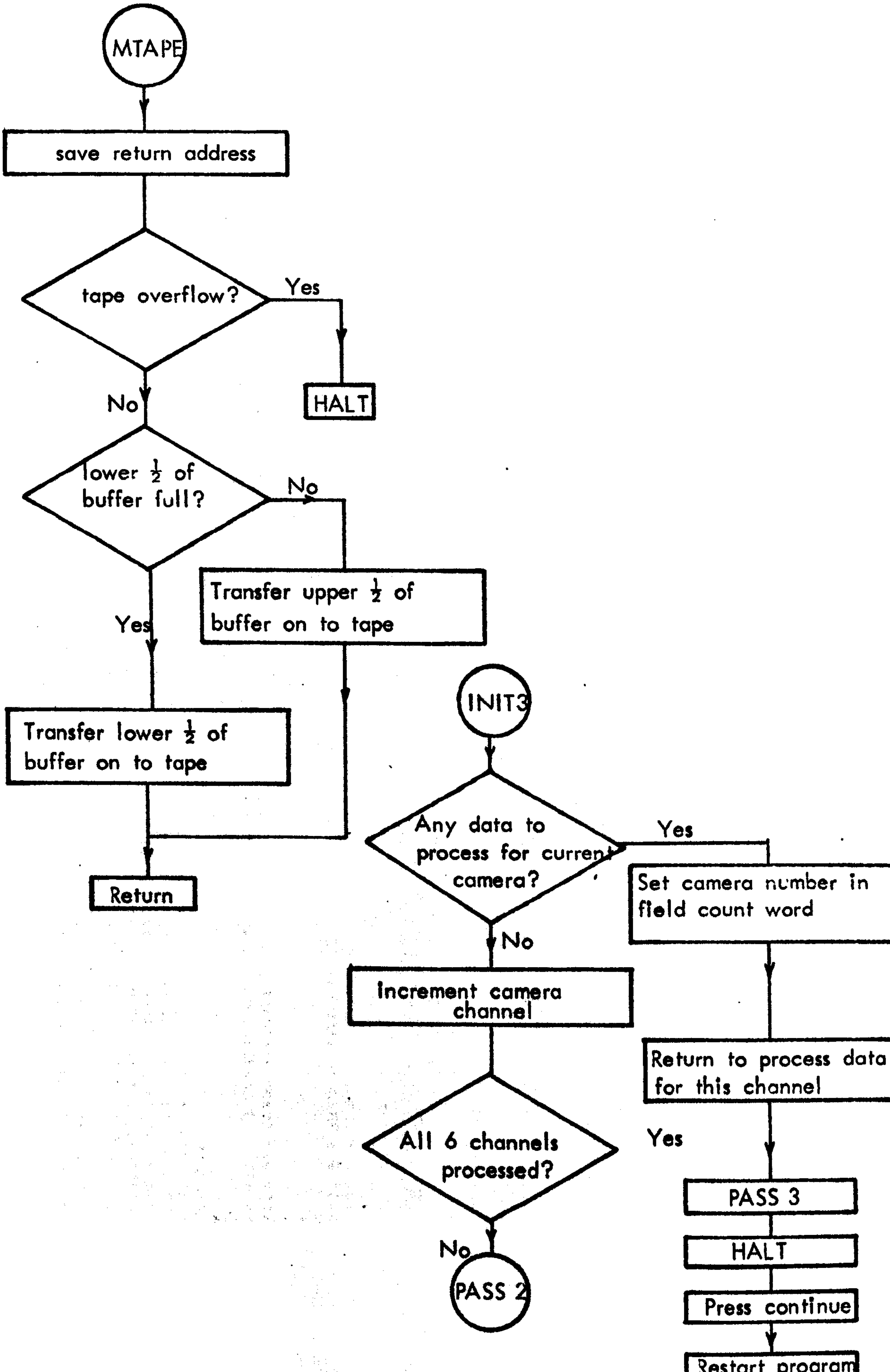

DA4
save address of calling program
Address limit reached?
No
Yes
Continue data acquisition (SNS 2)
Yes
No
Return
read current address and save then HALT
Press continue - INITI
INITI
Initialise data processing program for first pass (INITI)
MAIN 1
Analogue channels sampled? (SNS 3)
Yes
No
Reorganise analogue data
store on tape on unit 3 starting at TBLK
MAIN 2


MAIN 2
Reset counters and data pointers INIT 2
Start processing for each TV line START
Find next VC VCTEST
Process HC's PHC
Get camera code CODE
Count number of HC's for each channel CNTHC
This HC from channel 0?
No
Yes
Store Co-ordinates STORE
Process rest of HC's on current line
HCPI
PASS 2
Reset counters and data pointers INIT 2
Initialise for PASS 2 INIT 3
BEGIN2
Start processing for each line START
VC TEST
PHC
CODE
HC in current camera channel?
No
Yes
Process rest of HC's on current TV line
STORE
HCPI


VC TEST
save return address
end of data?
Yes
Fill remainder of tape store with 7777
PASS 2
No
Count number of HC's and check for errors CNTHC
VC?
No
Yes
Check for errors and save VC
save address of VC
return


CODE
save return address
evaluate camera code
store code
return


PHC
Save return address
Set up code word (SR) and test force plate bit
Force plate bit set?
Yes
Set bit Ø of field count
No
error flag set?
Yes
ignore first HC of TV line
clear flag
No
HCPI
Last HC?
Yes
return to BEGIN 1 if in PASS1, BEGIN 2 if in PASS2.
Fetch next HC and save
return
STORE
Save return address
Store co-ordinates in tape double buffer
Tape buffer ½ full?
Yes
MTAPE
No
Return


MTAPE
save return address
tape overflow?
Yes
HALT
No
lower ½ of buffer full?
No
Transfer upper ½ of buffer on to tape
Yes
Transfer lower ½ of buffer on to tape
Return
INIT3
Any data to process for current camera?
Yes
Set camera number in field count word
No
Increment camera channel
Return to process data for this channel
All 6 channels processed?
Yes
PASS 3
HALT
Press continue
Restart program
No
PASS 2

```
                *20
                /DP - DATA PROCESS
                /
                /17-6-75
                /
                /
                /M.O.JARRETT.
                /
                /
                /
                /PROGRAM CONTROLS ACQUISITION OF DATA
                /FROM INTERFACE, AND STORES IT ON TAPE
                /(UNIT 3) IN THE FORMAT - TV FIELD NUMBER,
                /VERTICAL COORDINATE,HORIZONTAL
                /COORDINATE; WITH THE CAMERA NUMBER
                /CONTAINED IN BITS 1,2,3 OF THE TV FIELD
                /NUMBER. BIT 0 OF THE TV FIELD NO IF SET
                /INDICATES THAT THE FORCE PLATE IS BEING
                /SAMPLED
                /
                /
                /8 MODE I/O PRESET START 20 AFTER SETTING
                /DESIRED SENSE SWITCHES ETC.
                /
                /
                /
                /SNS 0 - ENABLES FIELD COUNT
                /SNS 1 - ENABLES SIMULATOR
                /SNS 2 - ENABLES COORDINATE GENERATOR
                /IF RESET AFTER ENABLING CG THEN CG IS
                /DISABLED AND THE DATA COLLECTED IS PROCESSED
                /SNS 3 - IF SET THEN ANALOGUE CHANNELS
                /WILL BE SAMPLED,IF RESET ONCE PROGRAMME
                /HAS STARTED THEN SAMPLING WILL BE
                /DISCONTINUED
                /
                /
                /PROGRAM HALTS AFTER DATA HAS BEEN COLLECTED
                /PRESS CONTINUE TO PROCESS AND STORE DATA.
                /
                /
                /SFCT - LOCATION 101 CONTAINS FIELD COUNT
                /SLCT - LOCATION 102 CONTAINS LINE COUNT
                /CAD - LOCATION 103 CONTAINS COMPOSITE
                /ADDRESS
                /EFA - LOCATION 104 CONTAINS END FIELD
                /ADDRESS
                /EMA - LOCATION 105 CONTAINS END MEMORY
                /ADDRESS
                /VCERR - LOCATION 130 CONTAINS COUNT OF
                /VERTICAL COORDINATE ERRORS
                /HCERR - LOCATION 131 CONTAINS COUNT OF
                /HORIZONTAL COORDINATE ERRORS
                /
                /
                /TBLK - LOCATION 134 CONTAINS INITIAL
                /BLOCK NUMBER FOR TAPE TRANSFER AT START
                /OF PROGRAM. EACH TIME A BLOCK IS USED
                /TBLK IS INCREMENTED.SET TO 100 WHEN
                /PROGRAM IS FIRST LOADED.
                /
                /
                /
                /INTERFACE STORES DATA STARTING AT LOCATION
                /0 OF MEMORY FIELD 1. ALL LOCATIONS UP
                /TO 7777 OF MEMORY FIELD 3 ARE USED. A
                /LIMIT MAY BE PLACED BY SETTING EFA AND
                /EMA, THESE ARE INITIALLY SET TO 2
                /AND 4000 RESPECTIVELY.
                /
                /THE SAMPLED ANALOGUE DATA IS IN DF 0
                /ABSOLUTE LOCATIONS 6000-7777.IT IS
                /STORED IN THE FIRST SIX BLOCKS ON
                /TAPE IF SNS 3 IS SET.ONE TAPE BLOCK
                /FOR EACH ANALOGUE CHANNEL.
                /
                /
                /
                /
                        LOLSYM
                        PMODE
                        *20
0020  5500              JMP I DATA
                        *200
                /DATA ACQUISITION
0200  6002      DATA1,  IOF
0201  6322              DISCG
0202  7330              CLA CLL
0203  1101              TAD SFCT        /LD SIM FIELD CT
0204  6311              LDFC
0205  7300              CLA CLL
0206  1132              TAD SLCT
0207  6312              LDLC            /LD SIM LINE CT
0210  7200              CLA
0211  1133              TAD CAD
0212  6333              LLCA            /LD COMPOSITE ADDR
0213  6331              ENAD            /EN MEM ADDR
0214  6332              ENFAD           /EN FIELD ADDR
0215  6141              LINC
                        LMODE
0216  1000              LDA
0217  0105              EMA
0220  1560              PCL I
0221  0037              0037
0222  4105              STC EMA
0223  0440              SNS 0
0224  6227              JMP .+3
0225  0500              IOB
0226  6313              ENFC            /EN TV FIELD CT
0227  0441              SNS 1
0230  6233              JMP .+3
0231  0500              IOB
0232  6314              ENSM            /EN SIMULATOR
0233  0442              SNS 2
0234  6233              JMP .-1
0235  0500              IOB
0236  6321              ENCG            /EN COORD GEN
0237  0443              SNS 3           /SAMPLE FORCE PLATE?
0240  6304              JMP DA3         /NO
0241  0077              SET I 17        /YES
0242  3777              3777
0243  0643              LDF 3
0244  0002              PDP
                        PMODE
0245  7300              CLA CLL         /CLR CLK CTRL REG
```

```
0246  6132          CLLR          /RATE=STOP,MODE=0
0247  1350          TAD K0060     /EN INT ON EV1
0250  6134          CLEN          /I/P 1
0251  6141          LINC
                    LMODE
0252  0443          SNS 3         /CONTINUE SAMPLING?
0253  6304          JMP DA3       /NO
0254  0002          PDP
                    PMODE
0255  6131   DA1,   CLSK          /SAM?
0256  5251          JMP .-5       /NO
0257  6141          LINC          /YES
                    LMODE
0260  0110   DA2,   SAM 10
0261  1077          STA I 17
0262  0217          XSK 17
0263  0456          SKP
0264  6304          JMP DA3       /BUFFER FULL
0265  0002          PDP
                    PMODE
0266  6135          CLSA
0267  2260          ISZ DA2
0270  2351          ISZ SCTR
0271  5255          JMP DA1
0272  7200          CLA
0273  1347          TAD KN6
0274  3351          DCA SCTR
0275  1260          TAD DA2
0276  1347          TAD KN6
0277  3260          DCA DA2       /RESET SAM
0300  6141          LINC
                    LMODE
0301  6306          JMP DA4       /TEST FOR END DATA
0302  0002          PDP
                    PMODE
0303  5255          JMP DA1
                    LMODE
0304  6306   DA3,   JMP DA4       /TEST FOR END DATA
0305  6304          JMP .-1
0306  1000   DA4,   LDA
0307  0000          0
0310  4346          STC DA5
0311  0500          IOB
0312  6336          RCFA          /READ CURRENT FLD AD
0313  1443          SAE           /CFA=END FIELD ADDR ?
0314  0104          EFA
0315  6317          JMP .+2       /NO
0316  6322          JMP .+4       /YES
0317  0462          SNS I 2
0320  6346          JMP DA5       /CONTINUE
0321  6331          JMP .+10
0322  0500          IOB
0323  6335          RCA           /READ CURRENT ADDR
0324  1560          BCL I
0325  0037          0037
0326  1443          SAE
0327  0105          EMA
0330  6346          JMP DA5       /NO
0331  0500          IOB           /YES.
0332  6322          DISCG         /DISABLE CG
0333  0500          IOB
0334  6336          RCFA
0335  4106          STC CFA       /SAVE CURRENT FLD AD
0336  0500          IOB
0337  6335          RCA
0340  4107          STC CA        /SAVE CURRENT MEM AD
0341  1020          LDA I
0342  0020          0020
0343  0004          ESF
0344  0000          HLT
0345  6352          JMP INIT1
0346  6000   DA5,   JMP 0         /RETURN
             /
                    PMODE
0347  7772   KN6,   -6
0350  0060   K0060, 0060
0351  7772   SCTR,  -6
             /
             /
             /
             /
                    LMODE
             /FIRST INITIALISATION
0352  0062   INIT1, SET I 2
0353  0000          0
0354  1020          LDA I
0355  0540          BEGIN1
0356  4141          STC BEGIN
0357  1020          LDA I
0360  0052          CC1
0361  1040          STA
0362  1615          I3
0363  1040          STA
0364  1620          I4
0365  1040          STA
0366  1631          I5
0367  1040          STA
0370  1674          I6
0371  1020          LDA I
0372  0053          CC2
0373  1040          STA
0374  1606          I1
0375  1040          STA
0376  1613          I2
0377  1020          LDA I
0400  0001          1
0401  4140          STC CC
0402  1000          LDA           /COMP ADDR TO AC
0403  0103          CAD
0404  1560          BCL I
0405  7770          7770
0406  0002          PDP
                    PMODE
0407  7041          CIA           /TWOS COMPLEMENT
0410  1106          TAD CFA
0411  3213          DCA .+2
0412  5214          JMP .+2
0413  0000          0000
0414  7006          RTL           /X4
0415  6141          LINC
                    LMODE
0416  4110          STC NLF
0417  1000          LDA
0420  0107          CA
0421  1120          ADA I         /DIV BY 1777
0422  6000          -1777
```

```
0423  0451             APO            /REMAINDER +VE?
0424  6427             JMP .+3        /NO
0425  0222             XSK I 2        /YES, INC QUOTIENT
0426  6421             JMP .-5        /REPEAT
0427  1120             ADA I
0430  1777             1777
0431  4111             STC REM        /SAVE REMAINDER
0432  2002             ADD 2
0433  2110             ADD NLF
0434  4110             STC NLF        /STORE NO OF LINC
0435  2103             ADD CAD        /FIELDS
0436  1560             BCL I
0437  7770             7770
0440  4442             STC .+2
0441  6443             JMP .+2
0442  0000             0000           /INITIAL FIELD ADDR
0443  0242             ROL 2          /X4
0444  1120             ADA I
0445  0640             0640           /LDF N
0446  4112             STC DFD1       /SAVE INIT LINC FIELD
0447  0011             CLR
0450  4050             STC 50
0451  4051             STC 51
0452  4052             STC 52
0453  4053             STC 53
0454  4054             STC 54
0455  4055             STC 55
0456  4056             STC 56
0457  4057             STC 57
0460  4060             STC 60
0461  4061             STC 61
0462  4062             STC 62
0463  4063             STC 63
0464  4064             STC 64
0465  4065             STC 65
0466  4066             STC 66
0467  4067             STC 67
0470  0002             PDP
                       PMODE
0471  5513             JMP I MAIN
                /
                /
                /
                /
                /MAIN PROGRAM
0472  6141      MAIN1, LINC
                       LMODE
0473  0443             SNS 3
0474  6536             JMP MAIN2      /NO FP DATA TO STORE
0475  1020             LDA I
0476  2000             2000
0477  4623             STC AD3
0500  0077             SET I 17
0501  3777             3777
0502  6614             JMP AD1
0503  1020             LDA I
0504  2001             2001
0505  4623             STC AD3
0506  6614             JMP AD1
0507  6643             JMP TA1        /XFER 2 BLKS
0510  1020             LDA I
0511  2002             2002
0512  4623             STC AD3
0513  0077             SET I 17
0514  3777             3777
0515  6614             JMP AD1
0516  1020             LDA I
0517  2003             2003
0520  4623             STC AD3
0521  6614             JMP AD1
0522  6643             JMP TA1        /NEXT 2 BLKS
0523  1020             LDA I
0524  2004             2004
0525  4623             STC AD3
0526  0077             SET I 17
0527  3777             3777
0530  6614             JMP AD1
0531  1020             LDA I
0532  2005             2005
0533  4623             STC AD3
0534  6614             JMP AD1
0535  6643             JMP TA1        /LAST 2 BLKS
0536  0002      MAIN2, PDP
                       PMODE
0537  4514             JMS I INIT2
0540  4535      BEGIN1, JMS I START
0541  4520             JMS I VCTEST
0542  4521             JMS I PHC
0543  4522             JMS I CODE
0544  7200             CLA
0545  1123             TAD CAMCO      /CAMERA CODE
0546  7100             CLL
0547  7004             RAL            /X10 (BINARY)
0550  1124             TAD K2350      /ISZ FORMED
0551  3355             DCA .+4
0552  1355             TAD .+3
0553  1125             TAD K1         /2ND ISZ
0554  3357             DCA .+3
0555  0000             0000           /ISZ, COUNTS HC FOR
                /                      EACH CAMERA
0556  5361             JMP .+3
0557  0000             0000           /OVERFLOW
0560  7200             CLA
0561  1123             TAD CAMCO
0562  7440             SZA            /CAM 0?
0563  5365             JMP .+2        /NO
0564  4527             JMS I STORE    /YES, STORE COORDS
0565  6141             LINC
                       LMODE
0566  7247             JMP HCP1
0567  0000             HLT
0570  0002      PASS2, PDP
                       PMODE
0571  4514             JMS I INIT2
0572  4537             JMS I INIT3
0573  4535      BEGIN2, JMS I START
0574  4520             JMS I VCTEST
0575  4521             JMS I PHC
0576  4522             JMS I CODE
0577  6141             LINC
                       LMODE
0600  1000             LDA
0601  0123             CAMCO
0602  1440             SAE
0603  0140             CC
0604  6610             JMP .+4
```

```
0605  0002           PDP
                     PMODE
0606  4527           JMS I STORE
0607  6141           LINC
                     LMODE
0610  7247           JMP HCP1
0611  0000  PASS3,   HLT
0612  0002           PDP
                     PMODE
0613  5530           JMP I DATA        /RESTART
            /
            /
                     LMODE
            /
            /
            /REORGANISE FORCE PLATE DATA
0614  1000  AD1,     LDA
0615  0000           0
0616  4642           STC AD4
0617  0076           SET I 16
0620  7377           -400
0621  0643  AD2,     LDF 3
0622  1000           LDA
0623  2000  AD3,     2000
0624  0641           LDF 1
0625  1077           STA I 17
0626  0236           XSK I 16
0627  1020           LDA I
0630  0006           6
0631  1143           AIM
0632  0423           AL3
0633  0471           APO I             /OVERFLOW?
0634  6621           JMP AD2
0635  1020           LDA I             /YES
0636  7777           7777
0637  1077           STA I 17
0640  0236           XSK I 16
0641  6637           JMP .-2
0642  6000  AD4,     JMP 0
            /
            /
            /XFER 2 BLOCKS TO TAPE ON UNIT 3
0643  1000  TA1,     LDA
0644  0000           0
0645  4674           STC TA4
0646  1000           LDA
0647  0134           TBLK
0650  1120           ADA I
0651  4001           4001
0652  4657           STC TA2
0653  1020           LDA I
0654  0001           1
0655  0001           AXO               /UNIT 3
0656  0714           WRC U
0657  0000  TA2,     0000
0660  1000           LDA
0661  0657           TA2
0662  1120           ADA I
0663  1001           1001
0664  4666           STC TA3
0665  0714           WRC U
0666  0000  TA3,     0000
0667  1000           LDA
0670  0666           TA3
0671  1560           BCL I
0672  7000           7000
0673  4134           STC TBLK
0674  6000  TA4,     JMP 0
            /
            /
            /
            /
            /
            /
            /
            /
            /
            /
            /SUBROUTINE FOR SECOND INITIALISATION
                     PMODE
0675  0000  SINIT2,  0000              /RETURN JMP
0676  6141           LINC
                     LMODE
0677  1000           LDA
0700  0110           NLF
0701  0017           COM
0702  0470           AZE I             /NLF=0 ?
0703  6713           JMP .+10          /YES
0704  4006           STC FCOUNT
0705  1020           LDA I
0706  0016           NOP
0707  5056           STC END
0710  0065           SET I COUNT
0711  1777           1777
0712  6724           JMP .+12
0713  1000           LDA
0714  0111           REM
0715  0017           COM
0716  4005           STC COUNT
0717  0066           SET I FCOUNT
0720  7776           -1
0721  1000           LDA
0722  1077           END1
0723  5056           STC END
0724  0062           SET I TCNT
0725  6777           -1000
0726  0063           SET I TBUF
0727  3777           3777
0730  0061           SET I STAD
0731  2000           2000
0732  0064           SET I TVFCNT
0733  0000           0000
0734  1000           LDA
0735  0112           LFD1
0736  1040           STA
0737  0741           .+2
0740  5005           STC LFD
0741  0000           0000              /LDF N
0742  1020           LDA I
0743  2000           2000
0744  5023           STC IADDR
0745  4130           STC VCERR         /VCERR SET TO 0
0746  4131           STC HCERR         /HCERR SET TO 0
0747  4132           STC EFLAG1        /EFLAG1 SET TO 0
0750  1020           LDA I
```

```
0751  0471          APO I
0752  5417          STC M1
0753  1020          LDA I
0754  7757          -20
0755  5440          STC M2
0756  1000          LDA
0757  2000          2000
0760  4116          STC TVC          /INITIAL VC
0761  0002          PDP
                    PMODE
0762  5675          JMP I SINIT2
              /
              /
              /
              /
              /
                    *1000
              /SUBROUTINE TO TEST FOR VERTICAL COORDINATE
1000  0000    CVTEST, 0000           /RETURN JMP
1001  6141          LINC
                    LMODE
1002  0225          XSK I COUNT
1003  7005          JMP .+2
1004  7345          JMP FCNT         /END OF LINC FIELD
1005  0644    DFD,  0644             /LDF CURRENT DATA
              /                       FIELD
1006  1021          LDA I STAD       /NEXT WORD
1007  1560          BCL I
1010  1777          1777
1011  1460          SAE I            /VC ?
1012  6000          6000
1013  7150          JMP CNTHC        /NO
1014  1000          LDA              /YES
1015  0001          STAD
1016  1120          ADA I
1017  7776          -1
1020  1620          BSE I
1021  2000          2000
1022  1460          SAE I            /ERROR
1023  0000    IADDR, 0000
1024  7026          JMP .+2          /NO
1025  7035          JMP .+10         /YES
1026  1001          LDA STAD
1027  4116          STC TVC
1030  1000          LDA
1031  0001          STAD
1032  5323          STC IADDR
1033  0002          PDP
                    PMODE
1034  5600          JMP I CVTEST     /RETURN
                    LMODE
1035  0002          PDP
                    PMODE
1036  2130          ISZ VCERR        /INC VC ERROR COUNT
1037  5241          JMP .+2
1040  7402          HLT              /TOO MANY ERRORS
1041  7240          STA              /SET AC=7777
1042  3132          DCA EFLAG1       /SET ERROR FLAG
1043  6141          LINC
                    LMODE
1044  7150          JMP CNTHC
1045  0226    FCNT, XSK I FCOUNT
1046  7050          JMP .+2
1047  7056          JMP END
1050  0011          CLR
1051  3005          ADD DFD
1052  1120          ADA I
1053  0001          1
1054  5005          STC DFD          /INC DATA FIELD CNT
1055  7005          JMP DFD
1056  0016    END,  NOP
1057  0011          CLR
1060  2111          ADD REM          /REMAINDER
1061  0017          COM
1062  4005          STC COUNT
1063  1020          LDA I
1064  7776          -1
1065  4006          STC FCOUNT
1066  3005          ADD DFD
1067  1120          ADA I
1070  0001          1
1071  5005          STC DFD
1072  1020          LDA I
1073  7076          JMP .+3
1074  5056          STC END
1075  7005          JMP DFD          /RETURN TO PROCESS
1076  1020          LDA I            /REMAINDER
1077  7101    END1, JMP .+2
1100  5056          STC END
1101  0066          SET I FCOUNT     /PROCESS LAST
1102  7776          -1               /LINE OF DATA
1103  0065          SET I COUNT
1104  7776          -1
1105  1020          LDA I
1106  7111          JMP .+3
1107  5056          STC END
1110  7024          JMP IADDR+1
1111  1020          LDA I
1112  7777          7777
1113  4004          STC TVFCNT
1114  0017          COM
1115  4117          STC VC
1116  0017          COM
1117  4133          STC HC
1120  2134          ADD TBLK
1121  1120          ADA I
1122  0002          2
1123  5132          STC .+7
1124  0002          PDP
                    PMODE
1125  4527          JMS I STORE
1126  7200          CLA
1127  1134          TAD TBLK
1130  6141          LINC
                    LMODE
1131  1460          SAE I            /TAPE STORE FULL ?
1132  0000          0000             /TBLK+2
1133  7124          JMP .-7          /NO
1134  6570          JMP PASS2        /YES
              /
              /
              /
              /
              /
                    *1150
              /COUNT HORIZONTAL COORDINATES & [illegible]
```

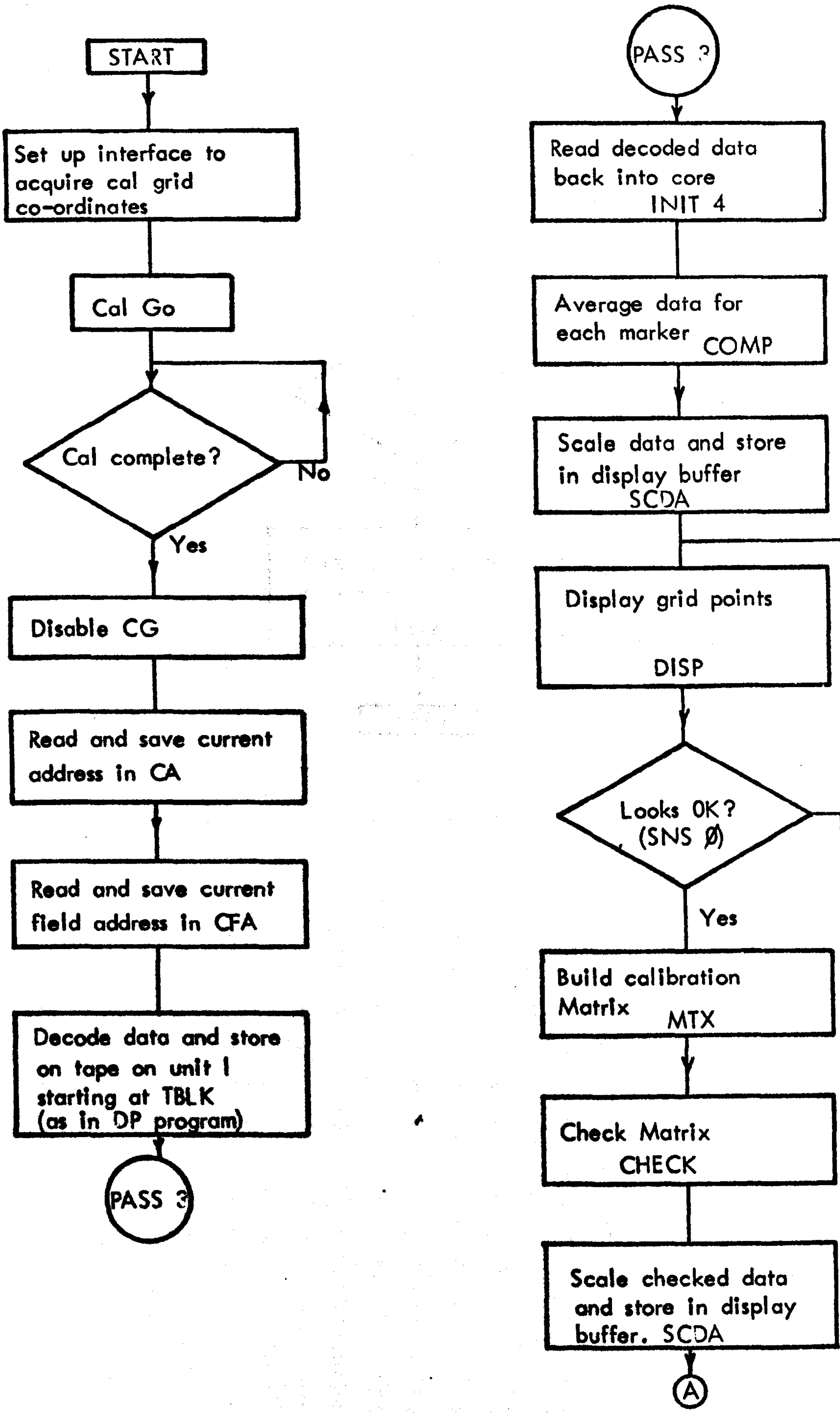
```
1150  0002  CNTHC,  LMODE
                    PDP
                    PMODE
1151  2115          ISZ HCNT        /ERROR?
1152  5357          JMP .+5         /NO
1153  2131          ISZ HCERR       /YES,COUNT ERRORS
1154  5356          JMP .+2
1155  7402          HLT             /TOO MANY ERRORS
1156  5541          JMP I BEGIN     /RETURN TO START
1157  6141          LINC
                    LMODE
1160  1001          LDA STAD        /STORE CURRENT HC
              /                      IN APROPRIATE LOC
1161  4030  TEMSTO, 4030            /STC 30,31,32 ETC
1162  3161          ADD TEMSTO
1163  1120          ADA I
1164  0001          1
1165  5161          STC TEMSTO
1166  7002          JMP CVTEST+2
              /
              /
              /
              /
                    *1200
              /SUBROUTINE TO PROCESS HORIZONTAL COORDINATE
                    PMODE
1200  0000  SPHC,   0000            /RETURN JMP
1201  6141          LINC
                    LMODE
1202  1000          LDA
1203  0115          HCNT
1204  1120          ADA I
1205  0005          5
1206  1120          ADA I
1207  2030          2030            /ADD 1-7
1210  5217          STC AD
1211  2115          ADD HCNT        /FORM ROL N TO
1212  1660          BCO I           /CORRECTLY ORIENTATE
1213  0007          0007            /SR WORD.
1214  1120          ADA I
1215  0253          0253            /ROL N, FORMED
1216  5231          STC PH1
1217  0000  AD,     0000            /ADD HCN
1220  0263          ROL I 3
1221  0472          LZE I           /F P?
1222  7231          JMP PH1         /NO
1223  5267          STC PH2         /YES
1224  2004          ADD TVFCNT
1225  1620          BSE I
1226  4000          4000
1227  4004          STC TVFCNT
1230  3267          ADD PH2
1231  0000  PH1,    0000            /ROL N
1232  4136          STC SR          /SAVE SR WORD
1233  2132          ADD EFLAG1
1234  0471          APO I           /FLAG SET ?
1235  7242          JMP .+5         /NO
1236  1020          LDA I           /YES
1237  2030          2030
1240  5256          STC LHC         /LAST HC
1241  7245          JMP .+4
1242  1020          LDA I
1243  2027          2027
1244  5256          STC LHC         /LAST HC
1245  0011          CLR
1246  4132          STC EFLAG1      /CLEAR FLAG
1247  0011  HCP1,   CLR
1250  3217          ADD AD
1251  1120          ADA I
1252  7776          -1
1253  1040          STA
1254  1217          AD
1255  1460          SAE I           /LAST HC ?
1256  0000  LHC,    0000            /2027 OR 2030
1257  7262          JMP .+3         /NO
1260  0002          PDP             /YES
                    PMODE
1261  5541          JMP I BEGIN
                    LMODE
1262  5263          STC .+1
1263  0000          0000            /ADD LATEST HC
1264  4133          STC HC
1265  0002          PDP
                    PMODE
1266  5600          JMP I SPHC
              /
1267  0000  PH2,    0
              /
              /
              /
              /SUBROUTINE TO EVALUATE CAMERA CODE
1270  0000  SCODE,  0000            /RETURN JMP
1271  6141          LINC
                    LMODE
1272  0011          CLR
1273  2136          ADD SR
1274  0261          ROL I 1
1275  4136          STC SR          /REPLACE SHIFTED SR
1276  2133          ADD HC
1277  0312          ROR 12
1300  0261          ROL I 1
1301  1560          BCL I
1302  7770          7770
1303  4123          STC CAMCO       /CAMERA CODE
1304  0002          PDP
                    PMODE
1305  5670          JMP I SCODE     /RETURN
              /
              /
              /
              /
              /SUBROUTINE TO STORE COORDINATES
1306  0000  SSTORE, 0000            /RETURN JMP
1307  6141          LINC
                    LMODE
1310  0641          LDF 1
1311  1000          LDA
1312  0004          TVFCNT          /TV FIELD COUNT
1313  1063          STA I TBUF
1314  0222          XSK I TCNT      /TAPE BUFFER FULL?
1315  7317          JMP .+2         /NO
1316  7452          JMP MTAPE       /YES,STORE ON TAPE
1317  1000          LDA
1320  0117          VC              /VERTICAL COORDINATE
1321  1063          STA I TBUF
1322  0222          XSK I TCNT
```

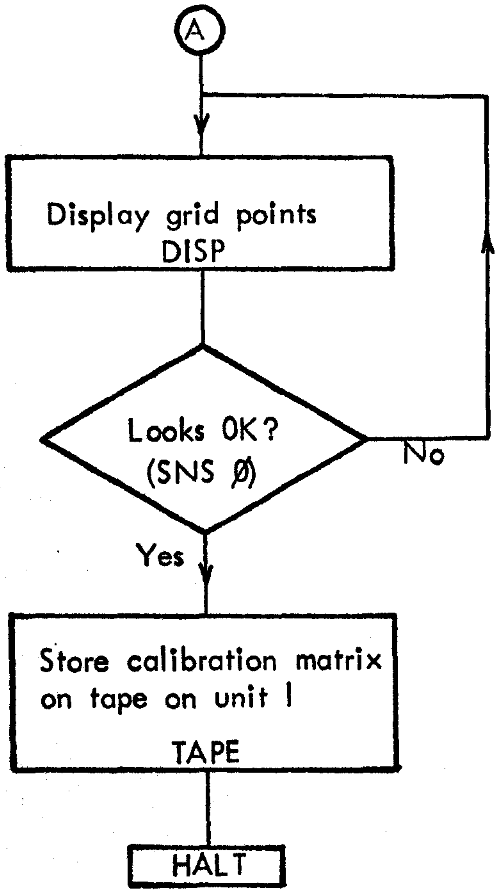
```
1323 7325          JMP .+2
1324 7450          JMP MTAPE
1325 1000          LDA
1326 0133          HC              /HORIZONTAL COORD
1327 1560          BCL I
1330 6000          6000
1331 1063          STA I TBUF
1332 0222          XSK I TCNT
1333 7335          JMP .+2
1334 7453          JMP MTAPE
1335 0002          PDP
                   PMODE
1336 5736          JMP I SSTORE
          /
          /
          /
          /
          /
          /SUBROUTINE TO START PROCESSING
                   *1400
1400 0000 START1,  0000
1401 6141          LINC
                   LMODE
1402 1020          LDA I
1403 7771          -6
1404 4115          STC HCNT        /SET UP HC COUNTER
1405 1020          LLA I
1406 4030          4030
1407 5161          STC TEMSTO
1410 2116          ADD TVC
1411 1560          BCL I
1412 6400          6400
1413 1040          STA
1414 0117          VC
1415 1120          ADA I
1416 7307          -470
1417 3471 M1,      APO I
1420 7446          JMP M3
1421 0224          XSK I TVFCNT    /INC TV FIELD COUNTER
1422 1000          LLA
1423 0004          TVFCNT
1424 1560          BCL I
1425 7400          7400
1426 1460          SAE I
1427 0377          0377
1430 7436          JMP M1A
1431 1000          LDA
1432 0004          TVFCNT
1433 1560          BCL I
1434 0377          0377
1435 4004          STC TVFCNT
1436 0011 M1A,     CLR
1437 1120          ADA I
1440 7757 M2,      -20
1441 3417          ADD M1          /ADD APO INST
1442 5417          STC M1          /REPLACE MODIFIED INS
1443 3440          ADD M2
1444 0017          COM
1445 5440          STC M2          /APO I INS CHANGED
1446 0002 M3,      PDP
                   PMODE
1447 5600          JMP I START1    /RETURN
          /
          /
          /
          /
          /
          /
          /
          /SUBROUTINE TO STORE DATA ON TAPE
                   LMODE
1450 1000 MTAPE,   LDA
1451 0000          0
1452 5541          STC RETURN      /SAVE RETURN ADDRESS
1453 1020          LDA I
1454 0001          1
1455 0001          AXO
1456 1020          LDA I
1457 6777          -1000
1460 4002          STC TCNT        /RESET TCNT
1461 1000          LDA
1462 0134          TBLK
1463 1120          ADA I
1464 0001          1
1465 1040          STA
1466 0134          TBLK
1467 1120          ADA I
1470 3000          3000
1471 0451          APO             /TAPE OVERFLOW?
1472 0000          HLT             /YES
1473 1000          LDA             /NO
1474 0003          TBUF
1475 1120          ADA I
1476 1000          1000
1477 0471          APO I           /LOWER HALF FULL?
1500 7506          JMP .+6         /YES
1501 1000          LDA             /NO, UPPER HALF FULL
1502 0134          TBLK
1503 1120          ADA I
1504 6000          6000
1505 7512          JMP .+5
1506 1000          LDA
1507 0134          TBLK
1510 1120          ADA I
1511 4000          4000
1512 5514          STC .+2
1513 0714          0714            /WRC 1
1514 0000 XFER1,   0000
1515 1000          LDA
1516 1514          XFER1
1517 1120          ADA I
1520 1001          1001
1521 1044          STA
1522 1540          XFER2
1523 1000          LLA
1524 1514          XFER1
1525 1560          BCL I
1526 7000          7000
1527 1120          ADA I
1530 0001          1
1531 1043          STA
1532 0134          TBLK            /RESET TBLK
1533 1120          ADA I
1534 3000          3000
1535 0451          APO             /TAPE OVERFLOW?
1536 0000          HLT             /YES
```

```
1537  0714            0714            /NO, WRC 1
1540  0000  XFER2,    0000
1541  0000  RETURN,   0000            /RETURN JMP
            /
            /
            /
            /
            /
            /
                      *1600
            /THIRD INITIALISATION, PASS 2
1600  0000  SINIT3,   0000            /RETURN ADDR
                      PMODE
1601  6141            LINC
                      LMODE
1602  1020            LDA I
1603  0573            BEGIN2
1604  4141            STC BEGIN
1605  1000            LDA
1606  0053  I1,       CC2
1607  0470            AZE I
1610  7617            JMP T2
1611  0011            CLR
1612  1040            STA
1613  0053  I2,       CC2             /CLEAR CC2
1614  1040            STA
1615  0052  I3,       CC1             /CLEAR CC1
1616  7672            JMP RET
1617  1000  T2,       LDA
1620  0052  I4,       CC1
1621  0451            APO             />2000 PTS ?
1622  7672            JMP RET         /YES RETURN
1623  1120            ADA I
1624  3400            3400
1625  0451            APO             />256 PTS
1626  7672            JMP RET         /YES, RETURN
1627  0011            CLR             /NO
1630  1040            STA
1631  0052  I5,       CC1
1632  1020            LDA I
1633  0002            2
1634  1140            ADM
1635  1606            I1
1636  1020            LDA I
1637  0002            2
1640  1140            ADM
1641  1613            I2
1642  1020            LDA I
1643  0002            2
1644  1140            ADM
1645  1615            I3
1646  1020            LDA I
1647  0002            2
1650  1140            ADM
1651  1620            I4
1652  1020            LDA I
1653  0002            2
1654  1140            ADM
1655  1631            I5
1656  1020            LDA I
1657  0002            2
1660  1140            ADM
1661  1674            I6
1662  1020            LDA I
1663  0001            1
1664  1140            ADM
1665  0140            CC              /INC CHAN COUNTER
1666  1460            SAE I
1667  0006            6
1670  6570            JMP PASS2
1671  6611            JMP PASS3
1672  0011  RET,      CLR
1673  1040            STA
1674  0052  I6,       CC1
1675  1000            LDA
1676  0140            CC
1677  0250            ROL 10
1700  5703            STC I7
1701  2004            ADD TVFCNT
1702  1620            BSE I
1703  0000  I7,       0000
1704  4004            STC TVFCNT
1705  0002            PDP
                      PMODE
1706  5600            JMP I SINIT3
            /
            /
            /
            /
            /
            /
                      *1
0001  0000  STAD,     0
0002  0000  TCNT,     0
0003  0000  TBUF,     0
0004  0000  TVFCNT,   0
0005  0000  COUNT,    0
0006  0000  FCOUNT,   0
0007  0000  LFCNT,    0
            /
            /
            /
                      *52
0052  0000  CC1,      0
0053  0000  CC2,      0
            /
            /
            /
            /
            /
                      *100
0100  0200  DATA,     200
0101  0000  SECT,     0
0102  0236  SLCT,     236
0103  0001  CAD,      0001
0104  0002  EFA,      2
0105  4000  EMA,      4000
0106  0000  CFA,      0
0107  0000  CA,       0
0110  0000  NLF,      0
0111  0000  NFM,      0
0112  0000  DFD1,     0
0113  0472  MAIN,     MAIN1
0114  0675  INIT2,    SINIT2
0115  0000  HCNT,     0
0116  0000  TVC,      0
```

```
1757      0117  0000  VC,       0
1760      0120  1000  VCTEST,   CVTEST
1761      0121  1200  PHC,      SPHC
1762      0122  1270  CODE,     SCODE
1763      0123  0000  CAMCO,    0
1764      0124  2050  K2050,    2050
1765      0125  0001  K1,       1
1766      0126  1247  HCP,      HCP1
1767      0127  1306  STORE,    SSTORE
1770      0130  0000  VCERR,    0
1771      0131  0000  HCERR,    0
1772      0132  0000  EFLAG1,   0
1773      0133  0000  HC,       0
1774      0134  0077  TBLK,     77
1775      0135  1400  START,    START1
1776      0136  0000  SR,       0
1777      0137  1600  INIT3,    SINIT3
2000      0140  0001  CC,       1
2001      0141  0540  BEGIN,    BEGIN1
2002                  /
2003                  /
2004                  /
2005                  /

NO ERRORS

AD      1217
AD1     0614
AD2     0621
AD3     0623
AD4     0642
BEGIN   0141
BEGIN1  0540
BEGIN2  0573
CA      0107
CAL     0100
CAGO    6303
CAGOFR  6305
CAMCO   0123
CC      0140
CCAFL   6306
CC1     0352
CC2     0353
CDPF    6347
CDPI    6344
CDPM    6342
CFA     0106
CFC     6315
CLAD    6334
CLCAL   6344
CNTHC   1150
CODE    0122
COUNT   0005
CSM     6316
CVTEST  1000
DATA    0100
DATA1   0200
DA1     0255
DA2     0260
DA3     0334
DA4     0306
DA5     0346
DPM     6341
-
DFD     1005
DFD1    0112
DISCG   6322
EFA     0104
EFLAG1  0132
EMA     0105
ENAD    6331
ENCG    6321
END     1056
ENDPI   6343
END1    1077
ENFAD   6332
ENFC    6313
ENMON   6301
ENSM    6314
FCNT    1045
FCOUNT  0006
HC      0133
HCERR   0131
HCNT    0115
HCP     0126
HCP1    1247
IADDR   1023
INIT1   0352
INIT2   0114
INIT3   0137
I1      1606
I2      1613
I3      1615
I4      1620
I5      1631
I6      1674
I7      1703
KN6     0347
K0060   0353
K1      0125
K2050   0124
LDCA    6333
LDCAM   6302
LDFC    6311
LDLC    6312
LFCNT   0007
LHC     1256
MAIN    0113
MAIN1   0472
MAIN2   0536
MTAPE   1450
M1      1417
M1A     1436
M2      1440
M3      1446
NLF     0110
PASS2   0570
PASS3   0611
PHC     0121
PH1     1231
PH2     1267
RCA     6335
RCFA    6336
REM     0111
RET     1672
RETURN  1541
SCAC    6307
SCPH    6345
SCODE   1270
SCTR    0351
SECT    0101
SINIT2  0675
SINIT3  1600
SLCT    0102
SPHC    1200
SR      0136
SSTORE  1306
STAD    0001
START   0135
START1  1400
STORE   0127
SUPH    6346
TA1     0643
TA2     0657
TA3     0666
TA4     0674
TBLK    0134
TBUF    0003
TCNT    0002
TEMSTO  1161
TVC     0116
TVFCNT  0004
T2      1617
VC      0117
VCERR   0130
VCTEST  0120
XFER1   1514
XFER2   1540
```

Flow chart for calibration grid data acquisition (CALMTX)




A
Display grid points
DISP
Looks OK?
(SNS Ø)
No
Yes
Store calibration matrix
on tape on unit 1
TAPE
HALT

```
                        *20
                        /CALMIX - CALIBRATION MATRIX ACQUISITION.
                        /
                        /16-5-75
                        /
                        /M.O.JARRETT.
                        /
                        /
                        /8 MODE I/O PRESET, START 20.
                        /
                        /
                        /PROGRAM OBTAINS THE CO-ORDINATES OF A
                        /GRID OF POINTS AND STORES IN THE FORMAT
                        /VC,HC, ON TAPE ON UNIT 1 STARTING AT TAPE
                        /BLOCK HELD IN TBLK (LOCATION 2360) INITIALLY
                        /SET TO 200. THIS DATA IS THEN REDUCED TO
                        /PROVIDE AN AVERAGED PAIR OF CO-ORDINATES FOR
                        /EACH GRID POINT, AND STORED IN A CALIBRATION
                        /MATRIX - FORMAT:-
                        /
                        /VC,VC ... VC,K ...K,HC,HC ...HC,K ...K
                        /
                        / .
                        / .
                        / .
                        /
                        /VC,VC ... VC,K ...K,HC,HC ...HC,K ...K
                        / K, K ...  K,K ...K, K, K ... K,K ...K
                        /
                        / .
                        / .
                        / .
                        /
                        / K, K ...  K,K ...K, K, K ... K,K ...K
                        /
                        /WHERE K=3777; THE MATRIX OCCUPIES LOCATIONS
                        /0000 - 2777 OF A PMODE DATA FIELD. FOR A
                        /CALIBRATION GRID OF 25X10 THE ACTIVE ELEMENTS
                        /OF THE MATRIX WILL BE FOUND IN LOCATIONS
                        /0000 - 2377.
                        /
                        /THE MATRIX IS STORED ON TAPE IN 6 BLOCKS
                        /STARTING AT THE BLOCK NUMBER HELD IN CTBLK
                        /(LOCATION 5273) INITIALLY SET TO 20.
                        /
                                LDBSYM
                                PMODE
                                *10
0010    7777    GD,             7777
0011    0000    FVC,            0
                        /
                        /
                                MTXV=GD
                                MTXH=FVC
                        /
                        /
                                *20
0020    5521                    JMP I CAL
                        /
                        /
                        /
                        /
                        /
                                *50
0050    0000            0                       /COORDINATE COUNTERS
0051    0000            0                       /FOR EACH CAMERA
0052    0000    CC1,    0                       /CHANNEL
0053    0000    CC2,    0
0054    0000            0
0055    0000            0
0056    0000            0
0057    0000            0
0060    0000            0
0061    0000            0
0062    0000            0
0063    0000            0
                /
                /
                /
                /
                /
                                *100
0100    0000    SFCT,   0                       /TV FIELD COUNT
0101    0036    SLCT,   36                      /SIM LINE COUNT
0102    0001    CAD,    0001                    /COMPOSITE ADDR
0103    0000    CFA,    0                       /CURRENT FIELD
0104    0000    CA,     0                       /CURRENT ADDR
0105    2100    INIT2,  SINIT2
0106    2600    VCTEST, CVTEST
0107    2434    PHC,    SPHC
0110    2512    CODE,   SCODE
0111    0000    CAMCO1, 0
0112    2050    K2050,  2050
0113    0001    K1,     1
0114    2542    STORE,  SSTORE
0115    2400    START,  START1
0116    3067    INIT3,  SINIT3
0117    0001    CC,     1
0120    0200    BEGIN,  BEGIN1
0121    0200    CAL,    SCAL
0122    7400    CAM,    7400                    /CAL RH MARGIN
0123    3474    DISP,   SDISP
0124    7777    KM1,    -1
0125    7776    KM2,    7776
0126    3400    SCDA,   SSCDA
0127    0000    NELS,   0000                    /NO DATA WORDS
0130    3200    INIT4,  SINIT4
0131    0000    TEMP,   0000
0132    2200    INIT1,  SINIT1
0133    4200    COMP,   SCOMP
0134    4400    RED,    SRED
0135    4531    STOR,   SSTOR
0136    3777    K3777,  3777
0137    4600    MTX,    SMTX
0140    5363    CHECK,  SCHECK
0141    0037    K37,    37
0142    0077    K77,    77
0143    0137    K137,   137
0144    5200    TAPE,   STAPE
                /
                /
                /
                /
                                *200
0200    0000    SCAL,   0000
```

```
0201  6322          DISCG
0202  7200          CLA
0203  1102          TAD CAD
0204  6333          LDCA             /COMPOSITE ADDR
0205  7200          CLA
0206  1122          TAD CAM
0207  6332          LDCAM            /RH MARGIN
0210  6303          CAGO
0211  6331          ENAD             /EN ADDR
0212  6332          ENFAD            /EN FIELD ADDR
0213  7200          CLA
0214  1101          TAD SLCT
0215  6312          LILC             /LD SIM LINE CNT
0216  6314          ENSM             /EN SIMULATOR
0217  6321          ENCG
0220  6337          SCAC             /CAL COMPLETE?
0221  5220          JMP .-1          /NO
0222  6322          DISCG            /YES
0223  6326          CCAFL            /CLR CAL COMP FLAG
0224  6335          RCA
0225  3104          DCA CA           /CURRENT MEM ADDDR
0226  6336          RCFA
0227  3103          DCA CFA          /CURRENT FIELD ADDR
                /
                /
                /
                /
                /
                /MAIN PROGRAM
0230  4532          JMS I INIT1
0231  4535  MAIN1,  JMS I INIT2
0232  4515  BEGIN1, JMS I START
0233  4506          JMS I VCTEST
0234  4507          JMS I PHC
0235  4510          JMS I CODE
0236  7200          CLA
0237  1111          TAD CAMCO1       /CAMERA CODE
0240  7100          CLL
0241  7004          RAL              /K10 (BINARY)
0242  1112          TAD K2050        /ISZ FORMED
0243  3247          DCA .+4
0244  1247          TAD .+3
0245  1113          TAD K1           /2ND ISZ
0246  3251          DCA .+3
0247  0000          0000             /ISZ, COUNTS HC FOR
0250  5253          JMP .+3          /EACH CAMERA
0251  0000          0000             /OVERFLOW
0252  7200          CLA
0253  1111          TAD CAMCO1
0254  7440          SZA              /CAM 0?
0255  5257          JMP .+2          /NO
0256  4514          JMS I STORE      /YES, STORE COORDS
0257  6141          LINC
                    LMODE
0260  0601          LIF 1
0261  6472          JMP HCP1
0262  0000          HLT
0263  0002  PASS2,  PDP
                    PMODE
0264  4535          JMS I INIT2
0265  4516          JMS I INIT3
0266  4515  BEGIN2, JMS I START
0267  4506          JMS I VCTEST
0270  4507          JMS I PHC
0271  4510          JMS I CODE
0272  6141          LINC
                    LMODE
0273  1000          LDA
0274  0541          CAMCO
0275  1440          SAE
0276  0117          CC
0277  6303          JMP .+4
0300  0002          PDP
                    PMODE
0301  4514          JMS I STORE
0302  6141          LINC
                    LMODE
0303  0601          LIF 1
0304  6472          JMP HCP1
0305  0002  PASS3,  PDP
                    PMODE
0306  4530          JMS I INIT4
0307  4533          JMS I COMP
0310  4535          JMS I STOR
0311  4526          JMS I SCDA
0312  4523          JMS I DISP
0313  4537          JMS I MTX
0314  4540          JMS I CHECK
0315  4526          JMS I SCDA
0316  4523          JMS I DISP
0317  4544          JMS I TAPE
0320  7402          HLT
                /
                /
                /
                /
                /
                /
                    LMODE
                    SEGMNT 1
                /FIRST INITIALISATION
                    *200
                    PMODE
2200  0000  SINIT1, 0000
2201  6141          LINC
                    LMODE
0202  0062          SET I 2
0203  0003          3
0204  0640          LDF 3
0205  1020          LDA I            /SETS UP RETURN
0206  0232          BEGIN1           /LOC FOR COORD
0207  1040          STA              /PROCESSING IN
0210  2120          BEGIN!2000       /PASS 1
0211  1020          LDA I
0212  2052          CC1!2000         /SETS UP CHAN
0213  1040          STA              /COORD COUNTERS
0214  1106          I3               /TO START AT
0215  1040          STA              /CHANNEL 1 FOR
0216  1112          I4               /PASS 2 PROCESSING
0217  1040          STA
0220  1123          I5
0221  1040          STA
0222  1167          I6
0223  1020          LDA I
```

```
0224  2053          CC2!2000
0225  1040          STA
0226  1077          I1
0227  1040          STA
0230  1104          I2
0231  1020          LDA I              /CAMERA CHAN
0232  0001          1                  /SET TO 1 FOR
0233  1040          STA                /FIRST PASS OF
0234  2117          CC!2000            /PASS 2
0235  1000          LDA                /COMP ADDR TO AC
0236  2102          CAD!2000
0237  1560          BCL I
0240  7770          7770
0241  0002          PDP
                    PMODE
2242  7041          CIA                /CALCULATE NO OF
2243  1103          TAD CFA            /LINC FIELDS IN
2244  3246          DCA .+2            /COMPLETE PMODE
2245  5247          JMP .+2            /FIELDS
2246  0000          0000
2247  1246          TAD .-1
2250  1246          TAD .-2
2251  1246          TAD .-3
2252  1246          TAD .-4            /X4
2253  6141          LINC
                    LMODE
0254  4355          STC NLF
0255  1000          LDA
0256  2104          CA1!2000
0257  0471          APO I              /<2 LINC FIELDS ?
0260  6265          JMP .+5            /YES
0261  1560          BCL I              /NO
0262  4000          4000
0263  0062          SET I 2
0264  0002          2
0265  1120          ADA I              /DIV BY 2000
0266  5777          -2000
0267  0451          APO                /REMAINDER +VE?
0270  6273          JMP .+3            /NO
0271  0222          XSK I 2            /YES, INC QUOTIENT
0272  6265          JMP .-5            /REPEAT
0273  1120          ADA I
0274  2000          2000
0275  4356          STC REM            /SAVE REMAINDER
0276  2002          ADD 2              /CALCULATE AND
0277  2355          ADD NLF            /STORE TOTAL NO
0300  4355          STC NLF            /OF LINC FIELDS
0301  1000          LDA
0302  2102          CAD!2000
0303  1560          BCL I
0304  7770          7770
0305  4307          STC .+2
0306  6310          JMP .+2
0307  0000          0000               /INITIAL PMODE
0310  2307          ADD .-1            /FIELD ADDR
0311  2307          ADD .-2
0312  2307          ADD .-3
0313  2307          ADD .-4            /X4
0314  1120          ADA I
0315  0640          0640               /LDF N
0316  4357          STC DFD1           /SAVE INIT LINC FIELD
0317  0011          CLR
0320  1040          STA                /THESE LOCATIONS
0321  2050          50!2000            /USED TO COUNT
0322  1040          STA                /NO OF COORDS
0323  2051          51!2000            /FROM EACH
0324  1040          STA                /CAMERA CHAN
0325  2052          52!2000
0326  1040          STA
0327  2053          53!2000
0330  1040          STA
0331  2054          54!2000
0332  1040          STA
0333  2055          55!2000
0334  1040          STA
0335  2056          56!2000
0336  1040          STA
0337  2057          57!2000
0340  1040          STA
0341  2060          60!2000
0342  1040          STA
0343  2061          61!2000
0344  1040          STA
0345  2062          62!2000
0346  1040          STA
0347  2063          63!2000
0350  1000          LDA                /INITIAL TAPE
0351  0360          TBLK               /BLOCK NO
0352  4361          STC ITBLK
0353  0002          PDP
                    PMODE
2354  5600          JMP I SINIT1
              /
              /
                    LMODE
              /
0355  0000    NLF,  0
0356  0000    REM,  0
0357  0000    DFD1, 0
0360  0177    TBLK, 177
0361  0177    ITBLK, 177
              /
              /
              /
              /
              /SUBROUTINE FOR SECOND INITIALISATION
                    *100
                    PMODE
2100  0000    SINIT2, 0000             /RETURN JMP
2101  6141          LINC
                    LMODE
0102  1000          LDA
0103  0355          NLF
0104  0017          COM
0105  0470          AZE I              /NLF=0 ?
0106  6116          JMP .+10           /YES
0107  4036          STC FCOUNT         /SET UP LINC FIELD
0110  1020          LDA I              /COUNTER
0111  0016          NOP                /SET END TO NOP
0112  4655          STC END
0113  0065          SET I COUNT
0114  1777          1777
0115  6127          JMP .+12
0116  1000          LDA                /<1 LINC FIELD
0117  0356          REM                /OF DATA, SET
0120  0017          COM                /COUNT TO REM
```

```
0121  4305          STC COUNT     /AND LINC FIELD
0122  0066          SET I FCOUNT  /COUNT TO -1
0123  7776          -1
0124  1000          LDA           /SET END TO JMP
0125  0677          ENDI          /INST AT ENDI
0126  4656          STC END
0127  0062          SET I TCNT    /2 BLOCKS OF DATA
0130  6777          -1000
0131  0063          SET I TBUF    /TAPE BUFFER SET
0132  3777          3777
0133  0061          SET I STAD    /START ADDR FOR
0134  2000          2000          /DATA
0135  0064          SET I TVFCNT  /TV FIELD COUNT
0136  0000          0000
0137  1000          LDA
0140  0357          DFD1
0141  1040          STA
0142  0144          .+2
0143  4605          STC DFD
0144  0000          0000          /LDF N
0145  1020          LDA I
0146  2000          2000
0147  4603          STC IADDR     /INITIAL ADDR
0150  4771          STC VCERR     /VCERR SET TO 0
0151  4770          STC HCERR     /HCERR SET TO 0
0152  4772          STC EFLAG1    /EFLAG1 SET TO 0
0153  1020          LDA I
0154  0471          APO I         /TV FIELD COUNT
0155  4417          STC M1        /ROUTINE SET TO
0156  1020          LDA I         /INITIAL CONDITIONS
0157  7757          -20
0160  4424          STC M2
0161  1000          LDA
0162  2000          2000
0163  4774          STC TVC       /INITIAL VC
0164  0002          PDP
                    PMODE
0165  5700          JMP I SINIT2
            /
            /
            /
            /
            /
            /
            /
            /
                    LMODE
            /SUBROUTINE TO START PROCESSING
                    *400
                    PMODE
0400  0000  START1, 0000
0401  6141          LINC
                    LMODE
0402  1020          LDA I
0403  7771          -6
0404  4773          STC HCNT      /SET UP HC COUNTER
0405  1020          LDA I
0406  4000          4000
0407  4762          STC TEMSTO    /RESET TEMSTO
0410  2774          ADD TVC
0411  1560          BCL I
0412  6000          6000
0413  1040          STA           /NEXT VC STORED
0414  0537          VC
0415  1120          ADA I
0416  7307          -470
0417  0471  M1,     APO I         /NEW TV FIELD?
0420  6432          JMP .+12
0421  0224          XSK I TVFCNT  /INC TV FIELD COUNTER
0422  0011          CLR
0423  1120          ADA I
0424  7757  M2,     -20
0425  2417          ADD .-6       /ADD APO INST
0426  4417          STC .-7       /REPLACE MODIFIED INS
0427  2424          ADD .-3
0430  0017          COM
0431  4424          STC .-5       /APO I INS CHANGED
0432  0002          PDP
                    PMODE
0433  5600          JMP I START1  /RETURN
            /
            /
            /
            /
            /SUBROUTINE TO PROCESS HORIZONTAL COORDINATE
0434  0000  SPHC,   0000          /RETURN JMP
0435  6141          LINC
                    LMODE
0436  1000          LDA
0437  0773          HCNT
0440  1120          ADA I
0441  0005          5
0442  1120          ADA I
0443  2000          2000          /ADD 1-7
0444  4453          STC AD
0445  2773          ADD HCNT      /FORM ROL N TO
0446  1660          BCO I         /CORRECTLY ORIENTATE
0447  0037          0037          /SR WORD.
0450  1120          ADA I
0451  0256          0256          /ROL N, FORMED
0452  4454          STC .+2
0453  0000  AD,     0000          /ADD HCN
0454  0000          0000          /ROL N
0455  4540          STC SR        /SAVE SR WORD
0456  2772          ADD EFLAG1
0457  0471          APO I         /FLAG SET ?
0460  6465          JMP .+5       /NO
0461  1020          LDA I         /YES
0462  2000          2000
0463  4501          STC LHC       /LAST HC
0464  6470          JMP .+4
0465  1020          LDA I
0466  2027          2027
0467  4501          STC LHC       /LAST HC
0470  0011          CLR
0471  4772          STC EFLAG1    /CLEAR FLAG
0472  0011  HCP1,   CLR
0473  2453          ADD AD
0474  1120          ADA I
0475  7776          -1
0476  1040          STA
0477  0453          AD
0500  1460          SAE I         /LAST HC ?
0501  0000  LHC,    0000          /2027 OR 2000
0502  6505          JMP .+3       /NO
0503  0002          PDP           /YES, RETURN TO
```

```
                        PMODE          /PROCESS NEXT
2504  5520              JMP I BEGIN    /TV LINE OF DATA
                        LMODE
0505  4506              STC .+1
0506  0000              0000           /ADD LATEST HC
0507  4536              STC HC
0510  0002              PDP
                        PMODE
2511  5634              JMP I SPHC
                /
                /
                /
                /
                /SUBROUTINE TO EVALUATE CAMERA CODE
2512  0000      SCODE,  0000           /RETURN JMP
2513  6141              LINC
                        LMODE
0514  0011              CLR
0515  2540              ADD SR
0516  0261              ROL I 1
0517  4540              STC SR         /REPLACE SHIFTED SR
0520  2536              ADD HC
0521  0312              ROR 12
0522  0261              ROL I 1
0523  1560              BCL I
0524  7770              7770
0525  4541              STC CAMCO      /CAMERA CODE
0526  2536              ADD HC
0527  1560              BCL I
0530  6000              6000
0531  4536              STC HC
0532  0002              PDP
                        PMODE
2533  1341              TAD CAMCO
2534  3111              DCA CAMCO1
2535  5712              JMP I SCODE    /RETURN
                /
                        LMODE
                /
0536  0000      HC,     0
0537  0000      VC,     0
0540  0000      SR,     0
0541  0000      CAMCO,  0
                /
                        PMODE
                /
                /SUBROUTINE TO STORE COORDINATES
2542  0000      SSTORE, 0000           /RETURN JMP
2543  6141              LINC
                        LMODE
0544  0650              LDF 10
0545  1000              LDA
0546  0537              VC             /VERTICAL COORDINATE
0547  1063              STA I TBUF
0550  0222              XSK I TCNT     /TAPE BUFFER FULL?
0551  6553              JMP .+2        /NO
0552  7000              JMP MTAPE      /YES,STORE ON TAPE
0553  1000              LDA
0554  0536              HC             /HORIZONTAL COORD
0555  1063              STA I TBUF
0556  0222              XSK I TCNT
0557  6561              JMP .+2
0560  7000              JMP MTAPE
0561  0002              PDP
                        PMODE
2562  5742              JMP I SSTORE
                /
                /
                /
                        LMODE
                /SUBROUTINE TO TEST FOR VERTICAL COORDINATE
                        *600
                        PMODE
2600  0000      CVTEST, 0000           /RETURN JMP
2601  6141              LINC
                        LMODE
0602  0225              XSK I COUNT
0603  6605              JMP .+2
0604  6645              JMP FCNT       /END OF LINC FIELD
0605  0644      DFD,    0644           /LDF CURRENT DATA
0606  1021              LDA I STAD     /FIELD
0607  1560              BCL I          /NEXT WORD
0610  1777              1777
0611  1460              SAE I          /VC ?
0612  6000              6000
0613  6751              JMP CNTHC      /NO
0614  1000              LDA            /YES
0615  0001              STAD
0616  1120              ADA I
0617  7776              -1
0620  1620              BSE I
0621  2000              2000
0622  1460              SAE I          /ERROR
0623  0000      IADDR,  0000
0624  6626              JMP .+2        /NO
0625  6635              JMP .+10       /YES
0626  1001              LDA STAD       /VC FOR NEXT TV
0627  4774              STC TVC        /LINE STORED
0630  1000              LDA
0631  0001              STAD           /INITIAL ADDR
0632  4623              STC IADDR      /RESET
0633  0002              PDP
                        PMODE
2634  5600              JMP I CVTEST   /RETURN
                        LMODE
0635  0002              PDP
                        PMODE
2636  2371              ISZ VCERR      /INC VC ERROR COUNT
2637  5241              JMP .+2
2640  7402              HLT            /TOO MANY ERRORS
2641  7240              STA            /SET AC=7777
2642  3372              DCA EFLAG1     /SET ERROR FLAG
2643  6141              LINC
                        LMODE
0644  6751              JMP CNTHC
0645  0226      FCNT,   XSK I FCOUNT   /INC LINC FIELD
0646  6650              JMP .+2        /COUNT
0647  6656              JMP END        /END OF L FIELDS
0650  0011              CLR
0651  2605              ADD DFD        /INCREMENT CURRANT
0652  1120              ADA I          /LINC FIELD
0653  0001              1
0654  4605              STC DFD
0655  6605              JMP DFD
0656  0016      END,    NOP
0657  0011              CLR
```

```
0660  2356          ADD REM          /SET UP COUNTER
0661  0017          COM              /FOR REMAINDER
0662  4005          STC COUNT
0663  1020          LDA I
0664  7776          -1
0665  4006          STC FCOUNT
0666  2605          ADD DFD          /INC LINC FIELD
0667  1120          ADA I
0670  0001          1
0671  4605          STC DFD
0672  1020          LDA I
0673  6676          JMP .+3
0674  4656          STC END
0675  6605          JMP DFD          /RETURN TO PROCESS
0676  1020          LDA I            /REMAINDER
0677  6701   END1,  JMP .+2
0700  4656          STC END
0701  0006          SET I FCOUNT     /PROCESS LAST
0702  7776          -1               /TV LINE OF
0703  0005          SET I COUNT      /DATA
0704  7776          -1
0705  1020          LDA I
0706  6711          JMP .+3
0707  4656          STC END          /RESET END
0710  6624          JMP IADDR+1
0711  1020          LDA I            /FILL REMAINING
0712  7777          7777             /TAPE LOCATIONS
0713  4537          STC VC           /WITH 7777
0714  0017          COM
0715  4536          STC HC
0716  0017          COM
0717  4034          STC TVFCNT
0720  2033          ADD TBUF .
0721  1120          ADA I
0722  4777          -3000
0723  0471          APO I
0724  6727          JMP .+3
0725  1120          ADA I
0726  1000          1000
0727  0640          LDF 0
0730  1040          STA
0731  2127          JWLS!2000
0732  0011          CLR
0733  2360          ADD TBLK
0734  1120          ADA I
0735  0002          2
0736  4745          STC .+7
0737  0002          PDP
                    PMODE
2740  4514          JMS I STORE
2741  6141          LINC
                    LMODE
0742  1000          LDA
0743  0360          TBLK
0744  1460          SAE I            /TAPE STORE FULL ?
0745  0300          0300             /TBLK+2
0746  6737          JMP .-7          /NO
0747  0630          LIF 0
0750  6263          JMP PASS2        /YES
             /
             /
             /
             /
             /
             /COUNT HORIZONTAL COORDINATES & SE WORD
                    LMODE
0751  0002   CNTHC, PDP
                    PMODE
2752  2373          ISZ HCNT         /ERROR?
2753  5360          JMP .+5          /NO
2754  2370          ISZ HCERR        /YES, COUNT ERRORS
2755  5357          JMP .+2
2756  7402          HLT              /TOO MANY ERRORS
2757  5520          JMP I BEGIN      /RETURN TO START
2760  6141          LINC
                    LMODE
0761  1001          LDA STAD         /STORE CURRENT HC
             /                        IN APROPRIATE LOC
0762  4030   TEMSTO, 4030            /STC 30,31,32 ETC
0763  2762          ADD TEMSTO
0764  1120          ADA I
0765  0001          1
0766  4762          STC TEMSTO
0767  6602          JMP CVTEST+2
             /
             /
             /
0770  0000   HCERR, 0
0771  0000   VCERR, 0
0772  0000   EFLAG1, 0
0773  7771   HCNT,  -6
0774  0000   TVC,   0
             /
             /
             /
             /
             /
             /SUBROUTINE TO STORE DATA ON TAPE
                    *1000
1000  1000   MTAPE, LDA
1001  0000          0
1002  5066          STC RETURN       /SAVE RETURN ADDRESS
1003  1020          LDA I
1004  6777          -1000
1005  4030          STC TCNT         /RESET TCNT
1006  1000          LDA
1007  0360          TBLK
1010  1120          ADA I
1011  0001          1
1012  1040          STA
1013  0360          TBLK
1014  1120          ADA I
1015  3000          3000
1016  0451          APO              /TAPE OVERFLOW?
1017  0000          HLT              /YES
1020  1000          LDA              /NO
1021  0033          TBUF
1022  1120          ADA I
1023  1000          1000
1024  0471          APO I            /LOWER HALF FULL?
1025  7033          JMP .+6          /YES
1026  1000          LDA              /NO, UPPER HALF FULL
1027  0360          TBLK
1030  1120          ADA I
1031  6000          6000
1032  7037          JMP .+5
```

```
1033  1000           LDA
1034  0360           TBLK
1035  1120           ADA I
1036  4000           4000
1037  5041           STC .+2
1040  0714           0714           /WRC 1
1041  0000  XFER1,   0000
1042  1000           LDA
1043  1041           XFER1
1044  1120           ADA I
1045  1001           1001
1046  1040           STA
1047  1065           XFER2
1050  1000           LDA
1051  1041           XFER1
1052  1560           BCL I
1053  7000           7000
1054  1120           ADA I
1055  0001           1
1056  1040           STA
1057  0360           TBLK           /RESET TBLK
1060  1120           ADA I
1061  3000           3000
1062  0451           APO            /TAPE OVERFLOW?
1063  0000           HLT            /YES
1064  0714           0714           /NO, WRC 1
1065  0000  XFER2,   0000
1066  0000  RETURN,  0000           /RETURN JMP
            /
            /
            /
            /
            /
            /THIRD INITIALISATION, PASS 2
1067  0000  SINIT3,  0000           /RETURN ADDR
                     PMODE
3070  6141           LINC
                     LMODE
1071  0640           LDF 0
1072  1020           LDA I          /SETS UP RETURN
1073  0266           BEGIN2         /LOCATION FOR
1074  1040           STA            /COORD PROCESSING
1075  2120           BEGIN!2000     /IN PASS 2
1076  1000           LDA
1077  2053  I1,      CC2!2000       /ANY COORDS
1100  0470           AZE I          /COLLECTED BY
1101  7111           JMP T2         /CURRENT CAM CHAN?
1102  0011           CLR            /YES, CLEAR CURRENT
1103  1040           STA            /CAM CHAN COORD
1104  2053  I2,      CC2!2000       /COUNTERS
1105  1040           STA
1106  2052  I3,      CC1!2000
1107  0002           PDP
                     PMODE
3110  5667           JMP I SINIT3
                     LMODE
1111  1000  T2,      LDA            /CHECK LOW ORDER
1112  2052  I4,      CC1!2000       /HALF OF CNTR
1113  0451           APO            />2000 PTS ?
1114  7165           JMP RET        /YES, RETURN AND
1115  1120           ADA I          /PROCESS
1116  3740           3740
1117  0451           APO            />40 (OCTAL) PTS
1120  7165           JMP RET        /YES, RETURN
1121  0011           CLR            /NO
1122  1040           STA
1123  2052  I5,      CC1!2000
1124  1020           LDA I          /INCREMENT CURRENT
1125  0002           2              /CAMERA CHANNEL
1126  1140           ADM            /COORDINATE COUNTERS
1127  1077           I1             /BY 2 IN THESE
1130  1020           LDA I          /LOCATIONS
1131  0002           2
1132  1140           ADM
1133  1104           I2
1134  1020           LDA I
1135  0002           2
1136  1140           ADM
1137  1106           I3
1140  1020           LDA I
1141  0002           2
1142  1140           ADM
1143  1112           I4
1144  1020           LDA I
1145  0002           2
1146  1140           ADM
1147  1123           I5
1150  1020           LDA I
1151  0002           2
1152  1140           ADM
1153  1167           I6
1154  1020           LDA I
1155  0001           1
1156  1140           ADM
1157  2117           CC!2000        /INC CHAN COUNTER
1160  0600           LIF 0
1161  1460           SAE I          /ALL CHANS PROC?
1162  0006           6
1163  6263           JMP PASS2      /NO, REPEAT PASS 2
1164  6305           JMP PASS3      /YES
1165  0011  RET,     CLR
1166  1040           STA
1167  2052  I6,      CC1!2000
1170  0002           PDP
                     PMODE
3171  5667           JMP I SINIT3
            /
            /
            /
                     LMODE
            /SUBROUTINE TO INITIALIZE PASS 3
                     *1200
                     PMODE
3200  0000  SINIT4,  0000
3201  6141           LINC
                     LMODE
1202  0011           CLR
1203  5267           STC NB1
1204  4002           STC NB
1205  1020           LDA I
1206  0650           LDF 10
1207  5232           STC A1
1210  1000           LDA
1211  0361           ITBLK
1212  0017           COM
1213  2360           ADD TBLK
```

```
        1214  0002         PDP
                           PMODE
        3215  1266         TAD KN4          /CALCULATE NO
        3216  2267         ISZ NB1          /OF LINC FIELDS
        3217  7540         SZA SMA
        3220  5215         JMP .-3
        3221  7300         CLA CLL
        3222  6141         LINC
                           LMODE
        1223  3267         ADD NB1
        1224  0017         COM              /SET LINC FIELD
        1225  4307         STC LFCNT        /COUNT
        1226  2361         ADD ITBLK
        1227  1120         ADA I
        1230  4001         4001             /SET INITIAL
        1231  5236         STC A2           /TAPE BLOCK NO
        1232  0650   A1,   LDF 10
        1233  0361         SET I TTC        /SET TO XFER
        1234  7773         -4               /4 BLOCKS
        1235  0710         0710             /RDC 1
        1236  0003   A2,   0003             /MBLK\TBLK,
        1237  1020         LDA I
        1240  1001         1001             /INC MBLK & TBLK
        1241  1140         ADM
        1242  1236         A2
        1243  0221         XSK I TTC        /4 BLOCKS?
        1244  7235         JMP A2-1         /NO
        1245  0227         XSK I LFCNT      /YES,ANY MORE?
        1246  0456         SKP              /YES
        1247  7264         JMP A3           /NO,RETURN
        1250  1020         LDA I
        1251  0001         1
        1252  1140         ADM              /INC CURRENT
        1253  1232         A1               /LINC FIELD
        1254  1000         LDA
        1255  1236         A2
        1256  1120         ADA I            /RESET MBLK
        1257  7776         -1
        1260  1120         ADA I
        1261  4000         4000
        1262  5236         STC A2
        1263  7232         JMP A1
        1264  0002   A3,   PDP
                           PMODE
        3265  5600         JMP I SINIT4
                     /
                     /
        3266  7774   KN4,  -4
                     /
                           LMODE
                     /
        1267  0000   NB1,  0
                     /
                     /
                     /
                     /
                           *1430
                           PMODE
                     /SCALE DATA AND STORE IN DISPLAY BUFFER
        3400  0000   SSCLA, 0000
        3401  6141         LINC
                           LMODE
```

```
        1402  1020         LDA I
        1403  0646         LDF 6
        1404  5414         STC B1
        1405  0011         CLR
        1406  0064         SET I RGD1       /DATA POINTER
        1407  3777         3777
        1410  0065         SET I RGD2       /DISP BUFFER
        1411  3777         3777             /POINTER,VC
        1412  0066         SET I RGD3       /DISP BUFFER
        1413  3777         3777             /POINTER,HC
        1414  0646   B1,   LDF 6
        1415  1024         LDA I RGD1       /VC
        1416  1460         SAE I
        1417  7777         7777
        1420  0456         SKP
        1421  7472         JMP B4           /END OF DATA
        1422  4537         STC VC
        1423  1024         LDA I RGD1       /HC
        1424  0341         SCR 1
        1425  4536         STC HC
        1426  2537         ADD VC
        1427  1120         ADA I
        1430  7307         -470
        1431  0471         APO I            /ODD OR EVEN FIELD
        1432  7444         JMP B2
        1433  1120         ADA I
        1434  0270         270
        1435  0017         COM
        1436  4537         STC VC
        1437  1020         LDA I
        1440  4000         4000
        1441  1140         ADM              /SET HC FOR DISPLAY
        1442  0536         HC               /ON CHANNEL 2
        1443  7450         JMP B3
        1444  1120   B2,   ADA I
        1445  7577         -240
        1446  0017         COM
        1447  4537         STC VC           /DISPLAY ON CHAN 1
        1450  0644   B3,   LDF 4
        1451  1000         LDA              /STORE IN DISPLAY
        1452  0537         VC               /BUFFER
        1453  1065         STA I RGD2
        1454  0645         LDF 5
        1455  1000         LDA
        1456  0536         HC
        1457  1066         STA I RGD3
        1460  0245         XSK RGD2         /DISP BUF FULL?
        1461  0456         SKP              /NO
        1462  7472         JMP B4           /YES,EXIT
        1463  0244         XSK RGD1         /END OF L FIELD?
        1464  7414         JMP B1           /NO
        1465  1020         LDA I            /YES,INC LDF
        1466  0001         1
        1467  1140         ADM
        1470  1414         B1               /INC L FIELD
        1471  7414         JMP B1
        1472  0002   B4,   PDP
                           PMODE
        3473  5600         JMP I SSCLA
                     /
                     /
                     /
```

```
                  /
                  /
                  /SUBROUTINE TO DISPLAY GRID
3474  0000  SDISP,  0000
3475  6141          LINC
                    LMODE
1476  1000          LDA
1477  0335          RGD2
1500  1560          ROL I
1501  6000          6000
1502  0017          COM
1503  1120          ADA I
1504  7776          -1
1505  5507          STC .+2
1506  0063  C1,     SET I RGD
1507  0000          0000
1510  0065          SET I RGD2
1511  3777          3777
1512  0066          SET I RGD3
1513  3777          3777
1514  0645  C2,     LIF 5
1515  1036          LDA I RGD3
1516  4037          STC DR          /HC
1517  0644          LIF 4
1520  1025          LDA I RGD2
1521  0147          DIS DR
1522  0223          XSK I RGD       /END OF BUFFER?
1523  7514          JMP C2          /NO
1524  0440          SNS 0
1525  7506          JMP C1          /YES
1526  1020          LDA I
1527  0020  C3,     20
1530  1140          ADM
1531  1524          C3-3
1532  1000          LDA
1533  1527          C3
1534  0017          COM
1535  5527          STC C3
1536  0002          PDP
                    PMODE
3537  5674          JMP I SDISP
                  /
                  /
                  /
                  /
                    LMODE
                  /
                    *1
0001  0000  STAD,   0
0002  0000  ICNT,   0
0003  0000  TRGP,   0
0004  0000  TVFCNT, 0
0005  0000  COUNT,  0
0006  0000  FCOUNT, 0
0007  0000  LFCNT,  0
                  /
                  /
                  /
                  /
                  /
                    TIC=STAD
                    VP=ICNT
                    RGD=TRGP
                    RGD1=TVFCNT
                    RGD2=COUNT
                    RGD3=FCOUNT
                    DR=LFCNT
                  /
                  /
                  /
                  /
                    SEGMNT 2
                  /
                    *200
                  /
                  /SUBROUTINE TO LOCATE COORDINATES BELONGING
                  /TO THE SAME MARKER.
                  /
                    PMODE
4200  0000  SCOMP,  0000
4201  6141          LINC
                    LMODE
4202  0074          SET I SGD
4203  3777          3777
4204  0002          PDP
                    PMODE
4205  7300          CLA CLL
4206  1124          TAD KM1
4207  3010          DCA GD
4210  7300  CO0,    CLA CLL
4211  1213          TAD .+2         /RESET CO2
4212  7410          SKP
4213  3346          DCA HC1
4214  3301          DCA CO2
4215  6221          CDF 20
4216  1410          TAD I GD        /VC TO AC
4217  7040          CMA
4220  7440          SZA             /END OF DATA?
4221  5223          JMP .+2         /NO
4222  5330          JMP CO4         /YES, RETURN
4223  7040          CMA
4224  3337          DCA RVC
4225  1410          TAD I GD        /HC TO AC
4226  7440          SZA             /ALREADY PROCESSED?
4227  7410          SKP             /NO
4230  5210          JMP CO0         /YES
4231  3340          DCA RHC
4232  1340          TAD RHC
4233  3344          DCA CHC1
4234  1337          TAD RVC
4235  1113          TAD K1          /VC+1
4236  3341          DCA CVC         /COMPARISON VC
4237  1010          TAD GD
4240  3011          DCA FVC         /SET UP DATA POINTER
4241  1411  CO1,    TAD I FVC       /NEXT VC TO COMPARE
4242  3342          DCA CVC1
4243  1342          TAD CVC1
4244  7040          CMA
4245  7440          SZA             /END OF DATA
4246  7410          SKP             /NO
4247  5323          JMP CO3         /YES, GO REDUCE DATA
4250  7001          IAC             /TWOS COMPLEMENT
4251  1341          TAD CVC         /CVC-VC
4252  7440          SZA             /VC=CVC?
4253  7410          SKP             /NO
4254  5264          JMP CO1A        /YES
```

```
4255  1124          TAD KN1
4256  7443          SZA             /VC=CVC-1?
4257  7410          SKP             /NO
4260  5264          JMP CO1A        /YES
4261  2311          ISZ FVC         /INC FVC
4262  7300          CLA CLL
4263  5241          JMP CO1         /GET NEXT VC
4264  1411  CO1A,   TAD I FVC       /VC=CVC,NOW
4265  3343          DCA CHC         /COMPARE HC
4266  1343          TAD CHC
4267  7041          CIA
4270  1344          TAD CHC1        /CHC1-CHC
4271  7510          SPA             /+VE?
4272  7041          CIA             /NO
4273  1336          TAD KN15        /-15
4274  7700          SMA CLA         /DIFF >I15I
4275  5241          JMP CO1         /YES,GET NEXT VC
4276  2345          ISZ NHC         /NO,COUNT HC
4277  7300          CLA CLL
4300  1343          TAD CHC
4301  3346  CO2,    DCA HC1         /STORES HC FOR
4302  2301          ISZ CO2         /EACH POINT IN
4303  1311          TAD FVC         /HC1,HC2,ETC
4304  1124          TAD KN1         /FVC-1
4305  3311          DCA FVC         /REPLACES HC WITH 0
4306  3411          DCA I FVC       /TO INDICATE IT HAS
4307  1342          TAD CVC1
4310  7041          CIA
4311  1341          TAD CVC
4312  7443          SZA
4313  2341          ISZ CVC         /BEEN PROCESSED
4314  7000          NOP
4315  1343          TAD CHC
4316  3344          DCA CHC1
4317  5241          JMP CO1
4320  4534  CO3,    JMS I RED       /REDUCE DATA
4321  4535          JMS I STOR      /STORE DATA
4322  7300          CLA CLL
4323  1325          TAD .+2
4324  7410          SKP
4325  3346          DCA HC1
4326  3301          DCA CO2
4327  5210          JMP CO3
4330  7240  CO4,    STA
4331  3337          DCA RVC
4332  7240          STA
4333  3340          DCA RHC
4334  4535          JMS I STOR
4335  5600          JMP I SCJMP
                /
                /
                /
4336  7763  KN15,   -15
                /
                    LMODE
0337  0000  RVC,    0
0340  0000  RHC,    0
0341  0000  CVC,    0
0342  0000  CVC1,   0
0343  0000  CHC,    0
0344  0000  CHC1,   0
0345  0000  NHC,    0
                /
0346  0000  HC1,    0
0347  0000  HC2,    0
0350  0000  HC3,    0
0351  0000  HC4,    0
0352  0000  HC5,    0
0353  0000  HC6,    0
0354  0000  HC7,    0
0355  0000  HC10,   0
0356  0000  HC11,   0
0357  0000  HC12,   0
0360  0000  HC13,   0
0361  0000  HC14,   0
0362  0000  HC15,   0
0363  0000  HC16,   0
0364  0000  HC17,   0
0365  0000  HC20,   0
                /
                /
                /
                /
                    *400
                    PMODE
                /
                /SUBROUTINE TO REDUCE DATA TO ONE
                /COORDINATE PAIR PER GRID POINT
                /
4400  0000  SRED,   0000
4401  6141          LINC
                    LMODE
0402  0011          CLR
0403  4521          STC AHC         /AHC SET TO 0
0404  1000          LDA
0405  0340          RHC
0406  0017          COM
0407  4520          STC AHC
0410  2345          ADD NHC
0411  1460          SAE I           /ONLY 1 PAIR OF
0412  0001          1               /COORDINATES?
0413  0456          SKP             /NO,REDUCE
0414  6516          JMP R3          /YES,STORE
0415  1120          ADA I
0416  7767          -10
0417  0451          APO             /> 10 HC COORDS
0420  6426          JMP .+6         /NO
0421  1020          LDA I           /YES,MAKE NHC=10
0422  0010          10
0423  1040          STA
0424  0345          NHC
0425  6430          JMP .+3
0426  1120          ADA I
0427  0010          10
0430  1120          ADA I
0431  2520          2000+RTAB-2     /FORM ADD INST
0432  4433          STC .+1         /TO GET APPROPRIATE
0433  0016          NOP             /RECIPROCAL
0434  4465          STC RDIV
0435  2345          ADD NHC
0436  0017          COM
0437  4011          STC CTR         /SET HC COUNTER
0440  0231  AVE,    XSK I CTR
0441  0456          SKP
0442  6455          JMP R2          /DIFF SUMMED
0443  1000          LDA             /CALCULATE SUM
```

```
0444  0346  R1,     HC1              /OF DIFFERENCES
0445  2520          ADD MHC
0446  1143          ADM
0447  0521          AHC
0450  1020          LDA I
0451  0001          1
0452  1143          ADM
0453  0444          R1               /INC R1
0454  6440          JMP AVE
0455  1000  R2,     LDA
0456  0521          AHC
0457  0241          ROL 1            /X10 (BINARY)
0460  1560          BCL I
0461  0001          1
0462  1240          MUL              /FRACTIONALY
0463  4465          .+4002           /MULTIPLY
0464  0456          SKP
0465  0000  RDIV,   0000             /MULTIPLIER
0466  0321          ROR I 1          /DIV BY 10
0467  0451          APO              /-VE OR +VE?
0470  6476          JMP .+6          /-VE, ROUND DOWN
0471  0472          LZE I            /+VE, ROUND UP?
0472  6502          JMP .+10
0473  1120          ADA I
0474  0001          1
0475  6502          JMP .+5
0476  0452          LZE              /ROUND DOWN?
0477  6502          JMP .+3          /NO
0500  1120          ADA I
0501  7776          -1
0502  1100          ADA
0503  0340          RHC
0504  4340          STC RHC          /AVERAGED HC
0505  2337          ADD RVC
0506  0017          COM
0507  2341          ADD CVC          /CVC-RVC
0510  1240          MUL              /DIV BY 2
0511  4513          .+4002
0512  0456          SKP
0513  2000          2000
0514  2337          ADD RVC
0515  4337          STC RVC
0516  0002  R3,     PDP
                    PMODE
4517  5600          JMP I SRED
              /
              /
                    LMODE
0520  0000  MHC,    0
0521  0000  AHC,    0
              /
0522  2000  RTAB,   2000             /RECIPROCAL OF 2
0523  1252          1252             /3
0524  1000          1000             /4
0525  0631          0631             /5
0526  0526          0526             /6
0527  0444          0444             /7
0530  0400          0400             /10
              /
              /
              /
              /SUBROUTINE TO STORE REDUCED COORDINATES
              /
                    PMODE
4531  0000  SSTOR,  0000
4532  6141          LINC
                    LMODE
0533  0646          LIF 6
0534  1000          LDA
0535  0337          RVC
0536  1070          STA I SGD
0537  1000          LDA
0540  0340          RHC
0541  1070          STA I SGD
0542  1020          LDA I
0543  0001          1
0544  4345          STC NHC
0545  1020          LDA I
0546  0346          HC1
0547  4444          STC R1
0550  0002          PDP
                    PMODE
4551  5731          JMP I SSTOR
              /
              /
                    LMODE
                    *600
                    PMODE
              /
              /SUBROUTINE TO BUILD CALIBRATION MATRIX
              /
4600  0000  SMTX,   0000
4601  7240          STA
4602  3010          DCA GD
4603  6221          CIF 20
4604  3131          DCA TEMP
4605  1136          TAD K3777
4606  3410          DCA I GD
4607  2131          ISZ TEMP
4610  5205          JMP .-3
4611  7240          STA
4612  3131          DCA TEMP
4613  7240          STA                  /SET UP MTX FOR
4614  3010          DCA MTXV             /VC
4615  1141          TAD K37              /SET UP MTX FOR
4616  3011          DCA MTXH             /HC
4617  6141          LINC
                    LMODE
0620  0070          SET I SGD
0621  3777          3777
0622  0646  MT1,    LIF 6
0623  1030          LDA I SGD
0624  1460          SAE I                /END OF DATA?
0625  7777          7777
0626  0456          SKP                  /NO
0627  6751          JMP MT4              /YES, MTX BUILT
0630  4761          STC VE1
0631  1030          LDA I SGD
0632  1460          SAE I                /ALREADY PROCESSED?
0633  0000          0
0634  0456          SKP                  /NO
0635  6622          JMP MT1              /YES
0636  4763          STC HE1
0637  1000          LDA
0640  3010          SGD
0641  1040          STA
```

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```
0642 0765          ADDR
0643 4012          STC FCO
0644 1032   MT2,   LDA I FCO
0645 1460          SAE I               /END OF DATA?
0646 7777          7777
0647 0456          SKP                 /NO
0650 6674          JMP MT3             /YES
0651 1040          STA
0652 0762          VE2
0653 0017          COM
0654 2761          ADD VE1
0655 1120          ADA I
0656 0010          10
0657 0471          APO I               /<VE1+10?
0660 6663          JMP .+3             /YES
0661 0232          XSK I FCO           /NO
0662 6644          JMP MT2
0663 1032          LDA I FCO
0664 1460          SAE I               /ALREADY PROCESSED
0665 0000          0
0666 0456          SKP                 /NO
0667 6644          JMP MT2             /YES
0670 4763          STC HE1
0671 2762          ADD VE2
0672 4761          STC VE1
0673 6644          JMP MT2             /NO
0674 1000   MT3,   LDA
0675 0010          SGD
0676 1120          ADA I
0677 7775          -2
0700 1620          BSE I
0701 2000          2000
0702 4704          STC .+2
0703 0072          SET I FCO
0704 0000          0000
0705 1032          LDA I FCO
0706 1460          SAE I
0707 7777          7777
0710 0456          SKP
0711 6753          JMP MT5             /END OF DATA
0712 1040          STA
0713 0762          VE2
0714 0017          COM
0715 2761          ADD VE1
0716 1120          ADA I
0717 0010          10
0720 0471          APO I               /<VE1+10?
0721 6724          JMP .+3             /YES
0722 0232          XSK I FCO           /NO
0723 6705          JMP MT3+11
0724 1032          LDA I FCO
0725 1460          SAE I               /ALREADY PROCESSED?
0726 0000          0
0727 0456          SKP                 /NO
0730 6705          JMP MT3+11          /YES
0731 1040          STA
0732 0764          HE2
0733 0017          COM
0734 2763          ADD HE1
0735 1120          ADA I
0736 0015          15
0737 0451          APO                 /<HE1+15?
0740 6705          JMP MT3+11          /NO
0741 1000          LDA                 /YES
0742 0764          HE2
0743 4763          STC HE1
0744 2762          ADD VE2
0745 4761          STC VE1
0746 2012          ADD FCO
0747 4765          STC ADDR
0750 6705          JMP MT3+11
0751 0002   MT4,   PDP
                   PMODE
4752 5600          JMP I SMTX
                   LMODE
0753 1000   MT5,   LDA
0754 0761          VE1
0755 5057          STC VE
0756 2763          ADD HE1
0757 5060          STC HE
0760 7000          JMP MT6
            /
            /
            /
0761 0000   VE1,   0
0762 0000   VE2,   0
0763 0000   HE1,   0
0764 0000   HE2,   0
0765 0000   ADDR,  0
            /
                   *1000
1000 0002   MT6,   PDP
                   PMODE
5001 7300          CLA CLL
5002 2131          ISZ TEMP            /FIRST COORD?
5003 7410          SKP
5004 5213          JMP MT7             /YES
5005 1257          TAD VE
5006 7041          CIA
5007 1261          TAD LVE
5010 1262          TAD K6
5011 7510          SPA                 /START NEW ROW?
5012 5237          JMP MT10                  /YES
5013 7300   MT7,   CLA CLL
5014 6201          CDF 00
5015 1257          TAD VE
5016 3410          DCA I MTXV
5017 1260          TAD HE
5020 3411          DCA I MTXH
5021 1257          TAD VE
5022 3261          DCA LVE
5023 6141          LINC
                   LMODE
1024 0046          LDF 6
1025 1000          LDA
1026 0765          ADDR
1027 1120          ADA I
1030 7775          -2
1031 1620          BSE I
1032 6000          6000
1033 4012          STC FCO
1034 1072          STA I FCO
1035 1072          STA I FCO
1036 6020          JMP MT1-2
                   PMODE
5037 7300   MT10,  CLA CLL
```

```
5040  1010           TAD MTKV
5041  6141           LINC
                     LMODE
1042  1560           BCL I
1043  0077           0077
1044  0002           PDP
                     PMODE
5045  1142           TAD K77
5046  3010           DCA MTKV
5047  1011           TAD MTKH
5050  6141           LINC
                     LMODE
1051  1560           BCL I
1052  0377           0377
1053  0002           PDP
                     PMODE
5054  1143           TAD K137
5055  3011           DCA MTKH
5056  5213           JMP MT7
                /
                /
                     LMODE
                /
1057  0000      VE,  0
1060  0000      HE,  0
1061  0000      LVE, 0
1062  0006      K6,  6
                /
                /
                /
                /SUBROUTINE TO PUT ACTIVE ELEMENTS OF
                /MATRIX INTO DISPLAY BUFFER
                     PMODE
5063  0000  SCHECK,  0000
5064  7300           CLA CLL
5065  1141           TAD K37
5066  3011           DCA MTKH
5067  7240           STA
5070  3010           DCA MTKV
5071  1173           TAD K027
5072  3131           DCA TEMP
5073  6141           LINC
                     LMODE
1074  0070           SET I SGD
1075  3777           3777
1076  1020           LDA I
1077  0646           LDF 6
1100  1040           STA
1101  1110           CH2
1102  5123           STC CH3
1103  0002           PDP
                     PMODE
5104  7200      CH1, CLA
5105  6221           CIF 20
5106  1410           TAD I MTKV
5107  6141           LINC
                     LMODE
1110  0646      CH2, LDF 6
1111  1460           SAE I
1112  3777           3777
1113  0456           SKP
1114  0456           SKP
1115  1070           STA I SGD
1116  0002           PDP
                     PMODE
5117  6221           CIF 20
5120  7200           CLA
5121  1411           TAD I MTKH
5122  6141           LINC
                     LMODE
1123  0646      CH3, LDF 6
1124  1460           SAE I
1125  3777           3777
1126  0456           SKP
1127  7142           JMP CH4
1130  1070           STA I SGD
1131  0210           XSK SGD
1132  7140           JMP .+6
1133  1020           LDA I
1134  0001           1
1135  1143           ADM
1136  1110           CH2
1137  5123           STC CH3
1140  0002           PDP
                     PMODE
5141  5304           JMP CH1
                     LMODE
1142  0002      CH4, PDP
                     PMODE
5143  7200           CLA
5144  1010           TAD MTKV
5145  6141           LINC
                     LMODE
1146  1560           BCL I
1147  0377           0377
1150  0002           PDP
                     PMODE
5151  1142           TAD K77
5152  3010           DCA MTKV
5153  1011           TAD MTKH
5154  6141           LINC
                     LMODE
1155  1560           BCL I
1156  0377           0377
1157  0002           PDP
                     PMODE
5160  1143           TAD K137
5161  3011           DCA MTKH
5162  2131           ISZ TEMP
5163  5304           JMP CH1
5164  6141           LINC
                     LMODE
1165  1020           LDA I
1166  7777           7777
1167  1070           STA I SGD
1170  1070           STA I SGD
1171  0002           PDP
                     PMODE
5172  5663           JMP I SCHECK
                /
                /
                /
5173  7751      K027, -27
                /
                /
                     LMODE
```

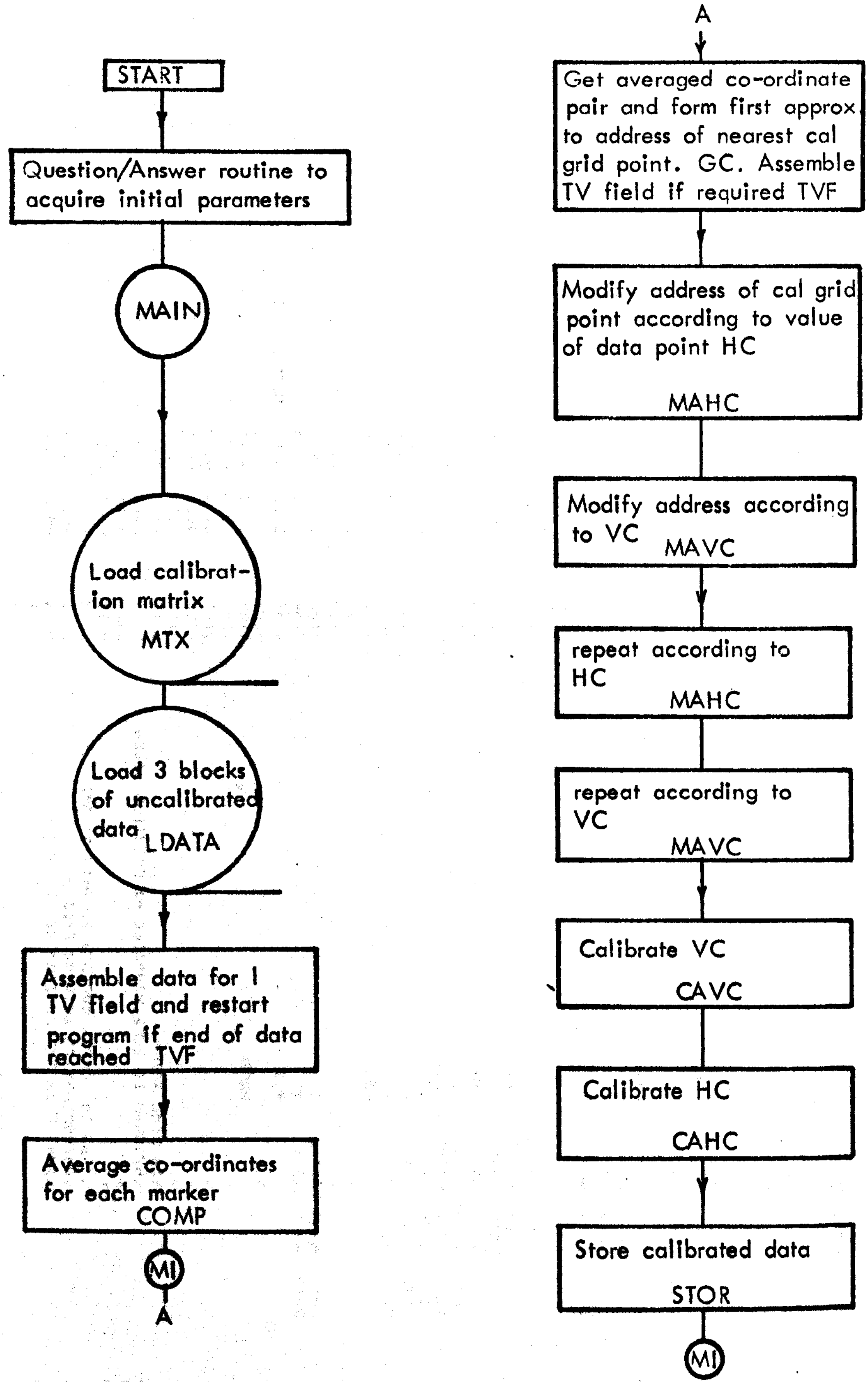
```
                  *1200
                  PMODE
      /SUBROUTINE TO STORE CALIBRATION MATRIX /ON TAPE.
      /
5200  0000  STAPE,  0000
5201  6141          LINC
                    LMODE
1202  1020          LDA I
1203  0650          LDF 10
1204  5216          STC TA1
1205  0071          SET I CTR
1206  7771          -6
1207  0072          SET I FCO
1210  7773          -4
1211  1000          LDA
1212  1270          CTBLK
1213  1120          ADA I
1214  4001          4001
1215  5220          STC TA2
1216  0650  TA1,    LDF 10
1217  0714          0714            /WRC 1
1220  0000  TA2,    0000            /MBLK\TBLK
1221  1020          LDA I
1222  1001          1001
1223  1140          ADM
1224  1220          TA2
1225  0232          XSK I FCO
1226  7244          JMP TA3
1227  1020          LDA I
1230  0001          1
1231  1140          ADM
1232  1216          TA1
1233  0072          SET I FCO
1234  7773          -4
1235  1000          LDA
1236  1220          TA2
1237  1120          ADA I
1240  7776          -1
1241  1120          ADA I
1242  4000          4000
1243  5220          STC TA2
1244  0231  TA3,    XSK I CTR
1245  7216          JMP TA1
1246  1020          LDA I
1247  0650          LDF 10
1250  5216          STC TA1
1251  3220          ADD TA2
1252  1120          ADA I
1253  7776          -1
1254  1560          BCL I
1255  7000          7000
1256  1040          STA
1257  1270          CTBLK
1260  1120          ADA I
1261  7707          -70
1262  0451          APO
1263  0456          SKP
1264  0000          HLT
1265  0011          CLR
1266  0002          PDP
                    PMODE
5267  5600          JMP I STAPE
      /
      /
                    LMODE
1270  0017  CTBLK,  17
      /
      /
                    *10
0010  3777  SGD,    3777
0011  0000  CTR,    0
0012  0000  FCO,    0
      /
      /
      /
```

NO ERRORS

```
AD      2453
ADDR    4765
AHC     4521
AVE     4440
A1      3232
A2      3236
A3      3264
BEGIN   0120
BEGIN1  0232
BEGIN2  0266
B1      3414
B2      3444
B3      3450
B4      3472
CA      1104
CAD     0102
CAGO    6303
CAGOFR  6305
CAL     0121
CAM     0122
CAMCO   2541
CAMCO1  0111
CC      0117
CCAFL   6306
CC1     0052
CC2     0053
CDBF    6347
CDBI    6344
CDBM    6342
CFA     0133
CFC     6315
CHC     4343
CHC1    4344
CHECK   0140
CH1     5104
CH2     5110
CH3     5123
CH4     5142
CLAD    6334
CLCAL   6314
CNTHC   2751
CODE    0110
COMP    0133
COUNT   2005
CO0     4210
CO1     4241
CO1A    4264
CO2     4301
```

CO3	4320
CO4	4330
CSM	6316
CTPLK	5270
CTP	4311
CVC	4341
CVC1	4342
CVTEST	2600
C1	3536
C2	3514
C3	3527
DPM	6341
DPD	2605
DPD1	2357
DISCG	6322
DISP	0123
DR	3307
EFLAG1	2772
ENAD	6331
ENCG	6321
END	2656
ENDPI	6343
END1	2677
ENFAD	6332
ENFC	6313
ENMON	6301
ENSM	6314
FCNT	2645
FCD	4312
FCOUNT	2346
FVC	3311
GL	3313
HC	2536
HCERR	2773
HCNT	2773
HCP1	2472
HC1	4346
HC10	4355
HC11	4356
HC12	4357
HC13	4360
HC14	4361
HC15	4362
HC16	4363
HC17	4364
HC2	4347
HC20	4365
HC3	4350
HC4	4351
HC5	4352
HC6	4353
HC7	4354
HF	5360
HF1	4763
HF2	4764
IADDR	2623
INIT1	0132
INIT2	3135
INIT3	3116
INIT4	3133
IPPLK	2361
I1	3077
I2	3104
I3	3106
I4	3112
I5	3123
I6	3167
KM1	0125
KN1	0124
KN15	4336
KN27	5173
KN4	3266
K1	0113
K137	0143
K2000	0112
K37	0141
K3777	0136
K6	5062
K77	0142
LDCA	6333
LICAM	6302
LIFC	6311
LILC	6312
LPCNT	2237
LHC	2501
LVE	5061
MAIN1	4031
MHC	4523
MTAPE	3000
MTK	0137
MTKH	0011
MTKV	0013
MT1	4622
MT10	5337
MT2	4644
MT3	4674
MT4	4751
MT5	4753
MT6	5300
MT7	5313
M1	2417
M2	2424
NR	3302
NP1	3267
NHC	4345
NLF	2355
NWDS	0127
PASS2	1063
PASS3	0305
PHC	0107
RCA	6335
RCFA	6336
RLIV	4465
RFD	0134
RFM	2356
RFT	3165
RETURN	3066
RGD	0043
RGD1	0044
RGD2	0035
RGD3	0046
RHC	4340
R1AB	4522
RVC	4337
R1	4444
R2	4455
R3	4516
SCAC	6307
SCAL	0200
SCPH	6345
SCLA	0126
SCHECK	5063
SCODE	2512
SCOMP	4200
SDISP	3474
SECT	0130
SGD	4010
SINIT1	2230
SINIT2	2100
SINIT3	3067
SINIT4	3200
SLCT	0131
SMTK	4600
SPHC	2434
SR	2540
SRF1	4400
SSCLA	3400
SSTOP	4531
SSTORE	2542
STAD	2031
STAPE	5200
START	0115
START1	2400
STOR	0135
STORE	0114
SUPH	6346
TAPE	0144
TA1	5216
TA2	5223
TA3	5244
TPLK	2360
TPLF	2043
TCNT	2132
TEMP	0131
TEMSTO	2762
TIC	4001
TVC	2774
TVFCNT	2034
T2	3111
VC	2537
VCERR	2771
VCTEST	0136
VF	5057
VF1	4761
VF2	4762
XFER1	3041
XFER2	3065

Flow Chart for calibration program (CAL)



```
                    *20
                    /CAL - CALIBRATES DATA.
                    /
                    /16-6-75
                    /
                    /
                    /M.O.JARRETT.
                    /
                    /
                    /TAPE WITH CALIBRATION MATRIX AND
                    /UNACALIBRATED DATA ON UNIT 3.
                    /TAPE TO ACCEPT CALIBRATED DATA ON UNIT 2.
                    /
                    /
                    /PROGRAM IS SELF STARTING AT LOCATION 06020
                    /IN LINC MODE.
                    /
                    /
                    /
                    /
                            PMODE
                    /
                            *10
0010  0000  PTR,    0
0011  0000  FD,     0
                    /
                    /
                            *50
0050  0001  K1,     1
0051  7777  KN1,    -1
0052  0024  K24,    24
0053  7754  KN24,   -24
0054  0030  K30,    30
0055  7750  KN30,   -30
0056  0040  K40,    40
0057  0100  K100,   100
0060  7700  KN100,  -100
                    /
                    /
0061  0000  VC,     0
0062  0000  HC,     0
0063  0000  ADDR,   0
0064  3141  SRD,    SSRD
0065  3000  RED,    SRED
0066  2600  COMP,   SCOMP
0067  2400  TVF,    STVF
0070  2251  LDATA,  SLDATA
0071  4200  VCC,    SVCC
0072  4304  HCC,    SHCC
0073  4400  DIV,    SDIV
0074  0000  DIF,    0
0075  2230  MTX,    SMTX
0076  2310  GC,     SGC
0077  4600  CAVC,   SCAVC
0100  4633  CAHC,   SCAHC
0101  5000  STOR,   SSTOR
0102  5024  TAPE,   STAPE
0103  3433  MAVC,   SMAVC
0104  3400  MAHC,   SMAHC
                    /
                    /
                    /
                            LMODE
                            SEGMNT 0
                            *400
0400  0641  MAIN,   LDF 1
0401  0011          CLR
0402  1040          STA
0403  2531          FLAG!2000
0404  0002          PDP
                            PMODE
0405  4475          JMS I MTX       /LOAD CAL MTX
0406  4470          JMS I LDATA     /LOAD 1K OF DATA
0407  4467          JMS I TVF       /ASSEMBLE TV-FIELD
0410  4466          JMS I COMP      /REDUCE DATA
0411  4476  M1,     JMS I GC        /GET COORD PAIR
0412  4504          JMS I MAHC      /MODIFY CAL ADDR
0413  4503          JMS I MAVC      /NOW FOR VC
0414  4504          JMS I MAHC      /REPEAT
0415  4503          JMS I MAVC      /REPEAT FOR VC
0416  4477          JMS I CAVC      /CALIBRATE DATA VC
0417  4500          JMS I CAHC      /CALIBRATE DATA HC
0420  4501          JMS I STOR      /STORE CALIBRATED DATA
0421  5211          JMP M1
                            LMODE
0422  0641  END,    LDF 1
0423  1040          STA             /SET FN,VC,HC TO 7777
0424  2507          FN!2000
0425  0642          LDF 2
0426  1040          STA
0427  2656          CALVC!2000
0430  1040          STA
0431  2657          CALHC!2000
0432  1000          LDA
0433  3114          CDTBLK!2000
0434  1120          ADA I
0435  0003          3
0436  4446          STC M3
0437  0002  M2,     PDP
                            PMODE
0440  4501          JMS I STOR
0441  6141          LINC
                            LMODE
0442  0642          LDF 2
0443  1000          LDA
0444  3114          CDTBLK!2000
0445  1460          SAE I
0446  0000  M3,     2000
0447  6437          JMP M2
0450  0603          LIF 3
0451  6020          JMP 20
                    /
                    /
                    /
                            LMODE
                            SEGMNT 1
                    /
                    /SUBROUTINE TO LOAD CALIBRATION MATRIX.
                            *230
                    /
                            PMODE
2230  0000  SMTX,   0000
2231  6141          LINC
                            LMODE
2232  1020          LDA I
```

```
0233  0001            1
0234  0001            AXO
0235  0062            SET I CTR
0236  7771            -6
0237  0063            SET I FCTR
0210  7773            -4
0211  1000            LDA
0212  0253            CTBLK          /START BLOCK FOR
0213  1120            ADA I          /CAL MTX
0214  4000            4000
0215  4223            STC MTX2
0216  1020            LDA I
0217  0650            LDF 10
0220  4221            STC MTX1
0221  0653  MTX1,     LDF 13
0222  0710            0710           /RDC 1
0223  0000  MTX2,     0000           /MBLK\TBLK
0224  1020            LDA I
0225  1001            1001           /INC MBLK\TBLK
0226  1140            ADM
0227  0223            MTX2
0230  0223            XSK I FCTR     /END OF L-FIELD?
0231  6244            JMP MTX3       /NO
0232  1020            LDA I          /YES,INC L-DATA
0233  0001            1              /FIELD
0234  1140            ADM
0235  0221            MTX1
0236  0063            SET I FCTR
0237  7773            -4
0240  1020            LDA I
0241  3777            3777
0242  1140            ADM
0243  0223            MTX2
0244  0222  MTX3,     XSK I CTR      /END OF CAL MTX?
0245  6221            JMP MTX1       /NO
0246  0002            PDP            /YES, EXIT
                      PMODE
2247  5600            JMP I SMTX
            /
                      LMODE
            /
0250  0020  CTBLK,    20
            /
            /
            /
            /SUBROUTINE TO LOAD 3 BLOCKS OF DATA
            /
                      PMODE
2251  0000  SLDATA,   0000
2252  6141            LINC
                      LMODE
0253  0063            SET I FCTR
0254  7774            -3
0255  1000            LDA            /CURRENT 1K START
0256  0307            DTBLK          /BLOCK NO.
0257  1120            ADA I
0260  5000            5000
0261  4267            STC LDAT1
0262  1020            LDA I
0263  0001            1
0264  0001            AXO
0265  0653            LDF 13
0266  0710            0710           /RDC 1
0267  0000  LDAT1,    0000           /MBLK\TBLK
0270  1020            LDA I
0271  1001            1001
0272  1140            ADM
0273  0267            LDAT1
0274  0223            XSK I FCTR     /DATA LOADED?
0275  6266            JMP LDAT1-1    /NO
0276  1000            LDA
0277  0267            LDAT1
0300  1120            ADA I
0301  7776            -1
0302  4307            STC DTBLK      /SAVE START BN
0303  0062            SET I CTR
0304  2377            2377
0305  0002            PDP
                      PMODE
2306  5651            JMP I SLDATA
            /
                      LMODE
            /
0307  0200  DTBLK,    200
            /
            /
            /SUBROUTINE TO GET COORDINATE PAIR AND
            /CALCULATE CALIBRATION ADDRESS.
                      PMODE
2310  0000  SGC,      0000
2311  6141            LINC
                      LMODE
0312  0651            LDF 11
0313  1024            LDA I RD       /VC
0314  1460            SAE I          /END OF CURRENT
0315  7777            7777           /TV FIELD?
0316  6321            JMP .+3        /NO
0317  6512            JMP SNFLD      /YES LOAD NEXT FIELD
0320  6312            JMP .-6
0321  0640            LDF 0
0322  1040            STA
0323  2061            VC!2000
0324  0345            SCR 5          /LEFT HALF OF ADDR
0325  1340            STH
0326  2063            ADDR!2000
0327  0651            LDF 11
0330  1024            LDA I RD
0331  0640            LDF 0
0332  1040            STA
0333  2062            HC!2000
0334  0345            SCR 5          /RIGHT HALF OF ADDR
0335  1340            STH
0336  6063            ADDR!6000
0337  0011            CLR
0340  0002            PDP
                      PMODE
2341  5710            JMP I SGC
            /
            /
            /
                      LMODE
            /SUBROUTINE TO GET 1 TV FIELD OF DATA
            /
                      *400
                      PMODE
2400  0000  STVF,     0000
```

```
2401  6141          LINC
                    LMODE
0402  0653          LDF 13
0403  1022          LDA I CTR          /FN
0404  1460          SAE I              /END OF DATA?
0405  7777          7777
0406  6411          JMP .+3
0407  4531          STC FLAG
0410  6470          JMP TVF2           /RETURN & PROCESS
0411  4507          STC FN             /SAVE TV FIELD NO.
0412  1022          LDA I CTR
0413  4510          STC TVC
0414  1022          LDA I CTR
0415  4511          STC THC
0416  0202          XSK CTR            /END OF DATA?
0417  6423          JMP .+4            /NO
0420  0002          PDP
                    PMODE
2421  4470          JMS I LDATA        /YES,LOAD MORE DATA
2422  7410          SKP
                    LMODE
0423  0002          PDP
                    PMODE
2424  6221          CDF 20
2425  1227          TAD .+2
2426  7410          SKP
2427  2777          2777
2430  3010          DCA PTR            /SET PTR TO STORE
2431  1310          TAD TVC            /CURRENT TV FIELD
2432  3410          DCA I PTR
2433  1311          TAD THC
2434  3410          DCA I PTR
2435  6141          LINC
                    LMODE
0436  0653  TVF1,   LDF 13
0437  1022          LDA I CTR
0440  1460          SAE I              /END OF DATA?
0441  7777          7777
0442  6445          JMP .+3            /NO
0443  4531          STC FLAG           /YES
0444  6470          JMP TVF2
0445  1440          SAE                /CURRENT TV FIELD?
0446  0507          FN
0447  6470          JMP TVF2           /NO,RETURN
0450  1022          LDA I CTR
0451  4510          STC TVC
0452  1022          LDA I CTR
0453  4511          STC THC
0454  0002          PDP
                    PMODE
2455  6221          CDF 20
2456  1310          TAD TVC
2457  3410          DCA I PTR
2460  1311          TAD THC
2461  3410          DCA I PTR
2462  6141          LINC
                    LMODE
0463  0202          XSK CTR            /END OF DATA FIELD?
0464  6436          JMP TVF1           /NO
0465  0002          PDP
                    PMODE
2466  4470          JMS I LDATA        /YES,LOAD MORE DATA
2467  5235          JMP TVF1-1
                    LMODE
0470  0002  TVF2,   PDP
                    PMODE
2471  6221          CDF 20
2472  7240          STA
2473  3410          DCA I PTR
2474  7240          STA
2475  3410          DCA I PTR
2476  6141          LINC
                    LMODE
0477  0064          SET I RD
0500  2777          2777
0501  1020          LDA I
0502  7776          -1
0503  1140          ADA
0504  0002          CTR
0505  0002          PDP
                    PMODE
2506  5600          JMP I STVF
            /
                    LMODE
            /
0507  0000  FN,     0
0510  0000  TVC,    0
0511  0000  THC,    0
            /
            /SUBROUTINE TO ASSEMBLE NEW TV FIELD.
0512  1000  SNFLD,  LDA
0513  0000          0
0514  4526          STC NF1
0515  2531          ADD FLAG
0516  1460          SAE I              /END OF DATA?
0517  7777          7777
0520  0456          SKP
0521  6527          JMP NF1+1          /YES
0522  0002          PDP
                    PMODE
2523  4467          JMS I TVF
2524  4466          JMS I COMP
2525  6141          LINC
                    LMODE
0526  0000  NF1,    0000               /RETURN JMP
0527  0600          LIF 0
0530  6422          JMP END
            /
            /
0531  0000  FLAG,   0
            /
            /SUBROUTINE TO FIND COORDINATES BELONGING
            /TO THE SAME MARKER.
                    *600
                    PMODE
2600  0000  SCOMP,  0000
2601  7300          CLA CLL
2602  1204          TAD .+2
2603  7410          SKP
2604  3353          DCA H01            /RESET C03
2605  3302          DCA C03
2606  1210          TAD .+2
2607  7410          SKP
2610  2777          2777
2611  3010          DCA PTR
2612  6141          LINC
```

```
                          LMODE
      0613  0064          SET I RD
      0614  3377          3377
      0615  0002          PDP
                          PMODE
      2616  6221  C01,    CDF 20
      2617  1410          TAD I PTR
      2620  7040          CMA
      2621  7440          SZA           /END OF TV-FIELD?
      2622  7410          SKP           /NO
      2623  5331          JMP C05       /YES
      2624  7040          CMA
      2625  3344          DCA RVC
      2626  1410          TAD I PTR
      2627  7440          SZA           /ALREADY PROCESSED?
      2630  7410          SKP           /NO
      2631  5216          JMP C01       /YES
      2632  3345          DCA RHC
      2633  1345          TAD RHC
      2634  3351          DCA CHC1
      2635  1344          TAD RVC
      2636  1350          TAD K1
      2637  3346          DCA CVC
      2640  1010          TAD PTR
      2641  3011          DCA FD
      2642  1411  C02,    TAD I FD
      2643  3347          DCA CVC1
      2644  1347          TAD CVC1
      2645  7040          CMA
      2646  7440          SZA           /END OF DATA?
      2647  7410          SKP           /NO
      2650  5321          JMP C04       /YES,GO REDUCE DATA
      2651  7001          IAC
      2652  1346          TAD CVC
      2653  7440          SZA           /VC=CVC?
      2654  7410          SKP
      2655  5265          JMP C02A      /YES
      2656  1351          TAD KN1
      2657  7440          SZA           /VC=CVC-1
      2660  7410          SKP           /NO
      2661  5265          JMP C02A      /YES
      2662  2011          ISZ FD
      2663  7300          CLA CLL
      2664  5242          JMP C02       /GET NEXT VC
      2665  1411  C02A,   TAD I FD
      2666  3350          DCA CHC
      2667  1350          TAD CHC
      2670  7041          CIA
      2671  1351          TAD CHC1      /CHC1-CHC
      2672  7510          SPA           /+VE?
      2673  7041          CIA           /NO,MAKE +VE
      2674  1343          TAD KN35      /-35
      2675  7700          SMA CLA       /DIFF>I35I?
      2676  5242          JMP C02       /YES,GET NEXT VC
      2677  2352          ISZ VHC       /NO,COUNT HC
      2700  7300          CLA CLL
      2701  1350          TAD CHC
      2702  3353  C03,    DCA HC1
      2703  2302          ISZ C03
      2704  1311          TAD FD
      2705  1351          TAD KN1
      2706  3011          DCA FD
      2707  3411          DCA I FD      /REPLACE HC WITH 0
      2710  1347          TAD CVC1
      2711  7041          CIA
      2712  1346          TAD CVC
      2713  7440          SZA
      2714  7410          SKP
      2715  2346          ISZ CVC
      2716  1350          TAD CHC
      2717  3351          DCA CHC1      /REPLACE COMP HC
      2720  5242          JMP C02
      2721  4465  C04,    JMS I RED
      2722  4464          JMS I SRD
      2723  7300          CLA CLL
      2724  1326          TAD .+2
      2725  7410          SKP
      2726  3353          DCA HC1
      2727  3302          DCA C03
      2730  5216          JMP C01
      2731  7240  C05,    STA
      2732  3344          DCA RVC
      2733  7240          STA
      2734  3345          DCA RHC
      2735  4464          JMS I SRD     /PUTS 7777 AT END
      2736  6141          LINC          /OF FIELD
                          LMODE
      0737  0064          SET I RD
      0740  3377          3377
      0741  0002          PDP
                          PMODE
      2742  5600          JMP I SCOMP
                          /
                          /
      2743  7743  KN35,   -35
                          /
                          LMODE
      0744  0000  RVC,    0
      0745  0000  RHC,    0
      0746  0000  CVC,    0
      0747  0000  CVC1,   0
      0750  0000  CHC,    0
      0751  0000  CHC1,   0
      0752  0001  VHC,    1
                          /
      0753  0000  HC1,    0
      0754  0000  HC2,    0
      0755  0000  HC3,    0
      0756  0000  HC4,    0
      0757  0000  HC5,    0
      0760  0000  HC6,    0
      0761  0000  HC7,    0
      0762  0000  HC10,   0
      0763  0000  HC11,   0
      0764  0000  HC12,   0
      0765  0000  HC13,   0
      0766  0000  HC14,   0
      0767  0000  HC15,   0
      0770  0000  HC16,   0
      0771  0000  HC17,   0
      0772  0000  HC20,   0
                          /
                          /
                          /
                          /SUBROUTINE TO REDUCE DATA TO ONE
                          /COORDINATE PAIR PER GRID POINT
```

```
                        *1000
                        PMODE
3000  0000  SRED,       0000
3001  6141              LINC
                        LMODE
1002  0011              CLR
1003  5121              STC AHC          /AHC SET TO 0
1004  1000              LDA
1005  0745              RHC
1006  0017              COM
1007  5120              STC MHC
1010  2752              ADD NHC
1011  1460              SAE I            /ONLY 1 PAIR OF
1012  0001              1                /COORDINATES?
1013  0456              SKP              /NO, REDUCE
1014  7116              JMP R3           /YES, STORE
1015  1120              ADA I
1016  7757              -20
1017  0451              APO              /> 20 HC COORDS
1020  7026              JMP .+6          /NO
1021  1020              LDA I            /YES, MAKE NHC=20
1022  0020              20
1023  1040              STA
1024  0752              NHC
1025  7030              JMP .+3
1026  1120              ADA I
1027  0020              20
1030  1120              ADA I
1031  3120              2000+RTAB1-2     /FORM ADD INST
1032  5033              STC .+1          /TO GET APPROPRIATE
1033  0316              NOP              /RECIPROCAL
1034  5065              STC RDIV
1035  2752              ADD NHC
1036  0017              COM
1037  4005              STC HCTR         /SET HC COUNTER
1040  0225  AVE,        XSK I HCTR
1041  0456              SKP
1042  7055              JMP R2           /DIFF SUMMED
1043  1000              LDA              /CALCULATE SUM
1044  0753  R1,         HC1              /OF DIFFERENCES
1045  3120              ADD MHC
1046  1140              ADM
1047  1121              AHC
1050  1020              LDA I
1051  0001              1
1052  1140              ADM
1053  1044              R1               /INC R1
1054  7040              JMP AVE
1055  1000  R2,         LDA
1056  1121              AHC
1057  0241              ROL 1            /X10 (BINARY)
1060  1560              RCL I
1061  0001              1
1062  1240              MUL              /FRACTIONALY
1063  5065              .+4002           /MULTIPLY
1064  0456              SKP
1065  0000  RDIV,       0000             /MULTIPLIER
1066  0321              ROR I 1          /DIV BY 10
1067  0451              APO              /-VE OR +VE?
1070  7076              JMP .+6          /-VE, ROUND DOWN
1071  0472              LZE I            /+VE, ROUND UP?
1072  7102              JMP .+10
1073  1120              ADA I
1074  0001              1
1075  7102              JMP .+5
1076  0452              LZE              /ROUND DOWN?
1077  7102              JMP .+3          /NO
1100  1120              ADA I
1101  7776              -1
1102  1100              ADA
1103  0745              RHC
1104  4745              STC RHC          /AVERAGED HC
1105  2744              ADD RVC
1106  0017              COM
1107  2746              ADD CVC          /CVC-RVC
1110  1240              MUL              /DIV BY 2
1111  5113              .+4002
1112  0456              SKP
1113  2000              2000
1114  2744              ADD RVC
1115  4744              STC RVC
1116  0002  R3,         PDP
                        PMODE
3117  5600              JMP I SRED
            /
            /
                        LMODE
1120  0000  MHC,        0
1121  0000  AHC,        0
            /
1122  2000  RTAB1,      2000             /RECIPROCAL OF 2
1123  1252              1252             /3
1124  1000              1000             /4
1125  0631              0631             /5
1126  0526              0526             /6
1127  0444              0444             /7
1130  0400              0400             /10
1131  0343              0343             /11
1132  0314              0314             /12
1133  0272              0272             /13
1134  0252              0252             /14
1135  0235              0235             /15
1136  0222              0222             /16
1137  0210              0210             /17
1140  0200              0200             /20
            /
            /
            /SUBROUTINE TO STORE REDUCED DATA
                        PMODE
3141  0000  SSRD,       0000
3142  6141              LINC
                        LMODE
1143  0651              LDF 11
1144  1000              LDA
1145  0744              RVC
1146  1064              STA I RD
1147  1000              LDA
1150  0745              RHC
1151  1064              STA I RD
1152  1020              LDA I
1153  0001              1
1154  4752              STC NHC
1155  1020              LDA I
1156  0753              HC1
1157  5344              STC R1
1160  0002              PDP
```

```
                        PMODE
3161  5741              JMP I SSRD
                  /
                  /
                  /
                        LMODE
                  /SUBROUTINE TO MODIFY ADDR ACCORDING TO
                  /VALUE OF DATA HC.
                        *1400
                        PMODE
3400  0000  SMAHC,      0000
3401  6221              CDF 20
3402  7300              CLA CLL
3403  1063              TAD ADDR
3404  1056              TAD K40
3405  3232              DCA MAHC1
3406  1062              TAD HC
3407  7041              CIA
3410  1632              TAD I MAHC1     /HC(CAL)-HC(DATA)
3411  7510              SPA             /+VE?
3412  5222              JMP MAHC2       /NO
3413  1055              TAD KN30        /YES
3414  7710              SPA CLA         /DIFF>30?
3415  5600              JMP I SMAHC     /NO,ADDR OK
3416  1063              TAD ADDR        /YES,MODIFY ADDR
3417  1051              TAD KN1
3420  3063              DCA ADDR
3421  5201              JMP SMAHC+1     /REPEAT
3422  1054  MAHC2,      TAD K30
3423  7710              SPA CLA         /DIFF<-30?
3424  7410              SKP             /YES
3425  5600              JMP I SMAHC     /NO,ADDR OK
3426  1063              TAD ADDR        /MODIFY ADDR
3427  1050              TAD K1
3430  3063              DCA ADDR
3431  5201              JMP SMAHC+1     /REPEAT
                  /
                  /
                  /
3432  0000  MAHC1,      0
                  /
                  /SUBROUTINE TO MODIFY ADDR ACCORDING TO
                  /VALUE OF DATA VC.
3433  0000  SMAVC,      0000
3434  6221              CDF 20
3435  7300              CLA CLL
3436  1061              TAD VC
3437  7041              CIA
3440  1463              TAD I ADDR      /VC(CAL)-VC(DATA)
3441  7510              SPA             /+VE?
3442  5252              JMP MAVC1               /NO
3443  1053              TAD KN24        /YES
3444  7710              SPA CLA         /DIFF<24
3445  5633              JMP I SMAVC     /YES,ADDR OK
3446  1063              TAD ADDR        /NO,MODIFY ADDR
3447  1060              TAD KN100
3450  3063              DCA ADDR
3451  5234              JMP SMAVC+1     /REPEAT
3452  1052  MAVC1,      TAD K24
3453  7710              SPA CLA         /DIFF>-24
3454  7410              SKP             /NO,MODIFY ADDR
3455  5633              JMP I SMAVC     /YES,ADDR OK
3456  1063              TAD ADDR
3457  1057              TAD K100
3460  3063              DCA ADDR
3461  5234              JMP SMAVC+1     /REPEAT
                  /
                  /
                        LMODE
                        *2
0002  0000  CTR,        0
0003  0000  FCTR,       0
0004  0000  RD,         0
0005  0000  HCTR,       0
                  /
                  /
                        SEGMNT 2
                  /
                        LMODE
                  /SUBROUTINE TO CALCULATE CORRECTION FACTOR
                  /FOR VERTICAL COORDINATE
                        *200
                        PMODE
4200  0000  SVCC,       0000
4201  6221              CDF 20
4202  7300              CLA CLL
4203  1061              TAD VC
4204  7041              CIA
4205  1463              TAD I ADDR      /VC(CAL)-VC(DATA)
4206  3074              DCA DIF
4207  1074              TAD DIF
4210  7710              SPA CLA         /VC(DATA)<VC(CAL)?
4211  5237              JMP VCC2        /NO
4212  1063              TAD ADDR        /YES
4213  6141              LINC
                        LMODE
0214  1560              BCL I
0215  0077              0077
0216  1460              SAE I
0217  0000              0
0220  0456              SKP
0221  6261              JMP VCC3        /TAKE YGN1-YGN0
0222  1440              SAE
0223  0341              CALIM2
0224  0456              SKP
0225  6261              JMP VCC3        /TAKE YGN14-YGN13
0226  0002  VCC1,       PDP
                        PMODE
4227  7300              CLA CLL
4230  1063              TAD ADDR
4231  1060              TAD KN100
4232  3277              DCA ADDR2
4233  1677              TAD I ADDR2
4234  7041              CIA
4235  1463              TAD I ADDR      /YGDN-YGD(N-1)
4236  5600              JMP I SVCC
4237  1063  VCC2,       TAD ADDR
4240  6141              LINC
                        LMODE
0241  1560              BCL I
0242  0077              0077
0243  1440              SAE
0244  0300              CALIM1
0245  0456              SKP
0246  6271              JMP VCC4        /TAKE YGN12-YGN11
```

```
0247 1440           SAE
0250 0302           CALIM3
0251 0456           SKP
0252 6271           JMP VCC4        /TAKE YGN25-YGN24
0253 0002           PDP
                    PMODE
4254 7300           CLA CLL
4255 1074           TAD DIF
4256 1051           TAD KN1         /MAKE ONES COMP
4257 3074           DCA DIF
4260 7410           SKP
                    LMODE
0261 0002 VCC3,     PDP
                    PMODE
4262 1063           TAD ADDR
4263 1057           TAD K100
4264 3277           DCA ADDR2
4265 1463           TAD I ADDR
4266 7041           CIA
4267 1677           TAD I ADDR2     /YGD(N+1)-YGDN
4270 5600           JMP I SVCC
                    LMODE
0271 0002 VCC4,     PDP
                    PMODE
4272 7300           CLA CLL
4273 1074           TAD DIF
4274 1051           TAD KN1
4275 3074           DCA DIF
4276 5230           JMP VCC1+2
          /
          /
                    LMODE
          /
0277 0000 ADDR2,    0
0300 1200 CALIM1,   1200
0301 1300 CALIM2,   1300
0302 2500 CALIM3,   2500
0303 0031 CALIM4,   31
          /
          /
          /SUBROUTINE TO CALCULATE CORRECTION FACTOR
          /FOR HORIZONTAL COORDINATE.
                    PMODE
4304 0000 SHCC,     0000
4305 6221           CDF 20
4306 7300           CLA CLL
4307 1063           TAD ADDR
4310 1056           TAD K40
4311 3372           DCA HADDR
4312 1062           TAD HO
4313 7041           CIA
4314 1772           TAD I HADDR     /HC(CAL)-HC(DATA)
4315 3074           DCA DIF
4316 1074           TAD DIF
4317 7710           SPA CLA         /HC(DATA)<HC(CAL)
4320 5345           JMP HCC2        /NO
4321 1074           TAD DIF         /YES
4322 7040           CMA
4323 3074           DCA DIF         /ONES COMP
4324 1063           TAD ADDR
4325 6141           LINC
                    LMODE
0326 1560           BCL I
0327 7700           7700
0330 1460           SAE I
0331 0000           0
0332 0456           SKP
0333 6360           JMP HCC3        /TAKE XGN1-XGN0
0334 0002 HCC1,     PDP
                    PMODE
4335 7300           CLA CLL
4336 1372           TAD HADDR
4337 1051           TAD KN1
4340 3371           DCA HADDR2
4341 1771           TAD I HADDR2
4342 7041           CIA
4343 1772           TAD I HADDR     /XGDN-XGD(N-1)
4344 5704           JMP I SHCC
4345 1074 HCC2,     TAD DIF
4346 7041           CIA
4347 3074           DCA DIF
4350 1063           TAD ADDR
4351 6141           LINC
                    LMODE
0352 1560           BCL I
0353 7700           7700
0354 1440           SAE
0355 0303           CALIM4
0356 0456           SKP
0357 6334           JMP HCC1        /TAKE XGN31-XGN30
0360 0002 HCC3,     PDP
                    PMODE
4361 7300           CLA CLL
4362 1372           TAD HADDR
4363 1050           TAD K1
4364 3371           DCA HADDR2
4365 1772           TAD I HADDR
4366 7041           CIA
4367 1771           TAD I HADDR2    /XGD(N+1)-XGDN
4370 5704           JMP I SHCC
          /
          /
                    LMODE
0371 0000 HADDR2,   0
0372 0000 HADDR,    0
          /
          /
          /SUBROUTINE TO COMPUTE AND SCALE CORRECTION
          /FACTORS.
                    *400
                    PMODE
4400 0000 SDIV,     0000
4401 6141           LINC
                    LMODE
0402 1120           ADA I
0403 2425           2000+RTAB-25
0404 4405           STC .+1
0405 0000           0000            /ADD RECIPROCAL
0406 4435           STC DIV3
0407 0011           CLR
0410 0640           LDF 0
0411 1000           LDA
0412 2074           DIF!2000
0413 0451           APO             /+VE DIFF?
0414 6423           JMP DIV1        /NO
0415 1020           LDA I           /YES
```

```
0416  0316          NOP
0417  4447          STC DIV4
0420  1030          LDA
0421  2074          DIF!2000
0422  6431          JMP DIV2
0423  1020  DIV1,   LDA I
0424  0317          COM
0425  4447          STC DIV4
0426  1030          LDA
0427  2074          DIF!2000
0430  0317          COM
0431  0246  DIV2,   ROL 6
0432  1240          MUL
0433  4435          .+4002
0434  0456          SKP
0435  0000  DIV3,   0000
0436  1240          MUL
0437  4441          .+4002
0440  0456          SKP
0441  0620          0620
0442  0321          ROR I 1
0443  0472          LZE I
0444  6447          JMP .+3
0445  1120          ADA I
0446  0001          1
0447  0316  DIV4,   NOP
0450  0002          PDP
                    PMODE
4451  5600          JMP I SDIV
            /
            /
                    LMODE
            /
0452  3030  RTAB,   3030            /RECIPROCAL OF 25
0453  2721          2721            /26
0454  2354          2354            /27
0455  2525          2525            /30
0456  2436          2436            /31
0457  2354          2354            /32
0460  2275          2275            /33
0461  2222          2222            /34
0462  2151          2151            /35
0463  2104          2104            /36
0464  2041          2041            /37
0465  2000          2000            /40
0466  1740          1740            /41
0467  1703          1703            /42
0470  1650          1650            /43
0471  1616          1616            /44
0472  1565          1565            /45
0473  1536          1536            /46
0474  1510          1510            /47
0475  1463          1463            /50
0476  1437          1437            /51
0477  1414          1414            /52
0500  1372          1372            /53
0501  1350          1350            /54
0502  1330          1330            /55
0503  1310          1310            /56
0504  1271          1271            /57
0505  1252          1252            /60
            /
            /

            /SUBROUTINE TO CALIBRATE VERTICAL COORDINATE
                    *600
                    PMODE
4600  0000  SCAVC,  0000
4601  7300          CLA CLL
4602  1063          TAD ADDR
4603  6141          LINC
                    LMODE
0604  0346          SCR 6
0605  1120          ADA I
0606  7765          -12
0607  0471          APO I           /ODD OR EVEN TV FIELD
0610  6615          JMP .+5
0611  1120          ADA I           /MAKE ORIGIN ABOUT
0612  0005          5               /CENTRE FOR A GRID
0613  0017          COM             /OF 11(DEC) VERTICAL
0614  6620          JMP .+4         /POINTS
0615  1120          ADA I           /AS ABOVE,FOR
0616  7771          -6              /OTHER FIELD
0617  0017          COM
0620  1260          MUL I           /SCALE(X10000)
0621  0144          0144
0622  4656          STC CALVC
0623  0002          PDP
                    PMODE
4624  4471          JMS I VCC       /CALCULATE AND SCALE
4625  4473          JMS I DIV       /CORRECTION FACTOR
4626  6141          LINC
                    LMODE
0627  1140          ADM             /CORRECT CALIBRATED
0630  0656          CALVC           /VERTICAL COORD
0631  0002          PDP
                    PMODE
4632  5600          JMP I SCAVC
            /
            /
            /
            /SUBROUTINE TO CALIBRATE HORIZONTAL COORDINATE
4633  0000  SCAHC,  0000
4634  7300          CLA CLL
4635  1063          TAD ADDR
4636  6141          LINC
                    LMODE
0637  1560          BCL I
0640  7700          7700
0641  1120          ADA I           /MAKE ORIGIN AT CENTRE
0642  7762          -15
0643  1260          MUL I           /SCALE(X10000)
0644  0144          0144
0645  4657          STC CALHC
0646  0002          PDP
                    PMODE
4647  4472          JMS I HCC       /CALCULATE AND SCALE
4650  4473          JMS I DIV       /CORRECTION FACTOR
4651  6141          LINC
                    LMODE
0652  1140          ADM             /CORRECT CALIBRATED
0653  0657          CALHC           /HORIZONTAL COORD
0654  0002          PDP
                    PMODE
4655  5633          JMP I SCAHC
            /
            /
```

```
                        LMODE
0656  0000  CALVC,      0
0657  0000  CALHC,      0
            /
            /
            /SUBROUTINE TO STORE CALIBRATED DATA
                        *1000
                        PMODE
5300  0000  SSTOR,      0000
5001  6141              LINC
                        LMODE
1002  0641              LDF 1
1003  1000              LDA
1004  2507              FV12000
1005  0652              LDF 12
1006  1062              STA I CBUF      /TV-FIELD NO
1007  1000              LDA
1010  0656              CALVC
1011  1062              STA I CBUF      /CALIBRATED VC
1012  1000              LDA
1013  0657              CALHC
1014  1062              STA I CBUF      /CALIBRATED HC
1015  0202              XSK CBUF        /BUFFER FULL?
1016  7022              JMP .+4
1017  0002              PDP
                        PMODE
5020  4532              JMS I TAPE      /PUT ON TAPE
5021  7410              SKP
                        LMODE
1022  0002              PDP
                        PMODE
5023  5600              JMP I SSTOR
            /
            /
            /
            /
            /SUBROUTINE TO PUT CALIBRATED DATA ON TAPE,
            /ON UNIT 2
5024  0000  STAPE,      0000
5025  6141              LINC
                        LMODE
1026  1000              LDA
1027  1114              CDTBLK          /START TAPE BN
1030  1120              ADA I
1031  5000              5000
1032  5040              STC TA1
1033  1020              LDA I           /SET EXTENDED UNIT
1034  0001              1               /BIT 11
1035  0011              AXO
1036  0652              LDF 12
1037  0726              WRI I
1040  0000  TA1,        0000
1041  1000              LDA
1042  1040              TA1
1043  1120              ADA I
1044  1001              1001
1045  5047              STC .+2
1046  0706              WRI I
1047  0000              0000
1050  1000              LDA
1051  1047              .-2
1052  1120              ADA I
1053  1001              1001
1054  5056              STC .+2
1055  0706              WRI
1056  0000              0000
1057  1000              LDA
1060  1056              .-2
1061  1120              ADA I
1062  0001              1
1063  1560              PCL I
1064  7000              7000
1065  5103              STC TA4
1066  1000              LDA
1067  1114              CDTBLK
1070  5072              STC .+2
1071  0707              CHK
1072  0000  TA3,        0000
1073  1460              SAE I           /TRANSFER OK?
1074  7777              7777
1075  7037              JMP TA1-1       /NO,REPEAT
1076  1020              LDA I           /YES,CHK NEXT BLOCK
1077  0001              1
1100  1140              AIM
1101  1072              TA3
1102  1460              SAE I
1103  0000  TA4,        0000
1104  7071              JMP TA3-1
1105  1000              LDA
1106  1103              TA4
1107  5114              STC CDTBLK      /RESET START BN
1110  0062              SET I CBUF
1111  2377              2377
1112  0002              PDP
                        PMODE
5113  5624              JMP I STAPE
            /
            /
                        LMODE
1114  0200  CDTBLK,     200
            /
                        *2
0002  2377  CBUF,       2377
            /
            /
            /
            /
                        SEGMNT 3
                        *20
0020  0076              SET I 16
0021  6022              .+6001
0022  7000              JMP QAINIT
0023  0600              MESS1           /CTBLK
0024  0500              ANSWER
0025  7053              JMP QARFSH
0026  0070              SET I 10
0027  0500              ANSWER
0030  6133              JMP PM
0031  1000              LDA
0032  0175              OCTAC
0033  1120              ADA I
0034  7001              -776
0035  0471              APO I           /CTBLK>777?
0036  6174              JMP XIT         /YES REPEAT MESS
0037  1000              LDA
```

```
0040  0175          OCTAC
0041  0641          LDF 1
0042  1040          STA
0043  2250          CTBLK!2000
0044  0076          SET I 16
0045  6046          .+6001
0046  7000          JMP QAINIT
0047  0625          MESS2                /DTBLK
0050  0500          ANSWER
0051  7353          JMP QARFSH
0052  0070          SET I 10
0053  0500          ANSWER
0054  6133          JMP PM
0055  1000          LDA
0056  0175          OCTAC
0057  1120          ADA I
0060  7001          -776
0061  0471          APO I
0062  6174          JMP XIT
0063  1000          LDA
0064  0175          OCTAC
0065  0641          LDF 1
0066  1040          STA
0067  2307          DTBLK!2000
0070  0076          SET I 16
0071  6072          .+6001
0072  7000          JMP QAINIT
0073  0652          MESS3                /CDTBLK
0074  0500          ANSWER
0075  7353          JMP QARFSH
0076  0070          SET I 10
0077  0500          ANSWER
0100  6133          JMP PM
0101  1000          LDA
0102  0175          OCTAC
0103  1120          ADA I
0104  7001          -776
0105  0471          APO I
0106  6174          JMP XIT
0107  1000          LDA
0110  0175          OCTAC
0111  0642          LDF 2
0112  1040          STA
0113  3114          CDTBLK!2000
0114  0076          SET I 16
0115  6116          .+6001
0116  7000          JMP QAINIT
0117  0700          MESS4                /PRESS S TO START
0120  0500          ANSWER
0121  7353          JMP QARFSH
0122  0070          SET I 10
0123  0500          ANSWER
0124  1330          LDH I 10
0125  1420          SHD I
0126  2300          2300                 /AN S?
0127  0456          SKP                  /YES
0130  6174          JMP XIT              /NO REPEAT MESS
0131  0630          LIF 0
0132  6400          JMP 400
0133  0055   PM,    SET 15
0134  0000          0
0135  0011          CLR
0136  4175          STC OCTAC
0137  1330   PM1,   LDH I 10
0140  1420          SHD I
0141  7400          7400
0142  6015          JMP 15
0143  1420          SHD I
0144  3400          3400
0145  6015          JMP 15
0146  1420          SHD I
0147  0000          0
0150  6137          JMP PM1
0151  1120          ADA I
0152  7717          -60
0153  1040          STA
0154  0176          NUM
0155  1120          ADA I
0156  0001          1
0157  0451          APO
0160  6174          JMP XIT
0161  1120          ADA I
0162  7767          -10
0163  0471          APO I
0164  6174          JMP XIT
0165  1000          LDA
0166  0175          OCTAC
0167  1260          MUL I
0170  0010          10
0171  2176          ADD NUM
0172  4175          STC OCTAC
0173  6137          JMP PM1
0174  6016   XIT,   JMP 16
             /
             /
0175  0000   OCTAC, 0
0176  0000   NUM,   0
             /
                    *500
0500  0000   ANSWER, 0
             /
             /
                    *600
0600  0640
0601  0301
0602  1440
0603  1524
0604  3040
0605  2324
0606  0122
0607  2440
0610  0214
0611  1703
             MESS1, TEXT ZF CAL MTX START BLOCK
0612  1343
0613  4740
0614  4347
0615  4343
0616  0640
0617  4040
0620  4000
0621  2432
0622  1413
0623  4074
```

```
0624  6334
            F       CTBLK <3\Z
0625  0640
0626  0401
0627  2401
0630  4023
0631  2401
0632  2224
0633  4032
0634  1417
            MESS2,  TEXT ZF DATA START BLOCK
0635  0313
0636  4347

0637  4043

0640  4740
0641  4347

0642  4043
0643  0640
0644  4040
0645  4304
0646  2402
0647  1413
0650  4374
0651  6334
            F       DTBLK <3\Z
0652  0640
0653  0301
0654  1440
0655  0401
0656  2401
0657  4023
0660  2401
0661  2224
0662  4032
0663  1417
            MESS3,  TEXT ZF CAL DATA START BLOCK
0664  0313
0665  4347

0666  4043

0667  4740
0670  4306
0671  4343
0672  4043
0673  0334
0674  2402
0675  1413
0676  4374
0677  6334
            F       CDTBLK <3\Z
0700  3624
0701  3120
0702  0540
0703  2340
0704  2417
0705  4023
0706  2401
0707  2224
0710  4074
0711  6134
            MESS4,  TEXT ZFTYPE S TO START <1\Z
            /
            /
            /QANDA SUBROUTINE FOR THE
            /PDP-12
            /REMOVE *1000 BELOW IF
            /INSERTING SOURCE DIRECTLY
            /INTO YOUR PROGRAM SOURCE
            *1000 /REMOVE,IF DESIRED
            /
            /TO HERE TO INITIALIZE THE ROUTINE
            /
1000  1020  QAINIT, LDA I           /SAVE JMP RETURN
1001  0002          2
1002  2000          ADD 0
1003  1060          STA I
1004  0000  QAB,    0               /JMP    +3
1005  3200          ADD QAL+3
1006  4001          STC 1           /PTR TO FIRST PARAM
1007  1001          LDA 1           /GET FIRST PARAM
1010  3264          ADD QAQ+1       /PTR TO HALFWORD-1
1011  5057          STC QAG-3
1012  1321          LDA I 1
1013  5052          STC QARFSH-1
1014  4006          STC 6           /XR6 USED AS A SWITCH. =0
            IF NO ANSWER FIELD, =1777 IF YES
1015  0043  QACA,   SET 3   /XR3 TO PTR TO ANSWERS
1016  1052          QARFSH-1
1017  0044          SET 4           /XR4 TO PTR TO QUESTIONS
1020  1057          QAG-3
                                    /TO HERE IF FIRST TIME TH.
            OUGH OR FOLLOWING A CR
1021  0041          SET 1
1022  0004          4
1023  7270          JMP QAT
1024  0016          NOP             /F
1025  1324          LDH I 4         /H. BUMP PTR IF H OR F
1026  7231  QAD,    JMP QAJ
1027  7035          JMP .+6         /74
1030  7050          JMP QAE         /34
1031  1460          SAE I           /CR?
1032  0043          43
1033  7026          JMP QAD         /NO
1034  7021          JMP QACA+4 /EXAMINE NEXT CHAR
                                    /INITIALIZE ANSWER BUFR
1035  1343          STH 3           /74 TO ANSWERS
1036  1324          LDH I 4         /NEXT HALFWORD
1037  1120          ADA I
1040  7717          -60
1041  0017          COM
1042  4006          STC 6
1043  1363          STH I 3         /0 IN AC
1044  0226          XSK I 6
1045  7043          JMP .-2
1046  1323          LDH I 3         /BUMP PTR TO ANSWERS
1047  7326          JMP QAD
                                    /ANSWER BUFR IS INITIATED
1050  1343  QAE,    STH 3
1051  0064          SET I 4         /XR4 TO PTR TO LAST TYPED
            CHAR IN ANSWER BUFR
1052  0000          0
                                    /----RE-ENTER HERE TO REFR
```

```
                FSH----
1053  1323  QARFSH, LDA I           /INITIAL Y POSITION
1054  0277  277
1055  5113          STC QAH-1
1056  0063          SET I 3         /XR3 TO PTR TO HALFWORD QU
            ESTIONS-1
1057  0000          0
1060  0045          SET 5           /XR5 TO PTR TO LAST DISPLA
            YED CHAR IN ANSWER BUFR
1061  1052          QARFSH-1
1062  0041  QAG,    SET 1
1063  0003          3
1064  7270          JMP QAT
1065  7074          JMP .+7         /F
1066  1323          LDH I 3         /H. BUMP PTR
1067  1020          LDA I           /NEITHER. ASSUME HALF SIZE
1070  1560          BCL I
1071  5103          STC QAM+2       /SET INSTR TO CLEAR FF FOR
            HALF SIZE
1072  3512          ADD QAW         /NOP IN AC
1073  7101          JMP QAM
1074  1323          LDH I 3         /BUMP PTR
1075  1020          LDA I
1076  1620          BSE I
1077  5103          STC QAM+2       /SET INSTR TO SET FF FOR F
            ULL SIZE
1100  3513          ADD QAW+1       /ADD 90 IN AC
1101  5245  QAM,    STC QAP+3
1102  0024          MSC I 4         /EAD CONTROL REGISTER
1103  1620          BSE I           /THIS INSTR CHANGES. EITHE
            R BSE & OR BCL &
1104  0200          200
1105  0004          MSC 4           /AC TO CONTROL REGISTER
1106  0061          SET I 1         /XR1 TO INITIAL X POSITION
1107  0100          100
1110  1020          LDA I           /Y COORDINATE MULTIPLE
1111  7737          -40
1112  1160          ADA I           /Y COORDINATE
1113  0000          0
1114  1323  QAH,    LDH I 3
1115  7232          JMP QAO+1
1116  7301          JMP QAZ         /74 BUMP PTR TO NEXT CHAR.
             PUT 40 IN AC
1117  7136          JMP QAJ         /34
1120  1420          SHD I           /NEITHER
1121  4300          4300
1122  7062          JMP QAG         /CR. MOVE X AND Y COORDINA
            TE
1123  7242          JMP QAP         /ISPLAY CHAR
1124  7114          JMP QAH         /PICK UP NEXT CHAR
1125  7242          JMP QAP         /TO HERE IF DISPLAYING ANS
            WER BUFR
1126  1520          SRO I   /SWITCH TO DISPLAY CURSOR. EITHER
            0000 OR 7777
1127  0000          0               /IFXR4=XR5, THEN SWITCH=77
            77
1130  7516          JMP QAF
                                    /QUESTION MODE
1131  1325  QAI,    LDH I 5
1132  7232          JMP QAO+1
1133  7114          JMP QAH         /74
1134  7114          JMP QAH         /34
1135  7125          JMP QAI-4       /NEITHER. DISPLAY IT
```

```
1136  7521  QAJ,    JMP GETKBD      /TO HERE IF DISPLAYED BUFF
            ER
1137  0470          AZE I
1140  7004          JMP QAB /NOTHING TYPED . EXIT
1141  0062          SET I 2
1142  1412          QAY
1143  1402          SHD 2           /LF?
1144  7311          JMP QAK+4       /YES. EXIT
1145  1422          SHD I 2         /CR?
1146  7223          JMP QAN
1147  0206          XSK 6           /IS THERE AN ANSWER FIELD?
1150  7053          JMP QARFSH
1151  1422          SHD I 2         /<?
1152  7175          JMP QAL
1153  1422          SHD I 2         />?
1154  7305          JMP QAK
1155  1422          SHD I 2         /ALT?
1156  7015          JMP QACA /REINITIALIZE
1157  1422          SHD I 2         /BACK SLASH?
1160  7053          JMP QARFSH      /IGNORE
1161  1422          SHD I 2         /RUBOUT?
1162  7175          JMP QAL         /IGNORE
1163  1422          SHD I 2         /TAB?
1164  7053          JMP QARFSH      /IGNORE
1165  5172          STC .+5         /ACCEPTABLE CHAR
1166  7231          JMP QAO         /TEST NEXT CHAR
1167  7263          JMP QAQ         /74 BACK PTR UP BY 1
1170  7263          JMP QAQ         /34 ↑
1171  1020          LDA I           /OK. STORE IT
1172  0000          0
1173  1344          STH 4
1174  7053          JMP QARFSH      /REDISPLAY
1175  1304  QAL,    LDH 4           /TO HERE IF RUBOUT OR <
1176  7232          JMP QAO+1
1177  7053          JMP QARFSH      /74 IGNORE
1200  1775          -6002
1201  1302          LDH 2           /TEST THE CHAR
1202  1460          SAE I           /RUBOUT?
1203  0037          37
1204  7263          JMP QAQ         /NO. BACK PTR UP BY 1
1205  0045          SET 5
1206  0004          4
1207  0043          SET 3
1210  0004          4
1211  7213          JMP .+2
1212  1325          LDH I 5         /BUMP PTR
1213  1323          LDH I 3         /GET NEXT CHAR
1214  7232          JMP QAO+1
1215  0016          NOP             /IF 74 OR 34, REPLACE CURR
            ENT CHAR WITH 0
1216  0011          CLR
1217  1345          STH 5
1220  0450          AZE             /WAS IT 74 OR 34?
1221  7212          JMP .-7         /NO. CONTINUE
1222  7263          JMP QAQ         /BACK PTR UP BY 1
                                    /TO HERE IF CR
1223  0206  QAN,    XSK 6
1224  7311          JMP QAK+4       /EXIT ROUTINE IF NO ANSWER
             FIELD
1225  7231          JMP QAO
1226  7053          JMP QARFSH      /74 MOVE PTR TO NEXT QUEST
            ION FIELD
1227  7051          JMP QAR+1       /34 END OF BUFR. MOVE PTR
```

```
1230 7225        JMP QAN+2

1231 1324 QAO,   LDH I 4       /S\R
1232 1420        SHD I         /        +1 74 BEGIN0
          FIELD
1233 7400        7400          /        +2 34 END BU
          FR
1234 6000        JMP 0         /        +3 NEITHER 7
          4 NOR 34
1235 1460        SAE I
1236 0034        34
1237 0220        XSK I 0
1240 0220        XSK I 0
1241 6000        JMP 0
                               /S\R TO DISP LINC CHA
          R IN AC
1242 0241 QAP,   ROL 1         /MULT BY 2 FOR INDEX
          TO ADDRESS OF TABLE
1243 3430        ADD QAX+4
1244 4002        STC 2         /ADDRESS OF CHAR TO D
          ISP IN XR2
1245 3506        ADD QAU       /THIS INSTR CHANGES.
          EITHER OP OR ADD 9U
1246 3536        ADD QAU
1247 2001        ADD 1         /ADD 4 TO XR1 TO SPAC
          E CHAR
1250 4001        STC 1
1251 2005        ADD 5         /GET ADDRESS OF ANSWE
          R BUFR
1252 0017        COM
1253 2004        ADD 4
1254 0450        AZE
1255 0011        CLR
1256 5127        STC QAI-2     /SWITCH=0 OR 7777
1257 3113        ADD QAH-1     /Y COORDINATE IN AC
1260 1742        DSC 2
1261 1762        DSC I 2       /DISPLAY CHAR
1262 6000        JMP 0
1263 1020 QAQ,   LDA I         /BACK UP PTR BY 1
1264 3777        -4000
1265 1140        ADM
1266 0004        4
1267 7353        JMP QARFSH    /REDISPLAY
                               /
1270 1321 QAT,   LDH I 1       /S\R
1271 1420        SHD I         /        +1 F
1272 0600        0600          /        +2 H
1273 6000        JMP 0         /        +3 NEITHER
1274 1460        SAE I
1275 0010        10
1276 0220        XSK I 0
1277 0220        XSK I 0
1300 6000        JMP 0
                               /
1301 1323 QAZ,   LDH I 3
1302 1020        LDA I
1303 0040        40
1304 7125        JMP QAI-4
                               /TO HERE IF >
1305 1324 QAK,   LDH I 4
1306 0470        AZE I         /IS CURRENT CHAR BLAN
          K?
1307 7263        JMP QAQ       /YES. IGNORE
1310 7424        JMP QAX       /MOVE DOT FORWARD
                               /TO HERE TO EXIT WITH
          SKIP
1311 1020        LDA I
1312 0001        1
1313 1140        ADM
1314 1004        QAB
1315 7004        JMP QAB
                               /CHARACTER PATTERNS
1316 0101 QAV,   0101          /KBD 0, ILLEGAL. USED
          AS MARKER
1317 0101        0101
1320 4477        4477          /1:A
1321 7744        7744
1322 5177        5177          /2:B
1323 2651        2651
1324 4136        4136          /3:C
1325 2241        2241
1326 4177        4177          /4:D
1327 3641        3641
1330 4577        4577          /5:E
1331 4145        4145
1332 4477        4477          /6:F
1333 4044        4044
1334 4136        4136          /7:G
1335 2645        2645
1336 1077        1077          /10:H
1337 7710        7710
1340 7741        7741          /11:I
1341 0041        0041
1342 4142        4142          /12:J
1343 4076        4076
1344 1077        1077          /13:K
1345 4324        4324
1346 0177        0177          /14:L
1347 0301        0301
1350 3077        3077          /15:M
1351 7730        7730
1352 3077        3077          /16:N
1353 7706        7706
1354 4177        4177          /17:O
1355 7741        7741
1356 4477        4477          /20:P
1357 3044        3044
1360 4276        4276          /21:Q
1361 0376        0376
1362 4477        4477          /22:R
1363 3146        3146
1364 5121        5121          /23:S
1365 4651        4651
1366 4040        4040          /24:T
1367 4077        4077
1370 0177        0177          /25:U
1371 7701        7701
1372 0176        0176          /26:V
1373 7402        7402
1374 0677        0677          /27:W
1375 7701        7701
1376 1463        1463          /30:X
1377 6314        6314
1400 0770        0770          /31:Y
1401 7007        7007
```

```
1402 4543          4543        /32:Z
1403 6151          6151
1404 4177          4177        /33:/
1405 0000          0000        /34:BACKSLASH IGNORED
                ON INPUT
1406 0000          0           /NOT USED
1407 0000          0           /NOT USED
1410 0000          0000        /35:]
1411 7741          7741
                               /CODES 36:ALT, 37:RUB
               OUT NOT DISPLAYED
1412 4543    QAY,  4543        /LF,CR
1413 7476          7476        /<,>
1414 3634          3634        /ALT, BACKSLASH
1415 3747          3747        /RUBOUT, TAB
1416 0000          0000        /40:SPACE
1417 0000          0000
1420 7500          7500        /41:X!
1421 0000          0000
1422 7000          7000        /42:"
1423 0070          0070
                               /CODES 43:, 44:, 45:L
               F NOT DISPLAYED
1424 7232    QAX,  JMP QAO+1
1425 7263          JMP QAQ
1426 7263          JMP QAQ
1427 7053          JMP QARFSH
1430 1316          QAV
1431 0000          0           /NOT USED
1432 5166          5166        /46: &
1433 0526          0526
                               /CODE 47:TAB NOT DISP
               LAYED
1434 0000          0           /NOT USED
1435 0000          0           /NOT USED
1436 3600          3600        /50:(
1437 0041          0041
1440 4100          4100        /51:)
1441 0036          0036
1442 2050          2050        /52:*
1443 0050          0050
1444 0404          0404        /53:+
1445 0437          0437
1446 0500          0500        /54:,
1447 0006          0006
1450 0404          0404        /55:-
1451 0404          0404
1452 0001          0001        /56:.
1453 0000          0000
1454 0601          0601        /57:\
1455 4030          4030
1456 4536          4536   /60:0
1457 3651          3651
1460 2101          2101        /61:1
1461 0177          0177
1462 4523          4523        /62:2
1463 2151          2151
1464 4122          4122        /63:3
1465 2651          2651
1466 2414          2414        /64:4
1467 0477          0477
1470 5172          5172        /65:5
1471 0651          0651
1472 1506          1506             /66:6
1473 4225          4225
1474 4443          4443             /67:7
1475 6050          6050
1476 5126          5126   /70:8
1477 2651          2651
1500 5122          5122             /71:9
1501 3651          3651
1502 2200          2200             /72::
1503 0000          0000
1504 4601          4601             /73:;
1505 0000          0000
                                    /CODE 74:<NOT DISPLAY
               ED
1506 0002    QAU,  2                /CONSTANT
1507 0000          0      /NOT USED
1510 1212          1212             /75:=
1511 1212          1212
                                    /CODE 76:> NOT DISPLA
               YED
1512 0316    QAW,  NOP
1513 3506          ADD QAU
1514 4020          4020             /77:?
1515 2055          2055
             /
1516 1760    QAF,  DSC I
1517 6000          6000
1520 7131          JMP QAI
             /
                                    /END Q+A
             /
             /
             /
             /
             /KEYBOARD INPUT ROUTINE
             /
             QAKBB=6036      /PDP-8 IOT KBB
             QATSF=6041      /TSF
             QATLS=6046      /TLS
             /
1521 1000    GETKBD, LDA
1522 0000          0
1523 5643          STC QAEXIT+6     /SAVE RETURN
1524 2001          ADD 1            /SAVE XRS 1 AND 2
1525 5643          STC QAEXIT+3
1526 2002          ADD 2
1527 5642          STC QAEXIT+5
1530 5636          STC QAEXIT+1
1531 0415          KST    /WAS SOMETHING TYPED?
1532 6000          JMP 0            /NO: EXIT
1533 0500          IOB
1534 6036          QAKBB  /GET TTY CHAR, CLEAR FLAG
1535 1060          STA I            /SAVE IT
1536 0000    QATY, 0
1537 1120          ADA I
1540 7540          -237
1541 0451          APO              /BETWEEN 200 AND 237?
1542 7634          JMP QACNTR       /CONTROL CHAR. CHECK F
             OR CR,LF,TAB
             /
1543 3061          SET I 1          /NO
1544 1654          QACHAR-1
```

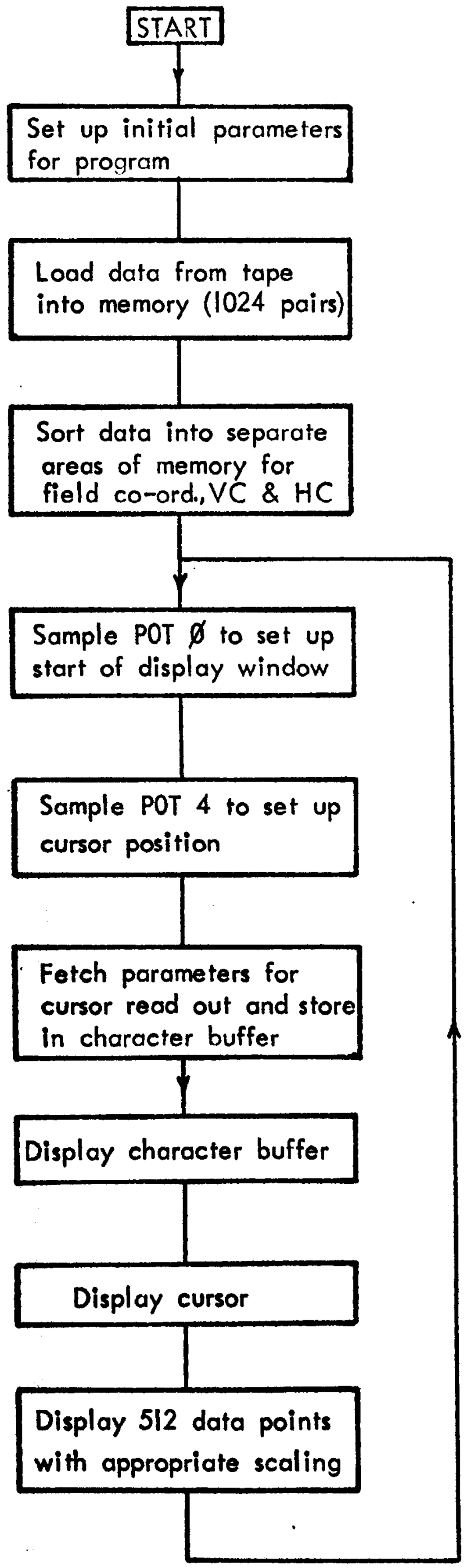
```
1545  0062          SET I 2
1546  7770          -7
1547  1000          LDA
1550  1536          QATY
1551  1461          SAE I 1
1552  7554          JMP .+2
1553  7635          JMP QAEXIT      /ILLEGAL CHAR. DONT EC
              HO
1554  0222          XSK I 2 /CHECKED THEM ALL?
1555  7551          JMP .-4
              /
1556  1120          ADA I
1557  7440          -337
1560  0451          APO             /BETWEEN 240 AND 337?
1561  7575          JMP QALEGL      /YES. LEGAL CHAR
              /
1562  1461          SAE I 1         /NO. CHECK FURTHER.
1563  7572          JMP .+7
1564  1020          LDA I           /RUBOUT
1565  0334          334
1566  7644          JMP QATPE       /ECHO BACKSLASH
1567  1020          LDA I
1570  0037          37
1571  7637          JMP QAEXIT+2    /LEGAL EXIT
              /
1572  1461          SAE I 1
1573  7635          JMP QAEXIT      /ILLEGAL
                                    /ALT
1574  7637          JMP QAEXIT+2    /EXIT, DONT ECHO
              /
1575  1000  QALEGL, LDA
1576  1536          QATY
1577  7644          JMP QATPE       /ECHO CHAR
1600  3536          ADD QATY
1601  1560          BCL I           /STRIP IT TO 6-BIT
1602  7700          7700
1603  7637          JMP QAEXIT+2
              /TO HERE IF CONTROL CHAR
1604  1460  QACNTR, SAE I
1605  7755          7755
1606  7621          JMP QACKLF
1607  1020          LDA I           /CR
1610  0043          43
1611  5636          STC QAEXIT+1
1612  1020          LDA I
1613  0215          215
1614  7644          JMP QATPE
1615  1020          LDA I
1616  0212          212
1617  7644          JMP QATPE
1620  7635          JMP QAEXIT
              /
1621  1460  QACKLF, SAE I
1622  7752          7752
1623  7627          JMP .+4
1624  1020          LDA I           /LF
1625  0045          45
1626  7611          JMP QACNTR+5
1627  1460          SAE I
1630  7751          7751
1631  7635          JMP QAEXIT      /ILLEGAL
1632  1020          LDA I
1633  0047          47
1634  7637          JMP QAEXIT+2    /EXIT, DONT ECHO
              /
1635  1020  QAEXIT, LDA I   /GET 6-BIT ASCII
1636  0000          0
1637  0061          SET I 1         /RESTORE XRS
1640  0000          0
1641  0062          SET I 2
1642  0000          0
1643  6000          JMP             /EXIT S\R GETKBD
              /S\R TO PRINT C(AC)
1644  0500  QATPE,  IOB
1645  6046          QATLS   /PDP-8 IOT TLS
1646  1000          LDA
1647  0000          0
1650  5654          STC .+4 /SAVE RETURN
1651  0500          IOB
1652  6041          QATSF   /WAIT FOR FLAG
1653  7651          JMP .-2
1654  6000          JMP     /EXIT
              /
1655  0243  QACHAR, 243     /HASH
1656  0244          244     /DOLLAR SIGN
1657  0245          245     /PER CENT
1660  0247          247     /APOSTROPHE
1661  0300          300     /AT SIGN
1662  0336          336     /UP ARROW
1663  0337          337     /BACK ARROW
1664  0340          40      /RUBOUT
1665  0036          36      /ALT
              /END OF S\R GETKBD

NO ERRORS

ADDR   0063
ADLP2  4277
AHC    3121
ANSWER 6530
AVE    3040
CAHC   3100
CALHC  4657
CALIM1 4300
CALIM2 4301
CALIM3 4302
CALIM4 4303
CALVC  4656
CAVC   0077
CBUF   4002
CDTBLK 5114
CHC    2750
CHC1   2751
COMP   0066
CO1    2616
CO2    2642
CO2A   2665
CO3    2702
CO4    2721
CO5    2731
CTBLK  2250
CTP    2302
CVC    2746
CVC1   2747
DIF    0074
DIV    0073
```

```
DIV1    4423
DIV2    4431
DIV3    4435
DIV4    4447
DIPLK   2307
END     0422
FCTR    2003
FD      0011
FLAG    2531
FN      2537
GC      0076
GETWRD  7501
HADDR   4372
HADDR2  4371
HC      0362
HCC     0072
HCC1    4334
HCC2    4345
HCC3    4360
HCTR    2005
HC1     2753
HC10    2762
HC11    2763
HC12    2764
HC13    2765
HC14    2766
HC15    2767
HC16    2770
HC17    2771
HC2     2754
HC20    2772
HC3     2755
HC4     2756
HC5     2757
HC6     2760
HC7     2761
KN1     0351
KN100   0360
KN24    0353
KN30    0355
KN35    2743
K1      0350
K100    0357
K24     0352
K30     0354
K40     0356
LDATA   0370
LDAT1   2267
MAHC    0104
MAHC1   3432
MAHC2   3422
MAIN    0430
MAVC    0103
MAVC1   3452
MESS1   6600
MESS2   6625
MESS3   6652
MESS4   6730
MHC     3123
MTX     3375
MTX1    2221
MTX2    2233
MTX3    2244
M1      0411
M2      0437
M3      0446
NF1     2526
NHC     2752
NUM     6176
OCTAC   6175
PM      6133
PM1     6137
PTR     0010
QAA     7004
QACA    7015
QACHAR  7655
QACKLF  7621
QACNTR  7634
QAD     7026
QAE     7050
QAEXIT  7635
QAF     7516
QAG     7062
QAH     7114
QAI     7131
QAINIT  7000
QAJ     7136
QAK     7305
QAKRR   6036
QAL     7175
QALEGL  7575
QAM     7101
QAN     7223
QAO     7231
QAP     7242
QAQ     7263
QARFSH  7053
QAT     7270
QATLS   6346
QATPE   7644
QATSF   6341
QATY    7536
QAU     7536
QAV     7316
QAW     7512
QAX     7424
QAY     7412
QAZ     7301
RD      2334
RDIV    3365
RED     0365
RHC     2745
RTAB    4452
RTAB1   3122
RVC     2744
R1      3344
R2      3055
R3      3116
SCAHC   4633
SCAVC   4600
SCOMP   2600
SDIV    4400
SGC     2313
SHCC    4304
SLDATA  2251
SMAHC   3400
SMAVC   3433
SMTX    2200
SNFLD   2512
SRD     0064
SRED    3000
SSRD    3141
SSTOR   5000
STAPE   5024
STOR    0101
STVF    2400
SVCC    4203
TAPE    0132
TA1     5040
TA3     5072
TA4     5103
THC     2511
TVC     2510
TVF     0067
TVF1    2436
TVF2    2470
VC      0361
VCC     0071
VCC1    4226
VCC2    4237
VCC3    4261
VCC4    4271
XIT     6174
```

Flow chart for display programs (DISC and derivations)



```
                        *20
                        /DISPLAY CALIBRATED DATA WITH CURSOR -
                        /DISC-CAL
                        /
                        /
                        /16-6-75
                        /
                        /
                        /
                        /M.J.JARRETT.
                        /
                        /DISPLAYS DATA FROM TAPE CONTAINING
                        /CALIBRATED DATA ON UNIT 2.A DISPLAY
                        /OF CAMERA CHANNEL NUMBER.TV FIELD
                        /NUMBER.VERTICAL COORDINATE.HORIZONTAL
                        /COORDINATE AND AN INDICATION AS TO
                        /WHETHER THE FORCE PLATE (FP) WAS SAMPLED
                        /IS ALSO PROVIDED.
                        /
                        /
                        /DATA TO BE DISPLAYED IS PLACED IN A
                        /1024 POINT BUFFER. AND A MOVING WINDOW
                        /TO DISPLAY THE DATA IS CONTROLLED BY
                        /POT 0. A CURSOR IS CONTROLLED BY POT 4
                        /TO PROVIDE A READOUT OF DATA AS DESCRIBED
                        /ABOVE.
                        /
                        /
                        /8-MODE I/O PRESET.START 20 TO START
                        /
                        /
                        /LOCATION 0436 CONTAINS INITIAL TAPE BLOCK
                        /NUMBER. 12 BLOCKS ARE LOADED.
                        /
                        /RE-STARTING THE PROGRAM LOADS THE NEXT 12
                        /BLOCKS.
                        /
                        /
                        /
                        /
                                PMODE
                                *20
0020    6141                    LINC
                                LMODE
0021    6200                    JMP MAIN
                        /
                                PMODE
                                *100
0100    0400    LDATA,          SLDATA
0101    0437    DSORT,          SDSORT
0102    0600    DISP,           SDISP
0103    0224    DSPL,           DSP
                        /
                        /
                                LMODE
                                *200
0200    1020    MAIN,           LDA I
0201    0650                    LDF 10
0202    1040                    STA
0203    0441                    LS1
0204    1040                    STA
0205    0445                    LS2
0206    1040                    STA
0207    0451                    LS3
0210    4414                    STC LDAT1
0211    0064                    SET I LPTR
0212    3777                    3777
0213    0002                    PDP
                                PMODE
0214    4500                    JMS I LDATA
0215    4501                    JMS I DSORT
0216    4500                    JMS I LDATA
0217    4501                    JMS I DSORT
0220    4500                    JMS I LDATA
0221    4501                    JMS I DSORT
0222    4500                    JMS I LDATA
0223    4501                    JMS I DSORT
0224    4502    DSP,            JMS I DISP
0225    5224                    JMP .-1
                        /
                        /
                        /
                        /SUBROUTINE TO LOAD 3 BLOCKS OF DATA
                        /
                                LMODE
                                *400
                                PMODE
0400    0000    SLDATA,         0000
0401    6141                    LINC
                                LMODE
0402    0067                    SET I FCTR
0403    7774                    -3
0404    1000                    LDA
0405    0436                    DTBLK
0406    1120                    ADA I
0407    5000                    5000
0410    4416                    STC LDAT2
0411    1020                    LDA I
0412    0001                    1
0413    0301                    AXO
0414    0650    LDAT1,          LDF 10
0415    0700                    RDC
0416    0000    LDAT2,          0000
0417    1020                    LDA I
0420    1001                    1001
0421    1140                    ADM
0422    0416                    LDAT2
0423    0227                    XSK I FCTR
0424    6415                    JMP LDAT1+1
0425    1000                    LDA
0426    0416                    LDAT2
0427    1120                    ADA I
0430    7776                    -1
0431    4436                    STC DTBLK
0432    0066                    SET I TPTR
0433    2377                    2377
0434    0002                    PDP
                                PMODE
0435    5600                    JMP I SLDATA
                        /
                                LMODE
                        /
0436    0200    DTBLK,          200
                        /
                        /
```

```
                  /SUBROUTINE TO SORT DATA INTO FIELDS OF
                  /IV FIELD NUMBERS, VERTICAL AND HORIZONTAL
                  /COORDINATES
                  /
                           PMODE
0437  0000  SDSORT, 0000
0440  6141          LINC
                    LMODE
0441  0650  DS1,    LIF 10
0442  1026          LIA I TPTR
0443  0644          LIF 4
0444  1064          STA I DPTR
0445  0650  DS2,    LIF 10
0446  1026          LDA I TPTR
0447  0645          LIF 5
0450  1044          STA DPTR
0451  0650  DS3,    LIF 10
0452  1026          LLA I TPTR
0453  0646          LIF 6
0454  1044          STA DPTR
0455  0206          XSK TPTR
0456  6441          JMP DS1
0457  0002          PDP
                    PMODE
0460  5637          JMP I SDSORT
                  /
                  /
                  /
                  /SUBROUTINE TO DISPLAY 512 POINTS AS A
                  /MOVING WINDOW OVER 1024 POINTS, WITH CURSOR
                  /
                    *600
0600  0000  SDISP,  0
0601  6141          LINC
                    LMODE
0602  0100  NDISP,  SAM 0               /SET UP START
0603  1120          ADA I               /LOCATION OF MOVING
0604  1000          1000                /WINDOW
0605  0341          SCR 1
0606  0450          AZE
0607  6612          JMP .+3
0610  1620          BSE I
0611  1777          1777
0612  1620          BSE I
0613  2000          2000
0614  1040          STA
0615  0004          LPTR
0616  0104          SAM 4               /CURSOR
0617  1120          ADA I
0620  1000          1000
0621  0341          SCR 1
0622  2004          ADD LPTR
0623  1620          BSE I
0624  2000          2000
0625  4005          STC CURS
0626  0646          LIF 6
0627  1005          LDA CURS
0630  0061          SFT I 1
0631  1106          LCT
0632  7021          JMP BI1
0633  0063          SFT I 3
0634  1324          LCBUF+47
0635  7116          JMP GLCS
0636  0645          LIF 5
0637  1005          LDA CURS
0640  0061          SFT I 1
0641  1106          LCT
0642  7021          JMP BD1
0643  0063          SFT I 3
0644  1302          DCBUF+25
0645  7116          JMP GLCS
0646  0644          LDF 4
0647  1005          LDA CURS
0650  1560          BCL I
0651  7400          7400
0652  0061          SFT I 1
0653  1106          DCT
0654  7021          JMP PL1
0655  0063          SFT I 3
0656  1260          LCBUF+3
0657  7116          JMP GLCS
0660  0063          SFT I 3
0661  1260          LCBUF+3
0662  1005          LDA CURS
0663  0310          ROR 10
0664  1560          BCL I
0665  7770          7770
0666  1120          ADA I
0667  1170          CTAP+20
0670  4672          STC .+2
0671  1000          LDA
0672  0000          0000
0673  1063          STA I 3
0674  1000          LDA
0675  0672          .-3
0676  1120          ADA I
0677  0040          40
0700  4702          STC .+2
0701  1000          LDA
0702  0000          0000
0703  1063          STA I 3
0704  1005          LDA CURS
0705  0261          ROL I 1
0706  0472          LZE I
0707  6725          JMP DI1
0710  0063          SFT I 3
0711  1340          LCBUF+63
0712  0062          SFT I 2
0713  1244          CTAB1-1
0714  0061          SFT I 1
0715  7772          -5
0716  1022          LDA I 2
0717  1063          STA I 3
0720  0221          XSK I 1
0721  6716          JMP .-3
0722  0076          SFT I 16
0723  7706          -71
0724  6727          JMP .+3
0725  0076  DI1,    SFT I 16
0726  7714          -63
0727  0424          SFA
0730  1560          BCL I
0731  0200          200
0732  0004          ESF
0733  0077          SFT I 17
0734  1254          LCBUF-1
```

```
3735   0361          SET I 1
0736   0000          0
0737   1020          LDA I
0740   0377          377
0741   1777          LSC I 17
0742   3236          KSK I 16
0743   6741          JMP .-2
0744   6751          JMP DCUR
0745   6777          JMP DDA1
0746   6751          JMP DCUR
0747   0002          PDP
                     PMODE
0750   5600          JMP I SLISP
              /
              /
                     LMODE
0751   1000   DCUR,  LDA
0752   0000          0
0753   4776          STC DCU1
0754   0646          LDF 6
0755   1035          LDA CURS
0756   0343          SCR 3
0757   1120          ADA I
0760   0400          400
0761   4001          STC 1
0762   0377          SET I 17
0763   7773          -4
0764   0645          LDF 5
0765   1035          LDA CURS
0766   0342          SCR 2
0767   1120          ADA I
0770   0004          4
0771   0141          DIS 1
0772   1120          ADA I
0773   0001          1
0774   0237          XSK I 17
0775   6771          JMP .-4
0776   6000   DCU1,  JMP 0
              /
              /
              /
0777   1000   DDA1,  LDA
1000   0000          0
1001   5020          STC DDA2
1002   0377          SET I 17
1003   2777          2777
1004   0646   DDA1,  LDF 6
1005   1024          LDA I LPTR
1006   0343          SCR 3
1007   1120          ADA I
1010   0400          400
1011   4001          STC 1
1012   0645          LDF 5
1013   1004          LDA LPTR
1014   0342          SCL 2
1015   0141          DIS 1
1016   0237          XSK I 17
1017   7004          JMP DDA1
1020   6000   DDA2,  JMP 0
              /
              /
              /
```

```
                     /
                     /
                     /BINDEC 1
                     /FOR PDP-12
                     /D.J.NICHOLS
                     /UNIV. WISCONSIN
                     /
                     /SIGNED 12-BIT BINARY TO DECIMAL CONVERSION
                     /
                     /ENTER VIA: JMP BD1
                     /  WITH BINARY NUMBER IN ACCUMULATOR
                     /  AND IR 1 PRESET
                     /DECIMAL 6-BIT ASCII CODE STORED VIA IR1
                     /  LEADING ZEROES SUPPRESSED
                     /  RIGHT JUSTIFIED
                     /NON-INTERRUPTABLE
                     /USES IR 1-3
                     /
1021   0361   BD1,    SCR I 1 /SIGN TO LINK BIT
1022   0261           ROL I 1
1023   0471           APO I   /MAKE NEGATIVE
1024   0017           COM
1025   5065           STC N9BD1 /SAVE IT
1026   2000           ADD 0   /SAVE RETURN
1027   5101           STC P9BD1
1030   1020           LDA I   /LOAD POSSIBLE SIGNS
1031   5540   K9BD1,  5540    /"- "
1032   0452           LZE     /GET CORRECT SIGN
1033   0306           ROR 6
1034   1361           STH I 1 /AND STORE IT
1035   0362           SET I 2 /SET ADDEND POINTER
1036   1101           Q9BD1-1
1037   7054           JMP M9BD1 /CONVERT A DIGIT
1040   0450           AZE     /IS IT A LEADING ZERO?
1041   7050           JMP L9BD1 /NO
1042   2031           ADD K9BD1 /YES:MOVE SIGN RIGHT 1 PLACE
1043   1341           STH 1   /STORE A SPACE OVER THE SIGN
1044   0452           LZE     /GET THE CORRECT SIGN
1045   0306           ROR 6
1046   1361           STH I 1 /AND STORE IT
1047   7037           JMP .-10 /THEN CONTINUE CONVERTING
1050   2077   L9BD1,  ADD P9BD1-2  /MAKE ASCII
1051   1361           STH I 1 /STORE A DIGIT
1052   7054           JMP M9BD1 /CONVERT NEXT DIGIT
1053   7050           JMP L9BD1 /AND STORE IT
                     /LITTLE SUBROUTINE TO DO THE CONVERSION
1054   1000   M9BD1,  LDA     /SAVE RETURN
1055   0000           0
1056   5075           STC P9BD1-4
1057   0063           SET I 3 /SET DIGIT COUNTER
1060   1777           1777
1061   0222           XSK I 2 /MOVE ADDEND POINTER
1062   2065           ADD N9BD1 /LOAD THE VALUE
1063   0223           XSK I 3 /BUMP COUNTER
1064   1060           STA I   /SAVE REMAINING PART
1065   0000   N9BD1,  0
1066   1102           ADA 2   /TRIAL ADD
1067   0451           APO     /STILL NEGATIVE?
1070   7063           JMP .-5 /YES:COUNT AND ADD AGAIN
1071   1003           LDA     /NO: GET THE COUNTER
1072   0003           3
1073   1520           SRO I   /LAST DIGIT?
1074   3567           3567
```

```
1075  6000            JMP 0     /NO: BACK TO THE SUBROUTINE
1076  1620            BSE I     /YES:MAKE ASCII
1077  0060            0060
1100  1361            STH I 1   /STORE IT
1101  6000  P9BL1,    JMP 0     /AND RETURN TO CALLING PGM
            /ADDEND TABLE
1102  1750  Q9BL1,    1750
1103  0144             144
1104  0012              12
1105  0001               1
            /END BINDEC 1
            /
            /
1106  0000  DC1,      0
1107  0000            0
1110  0000            0
1111  0000            0
1112  0000            0
1113  0000            0
1114  0000            0
1115  0000            0
                      LMODE
            /
            /
1116  1000  GLCS,     LDA
1117  0000            0
1120  5147            STC GD2
1121  0061            SET I 1
1122  1106            DC1
1123  0062            SET I 2
1124  7772            -5
1125  0011            CLR
1126  1321  GD1,      LDH I 1
1127  1120            ADA I
1130  1110            CTAB-40
1131  5133            STC .+2
1132  1000            LDA
1133  0000            0000
1134  1363            STA I 3
1135  1000            LDA
1136  1133            .-3
1137  1120            ADA I
1140  0040            40
1141  5143            STC .+2
1142  1000            LDA
1143  0000            0000
1144  1363            STA I 3
1145  0222            XSK I 2
1146  7126            JMP GD1
1147  6000  GD2,      JMP 0
            /
            /
            /
1150  0000  CTAB,     0
1151  0000            0
1152  0000            0
1153  0000            0
1154  0000            0
1155  0000            0
1156  0000            0
1157  0000            0
1160  0000            0
1161  0000            0
1162  0000            0
1163  0000            0
1164  0000            0
1165  0404            0404      /-
1166  0000            0
1167  0000            0
1170  4136            4136      /0
1171  2101            2101      /1
1172  4523            4523      /2
1173  4122            4122      /3
1174  2414            2414      /4
1175  5172            5172      /5
1176  1506            1506      /6
1177  4443            4443      /7
1200  5126            5126      /8
1201  5122            5122      /9
1202  0000            0
1203  0000            0
1204  0000            0
1205  0000            0
1206  0000            0
1207  0000            0
1210  0000            0
1211  0000            0
1212  0000            0
1213  0000            0
1214  0000            0
1215  0000            0
1216  0000            0
1217  0000            0
1220  0000            0
1221  0000            0
1222  0000            0
1223  0000            0
1224  0000            0
1225  0404            0404      /-
1226  0000            0
1227  0000            0
1230  3641            3641      /0
1231  0177            0177      /1
1232  2151            2151      /2
1233  2651            2651      /3
1234  0477            0477      /4
1235  0651            0651      /5
1236  4225            4225      /6
1237  6050            6050      /7
1240  2651            2651      /8
1241  3651            3651      /9
1242  0000            0
1243  0000            0
1244  0000            0
            /
            /
1245  4477  CTAB1,    4477
1246  4044            4044      /F
1247  0000            0000
1250  4477            4477
1251  3044            3044      /P
1252  0000            0
1253  0000            0
1254  0000            0
1255  4477  DCBUF,    4477
1256  4044            4044      /F
```

```
0766    1257  0000       0
0767    1260  0000       0
0770    1261  0000       0
0771    1262  0000       0
0772    1263  0000       0
0773    1264  0000       0
0774    1265  0000       0
0775    1266  0000       0
0776    1267  0000       0
0777    1270  0000       0
1000    1271  0000       0
1001    1272  0000       0
1002    1273  0000       0
1003    1274  0000       0
1004    1275  0000       0
1005    1276  0000       0
1006    1277  0176       0176
1007    1300  7402       7402            /V
1010    1301  0000       0
1011    1302  0000       0
1012    1303  0000       0
1013    1304  0000       0
1014    1305  0000       0
1015    1306  0000       0
1016    1307  0000       0
1017    1310  0000       0
1020    1311  0000       0
1021    1312  0000       0
1022    1313  0000       0
1023    1314  0000       0
1024    1315  0000       0
1025    1316  0000       0
1026    1317  0000       0
1027    1320  0000       0
1030    1321  1077       1077
1031    1322  7710       7710            /H
1032    1323  0000       0
1033    1324  0000       0
1034    1325  0000       0
1035    1326  0000       0
1036    1327  0000       0
1037    1330  0000       0
1040    1331  0000       0
1041    1332  0000       0
1042    1333  0000       0
1043    1334  0000       0
1044    1335  0000       0
1045    1336  0000       0
1046    1337  0000       0
1047    1340  0000       0
1050    1341  0000       0
1051    1342  0000       0
1052    1343  0000       0
1053    1344  0000       0
1054    1345  0000       0
1055    1346  0000       0
1056    1347  0000       0
1057    1350  0000       0
1060    1351  0000       0
1061    1352  0000       0
1062    1353  0000       0
1063                 /
1064                 /

1065                         /
1066                         /
1067                         *4
1070    0004  0000  DPTR,    0
1071    0005  0000  CURS,    0
1072    0006  0000  TPTR,    0
1073    0007  0000  FCTR,    0
1074                         *40

NO ERRORS

PD1     1021
CTAB    1150
CTAB1   1245
CURS    0005
DCBUF   1255
DCT     1106
DCUR    0751
DCU1    0776
DDAT    0777
DDA1    1004
DDA2    1020
DISP    0102
DI1     0725
DPTR    0004
DSORT   0101
DSP     0224
DSPL    0103
DS1     0441
DS2     0445
DS3     0451
DTBLK   0436
FCTR    0007
GDCS    1116
GD1     1126
GD2     1147
K9PD1   1031
LDATA   0100
LDAT1   0414
LDAT2   0416
L9PD1   1053
MAIN    0200
M9PD1   1054
NDISP   0602
N9PD1   1065
P9PD1   1101
Q9PD1   1102
SDISP   0600
SDSORT  0437
SDDATA  0400
TPTR    0006
```

```
                      *20
                      /DISPLAY CALIBRATED DATA WITH FIELD CURSORS -
                      /DISP-CAL
                      /
                      /
                      /16-6-75
                      /
                      /M.J.JARRETT.
                      /
                      /
                      /DISPLAYS DATA FROM TAPE CONTAINING
                      /CALIBRATED DATA ON UNIT 2.A DISPLAY OF TV
                      /FIELD NUMBER IS PROVIDED.CORRESPONDING TO
                      /CURSORS WHICH MARK EVERY POINT OCCURING
                      /IN THE TV FIELD SELECTED.
                      /
                      /
                      /DATA TO BE DISPLAYED IS PLACED IN A
                      /1024 POINT BUFFER. AND A MOVING WINDOW
                      /TO DISPLAY THE DATA IS CONTROLLED BY
                      /POT 0. THE TV FIELD ON WHICH CURSORS ARE
                      /TO BE DISPLAYED IS SELECTED BY POT 4.
                      /
                      /
                      /PROGRAM STARTED BY I/O PRESET.START 20
                      /IN 8 MODE
                      /
                      /
                      /LOCATION 436 CONTAINS START BLOCK FOR
                      /DATA TO BE DISPLAYED.
                      /RE-STARTING PROGRAM LOADS NEXT 12 BLOCKS
                      /OF DATA.
                      /
                      /
                      /
                      /
                              PMODE
                              *20
0020   6141                   LINC
                              LMODE
0021   6200                   JMP MAIN
                      /
                              PMODE
                              *100
0100   0400           LDATA,  SLDATA
0101   0437           DSORT,  SDSORT
0102   0600           DISP,   SDISP
                      /
                      /
                              LMODE
                              *200
0200   1020           MAIN,   LDA I
0201   0650                   LDF 10
0202   1040                   STA
0203   0441                   DS1
0204   1040                   STA
0205   0445                   DS2
0206   1040                   STA
0207   0451                   DS3
0210   4414                   STC LDAT1
0211   0064                   SET I DPTR
0212   3777                   3777
0213   0002                   PDP
                              PMODE
0214   4500                   JMS I LDATA
0215   4501                   JMS I DSORT
0216   4500                   JMS I LDATA
0217   4501                   JMS I DSORT
0220   4500                   JMS I LDATA
0221   4501                   JMS I DSORT
0222   4500                   JMS I LDATA
0223   4501                   JMS I DSORT
0224   4502                   JMS I DISP
0225   5224                   JMP .-1
                      /
                      /
                      /
                      /SUBROUTINE TO LOAD 3 BLOCKS OF DATA
                      /
                              LMODE
                              *400
                              PMODE
0400   0000           SLDATA, 0000
0401   6141                   LINC
                              LMODE
0402   0067                   SET I FCTR
0403   7774                   -3
0404   1000                   LDA
0405   0436                   DTBLK
0406   1120                   ADA I
0407   5000                   5000
0410   4416                   STC LDAT2
0411   1020                   LDA I
0412   0001                   1
0413   0001                   AXO
0414   0650           LDAT1,  LDF 10
0415   0700                   RDC
0416   0000           LDAT2,  0000
0417   1020                   LDA I
0420   1001                   1001
0421   1140                   ADM
0422   0416                   LDAT2
0423   0227                   XSK I FCTR
0424   6415                   JMP LDAT1+1
0425   1000                   LDA
0426   0416                   LDAT2
0427   1120                   ADA I
0430   7776                   -1
0431   4436                   STC DTBLK
0432   0066                   SET I TPTR
0433   2377                   2377
0434   0002                   PDP
                              PMODE
0435   5600                   JMP I SLDATA
                      /
                              LMODE
                      /
0436   0200           DTBLK,  200
                      /
                      /
                      /SUBROUTINE TO SORT DATA INTO FIELDS OF
                      /TV FIELD NUMBERS, VERTICAL AND HORIZONTAL
                      /COORDINATES
                      /
                              PMODE
```

```
0437  0000  SDSORT, 0000
0440  6141          LINC
                    LMODE
0441  0650  DS1,    LDF 10
0442  1026          LDA I TPTR
0443  0644          LDF 4
0444  1064          STA I DPTR
0445  0650  DS2,    LDF 10
0446  1326          LDA I TPTR
0447  0645          LDF 5
0450  1344          STA DPTR
0451  0650  DS3,    LDF 10
0452  1326          LDA I TPTR
0453  0646          LDF 6
0454  1044          STA DPTR
0455  0206          XSK TPTR
0456  6441          JMP DS1
0457  0002          PDP
                    PMODE
0460  5637          JMP I SDSORT
            /
            /
            /
            /SUBROUTINE TO DISPLAY 512 POINTS AS A
            /MOVING WINDOW OVER 1024 POINTS, WITH CURSOR
            /
                    LMODE
                    *600
                    PMODE
0600  0000  SDISP,  0000
0601  6141          LINC
                    LMODE
0602  0011          CLR
0603  0100          SAM 0           /SET UP START
0604  1120          ADA I           /LOCATION OF MOVING
0605  1000          1000            /WINDOW
0606  1620          BSE I
0607  2000          2000
0610  4004          STC DPTR
0611  0104          SAM 4           /CURSOR
0612  1120          ADA I
0613  1000          1000
0614  0342          SCR 2
0615  1040          STA
0616  0005          CURS
0617  0061          SET I 1
0620  1025          DCT
0621  6740          JMP RD1
0622  0063          SET I 3
0623  1177          DCBUF+3
0624  7035          JMP GDCS
0625  0024          SFA
0626  1560          BCL I
0627  0200          200
0630  0034          ESF
0631  0377          SET I 17
0632  1173          DCBUF-1
0633  0061          SET I 1
0634  0000          0
0635  0076          SET I 16
0636  7757          -20
0637  1020          LDA I
0640  0377          377
0641  1777          DSC I 17
0642  0236          XSK I 16
0643  6641          JMP .-2
0644  0356          SET 16
0645  0004          DPTR
0646  0075          SET I 15
0647  2776          2776
0650  0644          LDF 4
0651  0235  DI1,    XSK I 15
0652  0456          SKP
0653  6665          JMP DI2
0654  1036          LDA I 16
0655  1560          BCL I
0656  7400          7400
0657  1440          SAE
0660  0005          CURS
0661  6651          JMP DI1
0662  6670          JMP DCUR
0663  0644          LDF 4
0664  6651          JMP DI1
0665  6716  DI2,    JMP DDAT
0666  0002          PDP
                    PMODE
0667  5600          JMP I SDISP
            /
            /
```

```
                  *23
                  /DISPLAY DATA WITH CURSOR - DISC
                  /
                  /
                  /18-5-76
                  /
                  /
                  /M.J.JARRETT.
                  /
                  /DISPLAYS DATA FROM TAPE CONTAINING
                  /UNCALIBRATED DATA ON UNIT 2.A DISPLAY
                  /OF CAMERA CHANNEL NUMBER,TO FIELD
                  /NUMBER,VERTICAL COORDINATE,HORIZONTAL
                  /COORDINATE AND AN INDICATION AS TO
                  /WHETHER THE FORCE PLATE (FP) WAS SAMPLED
                  /IS ALSO PROVIDED.
                  /
                  /
                  /DATA TO BE DISPLAYED IS PLACED IN A
                  /1024 POINT BUFFER, AND A MOVING WINDOW
                  /TO DISPLAY THE DATA IS CONTROLLED BY
                  /POT 3, A CURSOR IS CONTROLLED BY POT 4
                  /TO PROVIDE A READOUT OF DATA AS DESCRIBED
                  /ABOVE.
                  /
                  /
                  /8-MODE I/O PRESET,START 20 TO START
                  /
                  /
                  /LOCATION 0436 CONTAINS INITIAL TAPE BLOCK
                  /NUMBER, 12 BLOCKS ARE LOADED.
                  /
                  /RE-STARTING THE PROGRAM LOADS THE NEXT 12
                  /BLOCKS.
                  /
                  /
                  /
                  /
                          PMODE
                          *20
0020  6141                LINC
                          LMODE
0021  6203                JMP MAIN
                  /
                          PMODE
                          *100
0100  0430  LDATA,        SLDATA
0101  0437  DSORT,        SDSORT
0102  3600  DISP,         SDISP
0103  0224  DSPL,         DSP
                  /
                  /
                          LMODE
                          *200
0200  1020  MAIN,         LDA I
0201  3650                LDF 10
0202  1040                STA
0203  0441                DS1
0204  1040                STA
0205  0445                DS2
0206  1040                STA
0207  0451                DS3
0210  4414                STC LDAT1
0211  0464                SET I DPTR
0212  3777                3777
0213  0302                PDP
                          PMODE
0214  4500                JMS I LDATA
0215  4501                JMS I DSORT
0216  4500                JMS I LDATA
0217  4501                JMS I DSORT
0220  4500                JMS I LDATA
0221  4501                JMS I DSORT
0222  4500                JMS I LDATA
0223  4501                JMS I DSORT
0224  4502  DSP,          JMS I DISP
0225  5224                JMP .-1
                  /
                  /
                  /
                  /SUBROUTINE TO LOAD 3 BLOCKS OF DATA
                  /
                          LMODE
                          *400
                          PMODE
0400  0000  SLDATA,       0000
0401  6141                LINC
                          LMODE
0402  0067                SET I FCTR
0403  7774                -3
0404  1000                LDA
0405  0436                DTPLK
0406  1120                ADA I
0407  5000                5000
0410  4416                STC LDAT2
0411  1020                LDA I
0412  0001                1
0413  0331                AXO
0414  0650  LDAT1,        LDF 10
0415  0700                RDC
0416  0000  LDAT2,        0000
0417  1020                LDA I
0420  1001                1001
0421  1140                ADM
0422  0416                LDAT2
0423  0227                XSK I FCTR
0424  6415                JMP LDAT1+1
0425  1000                LDA
0426  0416                LDAT2
0427  1120                ADA I
0430  7776                -1
0431  4436                STC DTPLK
0432  0066                SET I TPTR
0433  2377                2377
0434  0302                PDP
                          PMODE
0435  5600                JMP I SLDATA
                  /
                          LMODE
                  /
0436  0200  DTPLK,        200
                  /
                  /
                  /SUBROUTINE TO SORT DATA INTO FIELDS OF
                  /TO FIELD NUMBERS,VERTICAL AND HORIZONTAL
```

```
                     /COORDINATES
                     /
                             PMODE
0437    0000  SDSORT,  0000
0440    6141           LINC
                             LMODE
0441    0650  LS1,     LDF 10
0442    1026           LDA I TPTR
0443    0644           LDF 4
0444    1064           STA I DPTR
0445    0650  DS2,     LDF 10
0446    1026           LDA I TPTR
0447    0645           LDF 5
0450    1044           STA DPTR
0451    0650  DS3,     LDF 10
0452    1026           LDA I TPTR
0453    0646           LDF 6
0454    1044           STA DPTR
0455    0206           XSK TPTR
0456    6441           JMP DS1
0457    0002           PDP
                             PMODE
0460    5637           JMP I SDSORT
                     /
                     /
                     /
                     /SUBROUTINE TO DISPLAY 512 POINTS AS A
                     /MOVING WINDOW OVER 1024 POINTS, WITH CURSOR
                     /
                             *600
0600    0000  SDISP,   0
0601    6141           LINC
                             LMODE
0602    0100  NDISP,   SAM 0              /SET UP START
0603    1120           ADA I              /LOCATION OF MOVING
0604    1000           1000               /WINDOW
0605    0341           SCR 1
0606    0450           AZE
0607    6612           JMP .+3
0610    1620           BSE I
0611    1777           1777
0612    1620           BSE I
0613    2000           2000
0614    1040           STA
0615    0004           DPTR
0616    0104           SAM 4              /CURSOR
0617    1120           ADA I
0620    1000           1000
0621    0341           SCR 1
0622    2004           ADD DPTR
0623    1620           BSE I
0624    2000           2000
0625    4005           STC CURS
0626    0646           LDF 6
0627    1005           LDA CURS
0630    0061           SET I 1
0631    1122           DCT
0632    7035           JMP BD1
0633    0063           SET I 3
0634    1340           DCBUF+47
0635    7132           JMP GDCS
0636    0645           LDF 5
0637    1005           LDA CURS
0640    0061           SET I 1
0641    1122           DCT
0642    7035           JMP BD1
0643    0063           SET I 3
0644    1316           DCBUF+25
0645    7132           JMP GDCS
0646    0644           LDF 4
0647    1005           LDA CURS
0650    1560           BCL I
0651    7400           7400
0652    0061           SET I 1
0653    1122           DCT
0654    7035           JMP BD1
0655    0063           SET I 3
0656    1274           DCBUF+3
0657    7132           JMP GDCS
0660    0063           SET I 3
0661    1274           DCBUF+3
0662    1005           LDA CURS
0663    0310           ROR 10
0664    1560           BCL I
0665    7770           7770
0666    1120           ADA I
0667    1204           CTAB+20
0670    4672           STC .+2
0671    1000           LDA
0672    0000           0000
0673    1063           STA I 3
0674    1000           LDA
0675    0672           .-3
0676    1120           ADA I
0677    0040           40
0700    4702           STC .+2
0701    1000           LDA
0702    0000           0000
0703    1063           STA I 3
0704    1005           LDA CURS
0705    0261           ROL I 1
0706    0472           LZE I
0707    6725           JMP DI1
0710    0063           SET I 3
0711    1354           DCBUF+63
0712    0062           SET I 2
0713    1260           CTAB1-1
0714    0061           SET I 1
0715    7772           -5
0716    1022           LDA I 2
0717    1063           STA I 3
0720    0221           XSK I 1
0721    6716           JMP .-3
0722    0076           SET I 16
0723    7706           -71
0724    6727           JMP .+3
0725    0076  DI1,     SET I 16
0726    7714           -63
0727    0024           SFA
0730    1560           BCL I
0731    0200           200
0732    0004           ESF
0733    0077           SET I 17
0734    1270           DCBUF-1
0735    0061           SET I 1
0736    0000           0
```

```
0737  1020           LDA I
0740  0377           377
0741  1777           DSC I 17
0742  0236           XSK I 16
0743  6741           JMP .-2
0744  6751           JMP DCUR
0745  7005           JMP DDAT
0746  6751           JMP DCUR
0747  0002           PDP
                     PMODE
0750  5600           JMP I SDISP
              /
              /
                     LMODE
              /
0751  1000   DCUR,   LDA
0752  0000           0
0753  5004           STC DCU1
0754  0646           LDF 6
0755  1005           LDA CURS
0756  0341           SCR 1
0757  4001           STC 1
0760  0077           SET I 17
0761  7773           -4
0762  0645           LDF 5
0763  1005           LDA CURS
0764  1120           ADA I
0765  7307           -470
0766  0471           APO I
0767  6772           JMP .+3
0770  1120           ADA I
0771  0470           470
0772  1120           ADA I
0773  7577           -200
0774  0017           COM
0775  1120           ADA I
0776  0004           4
0777  0141           DIS 1
1000  1120           ADA I
1001  0001           1
1002  0237           XSK I 17
1003  6777           JMP .-4
1004  6000   DCU1,   JMP 0
              /
              /
              /
              /
              /
1005  1000   DDAT,   LDA
1006  0000           0
1007  5034           STC DDA2
1010  0077           SET I 17
1011  2777   COUNTR, 2777
1012  0646   DDA1,   LDF 6
1013  1024           LDA I DPTR
1014  0341           SCR 1
1015  4001           STC 1
1016  0645           LDF 5
1017  1034           LDA DPTR
1020  1120           ADA I
1021  7307           -470
1022  0471           APO I
1023  7026           JMP .+3
1024  1120           ADA I
1025  0470           470
1026  1120           ADA I
1027  7577           -200
1030  0017           COM
1031  0141           DIS 1
1032  0237           XSK I 17
1033  7012           JMP DDA1
1034  6000   DDA2,   JMP 0
              /
```

```
                    *20
                    /DISPLAY DATA WITH FIELD CURSOR - DISF
                    /
                    /
                    /18-5-76
                    /
                    /M.O.JARRETT.
                    /
                    /
                    /DISPLAYS DATA FROM TAPE CONTAINING
                    /CO-ORDINATE DATA ON UNIT 2.READ OUT
                    /OF THE TV FIELD NUMBER IS PROVIDED,
                    /CORRESPONDING TO CURSORS WHICH MARK
                    /EVERY POINT OCCURING IN THE TV FIELD
                    /SELECTED.
                    /
                    /
                    /DATA TO BE DISPLAYED IS PLACED IN A
                    /1024 POINT BUFFER, AND A MOVING WINDOW
                    /TO DISPLAY THE DATA IS CONTROLLED BY
                    /POT 0. CURSORS ARE CONTROLLED BY POT 4
                    /TO PROVIDE A READOUT OF DATA AS DESCRIBED
                    /ABOVE.
                    /
                    /
                    /PROGRAM STARTED BY I/O PRESET,START 20
                    /IN 8 MODE
                    /
                    /
                    /LOCATION 436 CONTAINS START BLK FOR DATA
                    /TO BE DISPLAYED.
                    /RE-STARTING PROGRAM LOADS NEXT 12 BLOCKS
                    /OF DATA.
                    /
                    /
                    /
                            PMODE
                            *20
0020  6141                  LINC
                            LMODE
0021  6200                  JMP MAIN
                    /
                            PMODE
                            *100
0100  0400         LDATA,   SLDATA
0101  0437         DSORT,   SDSORT
0102  0600         DISP,    SDISP
0103  0224         DSPL,    DSP
                    /
                    /
                            LMODE
                            *200
0200  1020         MAIN,    LDA I
0201  0650                  LDF 10
0202  1040                  STA
0203  0441                  DS1
0204  1040                  STA
0205  0445                  DS2
0206  1040                  STA
0207  0451                  DS3
0210  4414                  STC LDAT1
0211  0064                  SET I DPTR
0212  3777                  3777
0213  0002                  PDP
                            PMODE
0214  4500                  JMS I LDATA
0215  4501                  JMS I DSORT
0216  4500                  JMS I LDATA
0217  4501                  JMS I DSORT
0220  4500                  JMS I LDATA
0221  4501                  JMS I DSORT
0222  4500                  JMS I LDATA
0223  4501                  JMS I DSORT
0224  4502         DSP,     JMS I DISP
0225  5224                  JMP .-1
                   /
                   /
                   /
                   /SUBROUTINE TO LOAD 3 BLOCKS OF DATA
                   /
                            LMODE
                            *400
                            PMODE
0400  0000         SLDATA,  0000
0401  6141                  LINC
                            LMODE
0402  0067                  SET I FCTR
0403  7774                  -3
0404  1000                  LDA
0405  0436                  DTBLK
0406  1120                  ADA I
0407  5000                  5000
0410  4416                  STC LDAT2
0411  1020                  LDA I
0412  0001                  1
0413  0001                  AKO
0414  0650         LDAT1,   LDF 10
0415  0700                  RDC
0416  0000         LDAT2,   0000
0417  1020                  LDA I
0420  1031                  1031
0421  1140                  ADM
0422  0416                  LDAT2
0423  0227                  XSK I FCTR
0424  6415                  JMP LDAT1+1
0425  1000                  LDA
0426  0416                  LDAT2
0427  1120                  ADA I
0430  7776                  -1
0431  4436                  STC DTBLK
0432  0066                  SET I TPTR
0433  2377                  2377
0434  0002                  PDP
                            PMODE
0435  5600                  JMP I SLDATA
                   /
                            LMODE
                   /
0436  0112         DTBLK,   112
                   /
                   /
                   /SUBROUTINE TO SORT DATA INTO FIELDS OF
                   /TV FIELD NUMBERS,VERTICAL AND HORIZONTAL
                   /COORDINATES
                   /
```

```
                        PMODE
0437  0000  SDSORT,     0000
0440  6141              LINC
                        LMODE
0441  0650  DS1,        LDF 10
0442  1026              LDA I TPTR
0443  0644              LDF 4
0444  1064              STA I DPTR
0445  0650  DS2,        LDF 10
0446  1026              LDA I TPTR
0447  0645              LDF 5
0450  1044              STA DPTR
0451  0650  DS3,        LDF 10
0452  1026              LDA I TPTR
0453  0646              LDF 6
0454  1044              STA DPTR
0455  0206              XSK TPTR
0456  6441              JMP DS1
0457  0002              PDP
                        PMODE
0460  5637              JMP I SDSORT
            /
            /
            /
            /SUBROUTINE TO DISPLAY 512 POINTS AS A
            /MOVING WINDOW OVER 1024 POINTS, WITH CURSOR
            /
            /
                        *600
0600  0000  SDISP,      0
0601  6141              LINC
                        LMODE
0602  0100  NDISP,      SAM 0           /SET UP START
0603  1120              ADA I           /LOCATION OF MOVING
0604  1000              1000            /WINDOW
0605  0341              SCR 1
0606  0450              AZE
0607  6612              JMP .+3
0610  1620              BSE I
0611  1777              1777
0612  1620              BSE I
0613  2000              2000
0614  1040              STA
0615  0004              DPTR
0616  0104              SAM 4           /CURSOR
0617  1120              ADA I
0620  1000              1000
0621  0342              SCR 2
0622  1040              STA
0623  0005              CURS
0624  0061              SET I 1
0625  1046              DCT
0626  6761              JMP RD1
0627  0063              SET I 3
0630  1220              DCBUF+3
0631  7356              JMP GDCS
0632  0024              SFA
0633  1560              BCL I
0634  0200              200
0635  0034              ESF
0636  0077              SET I 17
0637  1214              DCBUF-1
0640  0061              SET I 1
0641  0000              0
0642  0076              SET I 16
0643  7757              -20
0644  1020              LDA I
0645  0377              377
0646  1777              DSC I 17
0647  0236              XSK I 16
0650  6646              JMP .-2
0651  0056              SET 16
0652  0004              DPTR
0653  0075              SET I 15
0654  2777              2777
0655  0644              LDF 4
0656  0235  DI1,        XSK I 15
0657  0456              SKP
0660  6672              JMP DI2
0661  1036              LDA I 16
0662  1560              BCL I
0663  7400              7400
0664  1440              SAE
0665  0005              CURS
0666  6656              JMP DI1
0667  6675              JMP LCUR
0670  0644              LDF 4
0671  6656              JMP DI1
0672  6731  DI2,        JMP LDAT
0673  0002              PDP
                        PMODE
0674  5600              JMP I SDISP
            /
            /
```

```
                        *20
                        /DISPLAY GRID DATA - DISG
                        /
                        /
                        /18-5-76
                        /
                        /M.J.JARRETT.
                        /
                        /
                        /DISPLAYS GRID DATA FROM TAPE ON UNIT
                        /2. 8 TAPE BLOCKS AT A TIME ARE READ
                        /INTO CORE GIVING 1024 POINTS FOR DISPLAY
                        /512 OF THESE CAN BE DISPLAYED AT ANY ONE
                        /TIME. THE STARTING POINT FOR THIS DISPLAY
                        /BEING CONTROLLED BY POT 0.ALLOWING THE
                        /1024 POINTS TO BE SCANNED.A READ OUT OF
                        /THE CO-ORDINATES OF A POINT INDICATED BY
                        /A CURSOR IS PROVIDED IN THE TOP LEFT
                        /CORNER. THE LOCATION OF THIS POINT FROM/THE STA
                        RT OF THE CURRENT 8 BLOCK BUFFER
                        /IS ALSO INDICATED (D).THIS CURSOR IS
                        /CONTROLLED BY POT 4.
                        /
                        /
                        /
                        /
                        /8-MODE I/O PRESET. START 20 TO START.
                        /
                        /
                        /INITIAL TAPE BLOCK NUMBER HELD IN
                        /LOCATION 0436.
                        /
                        /
                        /REPEATING START PROCEDURE LOADS NEXT
                        /8 BLOCKS
                        /
                        /
                        /
                        /
                                PMODE
                                *20
0020    6141                    LINC
                                LMODE
0021    6200                    JMP MAIN
                        /
                                PMODE
                                *100
0100    0400            LDATA,  SLDATA
0101    0437            ISORT,  SISORT
0102    0600            DISP,   SDISP
0103    0216            DSPL,   DSP
                        /
                        /
                                LMODE
                                *200
0200    1020            MAIN,   LDA I
0201    0650                    LDF 10
0202    1040                    STA
0203    0441                    IS2
0204    1040                    STA
0205    0445                    IS3
0206    4414                    STC LDAT1
0207    0064                    SET I DPTR
0210    3777                    3777
0211    0002                    PDP
                                PMODE
0212    4500                    JMS I LDATA
0213    4501                    JMS I ISORT
0214    4500                    JMS I LDATA
0215    4501                    JMS I ISORT
0216    4502            DSP,    JMS I DISP
0217    5216                    JMP .-1
                        /
                        /
                        /
                        /SUBROUTINE TO LOAD 4 BLOCKS OF DATA
                        /
                                LMODE
                                *400
                                PMODE
0400    0000            SLDATA, 0000
0401    6141                    LINC
                                LMODE
0402    0067                    SET I FCTR
0403    7773                    -4
0404    1000                    LDA
0405    0436                    DTBLK
0406    1120                    ADA I
0407    4000                    4000
0410    4416                    STC LDAT2
0411    1020                    LDA I
0412    0001                    1
0413    0001                    AXO
0414    0650            LDAT1,  LDF 10
0415    0700                    RDC
0416    0000            LDAT2,  0000
0417    1020                    LDA I
0420    1001                    1001
0421    1140                    ADM
0422    0416                    LDAT2
0423    0227                    XSK I FCTR
0424    6415                    JMP LDAT1+1
0425    1000                    LDA
0426    0416                    LDAT2
0427    1120                    ADA I
0430    7776                    -1
0431    4436                    STC DTBLK
0432    0066                    SET I DPTR
0433    3777                    3777
0434    0002                    PDP
                                PMODE
0435    5600                    JMP I SLDATA
                        /
                                LMODE
                        /
0436    0400            DTBLK,  400
                        /
                        /
                        /SUBROUTINE TO SORT DATA INTO FIELDS OF
                        /VERTICAL AND HORIZONTAL COORDINATES
                        /
                                PMODE
0437    0000            SISORT, 0000
0440    6141                    LINC
                                LMODE
```

```
0441   0650   DS2,    LDF 10
0442   1026           LDA I IPTR
0443   0645           LDF 5
0444   1064           STA I DPTR
0445   0650   DS3,    LDF 10
0446   1026           LDA I IPTR
0447   0646           LDF 6
0450   1044           STA DPTR
0451   0206           XSK IPTR
0452   6441           JMP DS2
0453   0002           PDP
                      PMODE
0454   5637           JMP I SDSORT
                      /
                      /
                      /
                      /SUBROUTINE TO DISPLAY 512 POINTS AS A
                      /MOVING WINDOW OVER 1024 POINTS, WITH CURSOR
                      /
                      *600
0600   0000   SDISP,  0
0601   6141           LINC
                      LMODE
0602   0100   DDISP,  SAM 0              /SET UP START
0603   1120           ADA I              /LOCATION OF MOVING
0604   1000           1000               /WINDOW
0605   0341           SCR 1
0606   0450           AZE
0607   6612           JMP .+3
0610   1620           BSE I
0611   1777           1777
0612   1620           BSE I
0613   2000           2000
0614   1040           STA
0615   0004           DPTR
0616   0104           SAM 4              /CURSOR
0617   1120           ADA I
0620   1000           1000
0621   0341           SCR 1
0622   2004           ADD DPTR
0623   1120           ADA I
0624   0001           1
0625   1620           BSE I
0626   2000           2000
0627   4035           STC CURS
0630   0646           LDF 6
0631   1035           LDA CURS
0632   0061           SET I 1
0633   1127           DCI
0634   7342           JMP RDI
0635   0063           SET I 3
0636   1345           DCBUF+47
0637   7137           JMP GDCS
0640   0645           LDF 5
0641   1035           LDA CURS
0642   0061           SET I 1
0643   1127           DCI
0644   7342           JMP RDI
0645   0063           SET I 3
0646   1323           DCBUF+25
0647   7137           JMP GDCS
0650   0061           SET I 1
0651   1127           DCI
0652   1000           LDA
0653   0035           CURS
0654   0310           ROR 10
0655   1620           BSE I
0656   0060           60
0657   1560           BCL I
0660   0014           14
0661   1361           STH I 1
0662   1000           LDA
0663   0035           CURS
0664   0305           ROR 5
0665   1620           BSE I
0666   0060           60
0667   1560           BCL I
0670   0010           10
0671   1361           STH I 1
0672   1000           LDA
0673   0035           CURS
0674   0302           ROR 2
0675   1620           BSE I
0676   0060           60
0677   1560           BCL I
0700   0014           14
0701   1361           STH I 1
0702   1000           LDA
0703   0035           CURS
0704   0241           ROL 1
0705   1620           BSE I
0706   0063           63
0707   1560           BCL I
0710   0011           11
0711   1361           STH I 1
0712   1560           BCL I
0713   0037           37
0714   1361           STH I 1
0715   1061           STA I 1
0716   0063           SET I 3
0717   1302           DCBUF+4
0720   7137           JMP GDCS
0721   0076   DDI1,   SET I 16
0722   7714           -63
0723   0024           SFA
0724   1560           BCL I
0725   0200           200
0726   0004           ESF
0727   0077           SET I 17
0730   1275           DCBUF-1
0731   0061           SET I 1
0732   0000           0
0733   1020           LDA I
0734   0377           377
0735   1777           DSC I 17
0736   0236           XSK I 16
0737   6735           JMP .-2
0740   6745           JMP DCUR
0741   7331           JMP DIA1
0742   6745           JMP DCUR
0743   0002           PDP
                      PMODE
0744   5600           JMP I SDISP
              /
              /
                      LMODE
```

APPENDIX A.4

Characteristics of "Scotchlite" Retro-reflective sheeting.

Optical Properties

"Scotchlite" Brand Reflective Sheetings High Gain # 7610 and # 7611 have the retro-reflectance values listed on the following tables. The values are expressed as a multiple of the brightness of a perfect diffuse white surface. This multiple is shown as the luminance factor. These values were obtained from retro-reflectance measurements of typical samples of #7610 and #7611 Sheetings.

Table I - Luminance Factor vs. Incidence Angle

Angle of Incidence	0°	10°	20°	30°	45°
Luminance Factor	590	595	620	660	710

(All readings were taken at an 0.5° divergence angle).

Table II - Luminance Factor vs. Divergence Angle

Angle of Divergence	0°	1/4°	1/3°	1/2°	3/4°	1°	1-1/2°
Luminance Factor	1610	1280	1090	590	195	115	55

(All readings were taken at a 0° incidence angle).

Table I data shows that retro-reflectance of # 7610/# 7611 Sheetings remain high up to very oblique angles of incidence.

Table II shows that retro-reflective efficiency of #7610/#7611 Sheetings decrease rapidly as the angle between the incident light ray and the sensor or receiver is increased only slightly.

Since the retro-reflective surface of "Scotchlite" Brand Reflective Sheetings High Gain # 7610 and # 7611 is actually a continuous bond of exposed glass spheres, the result is a surface which is non-specular and therefore resistant to glare interference from ambient light.

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