"SOME ENGINEERING ASPECTS OF THE FUNCTIONAL REHABILITATION OF QUADRIPLEGICS"

A DISSERTATION PRESENTED TO
THE FACULTY OF ENGINEERING
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IN FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY IN ENGINEERING

BY
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I hereby declare that the dissertation entitled "Some Engineering Aspects of the Functional Rehabilitation of Quadriplegics" is my own work and has not been submitted to any other University for a degree.

C. Ruch

Colin Ruch

March, 1973.

TO

MY WIFE, AVIS

AND

OUR PARENTS,

WITHOUT WHOSE MORAL

AND FINANCIAL SUPPORT THIS

EFFORT WOULD NOT HAVE BEEN

POSSIBLE

PREFACE

The author's early experiences with severely disabled persons was initially gained while employed at the Bio-Mechanics Laboratory, attached to the Department of Orthopaedics of the H.F. Verwoerd Hospital, Pretoria. A small number of quadriplegics were admitted per year to the Spinal Unit of the Department, and those requiring augmentation of their residual function by Orthotic means were referred to the Bio-Mechanics Laboratory where bio-engineering techniques were applied to improve their functional capacity. Thus, the early techniques used by the author for the activation of partially and totally paralysed upper extremities were developed at the Bio-Mechanics Laboratory. These form the basis on which many of the procedures described in this thesis were formulated.

In 1971, a programme was initiated by the Department of Bio-Engineering and Medical Physics of the University of Cape Town, in co-operation with the Cape Provincial Hospital Services, to investigate techniques for the functional rehabilitation of patients who had suffered damage to the spine. The Spinal Injuries Centre at Conradie Hospital, at Pinelands in the Cape, one of the largest such centres in the Southern Hemisphere, was the obvious choice for the centralisation of these activities. It was here, in a positive and stimulating academic environment, that the author was provided with the opportunity to practically realise new ideas and refine existing procedures directed at the functional rehabilitation of quadriplegics.

C. RUCH

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To the author's colleagues both at Conradie Hospital and at the Department of Bio-Engineering and Medical Physics of the University of Cape Town, for their continual and unstinting assistance, advice and constructive criticism the author is grateful; especially to Messrs. Korubel, Metcalf and Stuart of the Department of Bio-Engineering, U.C.T., and Mr. J.J. O'Toole of the Bio-Mechanics Laboratory, H.F. Verwoerd Hospital, thanks are due for their able technical assistance in the construction of various mechanical and electronic items. To Mrs. I. Shipman, of the Occupational Therapy Department, H.F. Verwoerd Hospital, and the Occupational Therapy Staff at Conradie Hospital for their assistance in collecting the Myo-Electric Signal Monitor data, the author would like to express his appreciation.

To Miss Christa Mayer, who as head of the team of Occupational therapists at Conradie Hospital closely associated with instructing patients in the use of their equipment, and on whose efforts and enthusiasm much of the success and progress of the projects hinged, the author is in debt. Her dedication to her profession, loyalty and devotion to her patients and colleagues are an example for all interested in rehabilitation to follow.

And finally, to those quadriplegics who participated in the research programme, the author wishes to record his gratitude for their perserverance, faith and confidence in all the techniques suggested, and also to record his admiration for their courage and fortitude in the face of so grave a physical disability.

INDEX.

CHAPTER 1

1.1 INTRODUCTION AND DEFINITION OF SCOPE OF THESIS

Because of recent advances in medical technology, patients who have undergone severe trauma or illness are surviving where they would not have in the past. In many instances it is necessary for patients' stay in hospital to be protracted for a number of months until they are sufficiently medically fit for discharge. Many times, before such a patient can return as a productive member of society a programme of intensive rehabilitation is necessary.

Amongst the most difficult tasks confronting those responsible for rehabilitating such long stay non-acute patients, is that of rehabilitating a quadriplegic. Quadriplegia, or as it is sometimes referred to, - tetraplegia -, is defined [(1)] as the partial or total loss of motor function in both upper and lower limbs.

This thesis deals with some of the problems that are presented by patients who suffer quadriplegia, and with practical engineering solutions to some of these problems. Functional rehabilitation, by augmenting and supplementing the patient's residual ability so that he may most effectively interface with his surroundings, is the chief theme of this work. Particular emphasis is laid on the contribution of the bio-engineer to the efforts of the team of specialists assigned to rehabilitate the quadriplegic.

The purpose of this project is two-fold, being directed toward returning as great a degree of independence to the patient as possible, and relieving to some extent the burden placed on the family and those having to tend to the patient's needs.

1.2. STRUCTURE OF THESIS

1.2.1.

Chapter 2 of the thesis provides the medical background to the problems of quadriplegia and details the causes and implications of severe trauma to the spine. The extent of loss of motor and sensory function related to the level of injury of the spine is clearly defined to enable the engineer to appreciate fully the residual functional capacity of the living system with which he is dealing. Some of the dangers and complications which beset patients who have suffered quadriplegia and the procedures and necessary precautions which must be exercised to promote the independent existence of such a patient are outlined. A Glossary of medical terms to which the reader is referred, is presented in Appendix A. The diverse problems presented by the quadriplegic patient necessitate co-operation between a number of specialists in both the medical and non-medical disciplines. In the latter half of this chapter the role that each specialist must play is examined and a plea is made for a truly co-ordinated approach to ensure the optimisation of the patient's rehabilitation programme and its success. The contribution that the bio-engineer is able to offer particularly in the early post traumatic stages, is also highlighted.

1.2.2.

The development of a diagnostic and therapeutic instrument which can be used by para-medical personnel to assess the extent of any recovery of muscular innervation in a particular muscle and which permits even a flicker of muscular activity to be used in a therapy programme, is presented in Chapter 3. The rationale behind the development of the apparatus which uses the myo-electric signal of the muscle under test as its input, is thoroughly explained and the author's method of signal processing is contrasted with different methods employed by other researchers.

The practical realisation of the instrument in both block and circuit diagram form is presented.

Based on results obtained in investigations conducted by the author, norms for quantitative readings from the instrument for specific muscle groups have been predicted and in the light of the author's experience, and data collected from spinal injuries centres using the instrument on a day to day basis, the value of the instrument is assessed.

1.2.3.

The enigineering procedures and techniques that are applied to the quadriplegic to supplement his functional capacity necessitate the use of some form of appliance or machine. Such a device may be attached directly to a functionally deficient limb and may be used to supplement movement of that particular body segment. Alternately, the patient may influence his surroundings through machines which are not necessarily attached to a particular part of his body, but to which he has easy access. In either instance, the interface between the patient and his appliance must be carefully considered to ensure harmonious interaction between the human controller and his machine. Chapter 4 is devoted in its entirety to an appraisal of the quadriplegic and his machines, the considerations of feed-forward from the patient and feedback from the machine and to the folly of overtaxing the disabled patient's effective machine control capacity.

1.2.4.

The actual hardware used by quadriplegics is the subject of Chapters 5, 6 and 7, of the thesis. Chapter 5 outlines the purposes of the different splinting procedures, the criterea by which these are applied and the functional usefulness of the various orthotic devices which are body or internally(') powered.

(') internally as opposed to externally powered motorised devices

The development of the most important type of hand splint used for lower lesion quadriplegics, the tenodesis splint, is detailed together with modifications and adaptations which extend the usefulness of the splint.
A design for an active spring loaded orthesis for treating contractures of the elbow is discussed as well as its potential usefulness in providing artificial triceps action.
The improvement in functional capacity of the hands of $C_{5,6}$ and $C_{6,7}$ quadriplegics when mechanical splinting techniques are employed, are contrasted with results obtained when surgical procedures aimed at providing return of function are attempted.
Chapter 5 concludes with some pertinent remarks on the subjects of splint manufacture and patient motivation and training to obtain the the best functional use from an orthesis.

1.2.5.

In recent times myo-electric control has been hailed as the ultimate control medium for both prosthetic and orthotic appliances. Chapter 6 deals extensively with this subject and with a number of control systems which have been developed over the years by the author and by others.
Myo-electric control of electrically powered motor driven ortheses as well as of physiological stimulators is considered. Other motorised orthesis control media suitable for use by the quadriplegic are also described.
Constructional details of the powered splints used by the author are presented and the extent to which complex multidegree of freedom of movement ortheses may be used to implement functional return to the patient is outlined. Case studies of patients who have been fitted with complex ortheses are used to illustrate the necessity of ensuring complete compatability between the patient and his machine. Computer aided control of ortheses and of ordered stimulation of the existing musculature are explored

as possible (future) solutions to achieve improved patient functional capacity.

1.2.6.

The concept of the environmental controller and its use as one of the most effective techniques that might be employed to facilitate return of function to high lesion quadriplegics is introduced in Chapter 7. Two multifunction environmental control units are described in detail and guidelines for creating an 'artificial environment' in which the disabled person can spend most of his waking hours are set out. Descriptions of all circuitry in both block diagram form and printed circuit component layout are provided to enable the reader to synthesise part or all of the controller system if required.

1.2.7.

Chapter 8 revolves about some of the rehabilitation problems of the quadriplegic encounters once has left the confines of the hospital. Difficulties at home, in obtaining employment, in overcoming prejudice against the handicapped and the general ignorance of the public at large to the needs of the quadriplegic are discussed. Further, the author's views on rehabilitation particularly as far as the use of environmental controllers are concerned, are contrasted with the opposing views of some of his colleagues.

The concluding pages of this chapter (and of this thesis) deal with the lack of organised after-care of the quadriplegic patient and the need for a technical follow up service to effect maintenance and repairs of patients' hardware and equipment. Also, suggestions for improvements to existing techniques and procedures as discussed in the preceeding chapters, are reviewed.

1.3. DESIGN CRITERIA.

The following criteria were considered essential to the success of the engineering techniques detailed in Chapters 5,6 and 7:-

i) Any added increase in the patient's ability to influence his surroundings should be consistent with the degree of effort required to effect such influence, and

ii) the financial cost of adding to the patient's ability should not be so excessive as to place beyond the reach of the patient the acquisition of the equipment necessary to achieve any such extra functional ability.

REFERENCES - CHAPTER 1.

1) Elsburg C.A. 1944.
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CHAPTER 2

2.1. CAUSES OF QUADRIPLEGIA

Quadriplegia may result from numerous diseases, pathologies or trauma which cause damage of the spinal cord and/or to the anterior horn cells. Amongst the more common neurological diseases which may give rise to quadriplegia are acute myelitis such as polio-myelitis, Guillan Barré syndrome, and multiple sclerosis. Spinal cord compression following extra-medullary or intra-medullary tumors or granulomas, or bone diseases such as osteomyelitis and tubercular spondylitis and consequent spinal cord involvement may also result in quadriplegia. The most common incidence of quadriplegia however is due to traumatic lesions of the spinal cord. Recent statistics (1) indicate that trauma accounts for as much as 97% of all new hospital admissions of patients suffering from pathologies associated with spinal cord malfunctions. It is thus predominantly for the treatment of patients who are quadriplegic following severe spinal cord trauma that the techniques described in this thesis are directed.

2.2. THE SPINE

2.2.1. Anatomical Considerations

The spinal column or as it is more correctly termed, the vertebral column, is the central axis of all vertebrate animals. It may be described broadly as a flexible curved column of bony segments separated from each other by fibro-cartilagenous pads and interconnected by a lattice of ligaments. Since the column is made up of segmented components and is not a single continuous bone, a limited amount of movement, both radially and along its longitudinal axis, can take place. The vertebral column supports the weight of the trunk and it is the central structure to which the pelvis and lower limbs are connected. Further, the spinal cord - the complex bundle of communication connections which relay both afferent and efferent data between the brain and the motor system - passes down a central canal in the column. The bony surround of the individual vertebrae affords protection to it.

2.2.2. Segmental Levels

The vertebrae are classified into five main groups (4 major and 1 minor) according to their anatomical situation along the spinal column: namely the cervical - 8 segments, thoracic - 12 segments, lumbar - 5 segments, sacral - 5 segments, and caudal - 1 segment (cf. fig. 2.1). At each vertebral segment, both motor and sensory nerves branch off from the spinal cord and pass through two secondary canals(intervertebral foraminae). These nerves, referred to as spinal nerves, branch out further to innervate specific areas peculiar to each nerve. The spinal nerves are classified by relating them to the particular area of the vertebral column from which they originate; the nerve originating from between the third and fourth cervical vertebrae would thus be classified as spinal nerve C_4. Fig. 2.2 details the areas of the body innervated by the different spinal nerves. The effects of transections of the spinal column at particular segmental levels are consistent from patient to patient, and result in permanent loss of both motor and sensory function below the damaged segment. Patients who have suffered trauma to the cervical spine may become quadriplegic. According to Wilcox and Stauffer [2], injuries to the cervical spine account for over 50% of all spinal injuries.

2.3. MECHANICS OF SPINAL INJURIES

The bony elements of the spine are by no means homogeneous in their shape and size. The cervical vertebrae are smaller than the thoracic and lumber vertebrae and their construction permits a large degree of extension and flexion. The upper thoracic vertebrae permit a larger degree of spinal rotation than does the cervical spine while the lumbar region, the most stable section of the spine structurally, permits little extension -

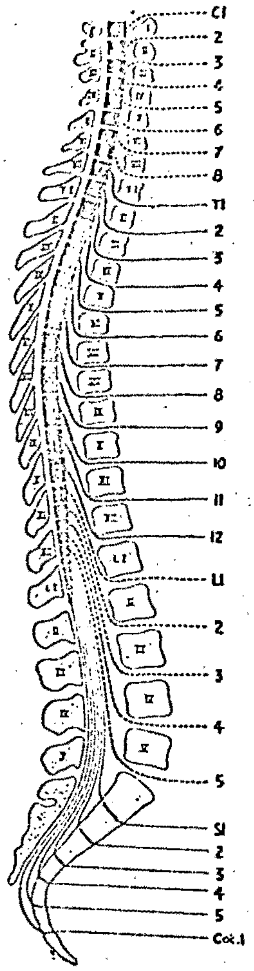

Fig 2.1 Alignment of Spinal Segments. Spinal Segments & Nerves are indicated by Arabic numerals, the Bodies & Spinous Processes by Roman. (After Elsburg)

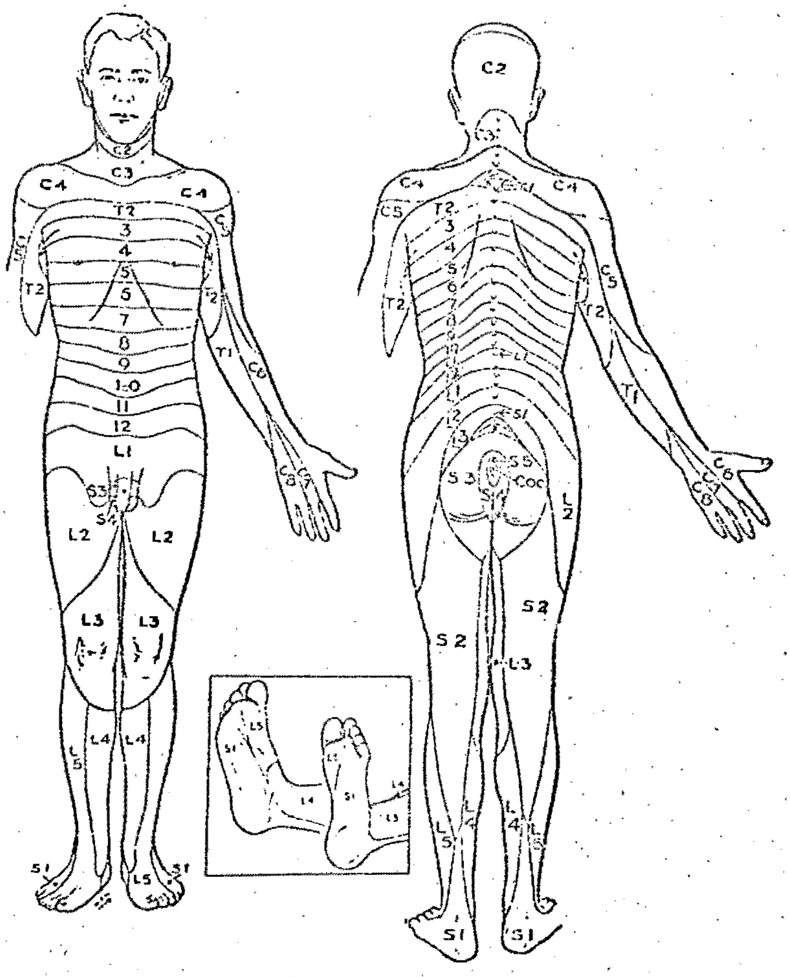

Fig. 2.2 Spinal Nerve Innervation after Brock[6]

flexion and rotational movements. Because of the different physical properties of the vertebral column segments, it is to be expected that they will react differently to injuries likely to cause damage to the spine.

2.3.1. Fracture - Dislocations of the Cervical Spine

Since the cervical spine is the most mobile section of the spine, the articulating facets of the vertebrae are shallow and are loosely linked. This anatomical structure predisposes dislocation of the cervical spine in injuries where the forward motion of the body is suddenly arrested (for example when a motor car crashes into a stationary mass). The head being weighty tends to continue on its forward trajectory pulling several of the uppermost vertebrae with it. A forward dislocation of the upper vertebrae on the lower vertebrae and luxation of the spinal cord therefore takes place. Luxation is usually effected at the 4th, 5th or 6th cervical vertebrae and is more often than not accompanied by fractures of the articulating facets of the vertebrae.

2.3.2. Compression Fracture of the Cervical Spine

This type of injury may occur when a heavy weight is dropped directly onto a person's head or when a person dives onto his head into a shallow pool. The vertebrae are severely compressed and bone fragments are usually forced into the spinal canal causing extensive damage to the spinal cord; as is to be expected head or brain injuries often accompany this type of fracture. Compression fractures occur less frequently than do dislocation fractures.

2.3.3. Fractures of the Thoracic Spine

Because of the strong anatomical structure of the thoracic spine, injury to this area is rare except in cases of extreme violence. The nature of the injury is usually such that gross damage to the spine and ribs is caused.

2.3.4. Compression Fracture of the Lumbar Spine

Dislocation fractures of the lumbar spine are rare because of the large size and strength of the lumbar vertebrae. However, compression fractures do occur when, for example, a heavy weight falls on a person's back. The back bends forward into flexion and the thoracic vertebrae provide a fulcrum effect on the lumbar vertebrae. This results usually in a compression fracture of one of the lumbar vertebrae and damage to the spinal cord by bony fragments.

2.3.5. Other Injuries

Crushing injuries caused by persons being pinned under heavy weights can cause severe damage to the vertebral column and spinal cord. Penetrating wounds of the spine usually result from stabbings or gunshot wounds. Generally such spinal damage results in incomplete paralysis since in most cases transection or damage to a complete cross-section of the cord is unusual. Table 2-3 details the direct causes and frequency of occurrence of spinal cord lesions. As can be seen motor vehicle accidents are the greatest single cause of spinal injuries.

2.4. SEX AND AGE DISTRIBUTION OF SPINAL CORD INJURIES

Approximately 66% of spinal injuries are younger than 40 years of age. over 80% of these patients fall in the 20-40 years age group (3). The ratio of males to females of such patients is approximately 9:1. The relative youth of most spinal patients is probably one of the few advantageous factors that the condition of quadriplegia affords.

2.5. THE FUNCTIONAL SIGNIFICANCE OF INJURIES AT DIFFERENT CERVICAL SPINE LEVELS

In discussing the functional significance of injuries at different spinal levels it will be assumed for the sake of clarity, that the lesion has resulted in a complete transection of the cord at a particular segment. (In practice however, as many as 66% of cervical spine injuries are

MVA	34.0%	Medical	3.0%
Independent accidents	23.0%	Gunshots	2.0%
Fights & falls	12.3%	Train accidents	1.3%
Sport	5.3%	Rockfalls	1.05

Table 2.3 Cause & Frequency of Spinal Cord Lesions (After Key & Retief)

	C-1	C-2	C-3	C-4	C-5	C-6	C-7	C-8	T-1
Sternomastoid	×	×	×	×					
Trapezius		×	×	×					
Levator Scapulae			×	×	×				
Diaphragm			×	×					
Teres Minor				×	×				
Supra Spinatus				×	×				
Rhomboids				×	×				
Infra Spinatus				×	×	×			
Deltoid					×	×			
Teres Major					×	×			
Biceps					×	×			
Brachialis					×	×			
Serratus Anterior					×	×	×		
Subscapularis					×	×	×	×	
Pectoralis Major					×	×	×	×	×
Pectoralis Minor						×	×	×	
Coracobrachialis						×	×		
Latissimus Dorsi						×	×	×	
Anconeus							×	×	
Triceps						×	×	×	
Brachioradialis					×	×			
Supinator					×	×			
Pronator Teres						×	×		
Ext. Carpi Radialis long, and brev.						×	×	×	
Flexor Carpi Ulnaris						×	×	×	
Flexor Carpi Radialis						×	×	×	
Extensor Digitorum							×	×	
Extensor Carpi Ulnaris							×	×	
Extensor Indices							×	×	
Ext. Digiti Quinti							×	×	
Ext. Pollicis Longus							×	×	
Ext. Pollicis Brevis							×	×	
Abductor Pollicis Longus							×	×	
Palmaris Longus							×	×	×
Pronator Quadratus							×	×	×
Flexor Digitorum Sublimis							×	×	×
Flexor Digitorum Profundus							×	×	×
Flexor Pollicis Longus							×	×	×

Fig 2.4 Segmental Innervation of the Upper Extremity. (Modified after Elsburg)

incomplete and two, three or more segments are usually involved). Referring to Fig. 2.4 it is seen that as the cord is injured at successively lower segments, more residual functional capacity is available to the patient. Injuries to the spinal cord at levels C_3 i.e. transection of the cord between the second and third vertebrae, involve the phrenic nerve and consequent paralysis of the muscles of the diaphragm. Invariably the patient who has sustained such severe injury does not survive until medical aid can be summoned. Only patients with lesions at levels C_4 and lower are therefore considered.

2.5.1. Lesions at Levels C_4

Patients with lesions at segmental level C_4 pose the most complex rehabilitation problems. The diaphragm, trapezius, rhomboids, scapulae and the mid-cervical extensors and flexors are virtually all that are left to the patient. There is no voluntary function whatever in the limbs; shoulder elevation and good neck and head movements are the only voluntary functions that the patient can effect. Respiratory insufficiency is also prevalent in patients with lesions at C_4 since the intercostal (Th 1) and the Scalenus muscles are not innervated.

2.5.2. Lesions at Levels C_5

The added function of the biceps muscles and brachialis which are partially innervated at segmental level C_5, permit the patient to flex his elbow. Deltoids are also partially innervated at this level but are unable to function efficiently since innervation of latissimus, pectoralis, and serratus is absent. There is no voluntary function of the wrist and hand.

2.5.3. Lesions at Levels C_6

At segment C_6 the radial wrist extensor muscles (extensor carpi radialis) are present and brachi radialis and biceps are totally innervated thereby permitting good upper arm movement. The latissimus, seratus and pectoralis are partially innervated and thus the patient has rotational movement and adduction of the gleno-humeral joint. Also a marked increase in ability to maintain postural balance in a wheelchair is evident in patients with lesions at C_6.

2.5.4. Lesions at Level C_7

The contribution of segment C_7 has a dramatic effect on the improvement of voluntary function of the upper limbs and hands. Triceps which enable the patient to stabilise his elbow in extension are almost fully innervated as are the wrist extensors and flexors; the long finger extensors are also innervated. Complete hand function however is only restored below segmental levels C_8 and T_1.

Unlike patients with higher lesions, the C_7 quadriplegic is able to transfer from his wheelchair to his bed with little or no aid because of improved nerve supply of the back and trunk muscles.

2.6. IMPLICATIONS OF THE LOSS OF MOTOR AND SENSORY FUNCTION AS A RESULT OF QUADRIPLEGIA

Aside from the motor and sensory loss of function which result from severe trauma of the spine, many normal bodily functions are disrupted as a consequence of quadriplegia. Treatment of the quadriplegic patient is therefore extremely complex, and highly trained medical personnel are required to attend to the patient's medical condition, particularly in the acute early stages of treatment.

2.6.1. Stabilisation of the Spinal Fracture

Fracture dislocations of the cervical spine are most commonly treated by traction methods. Crutchfield skull tongs(4) applied directly to the head have proved to be the most efficient method of applying traction. Traction is maintained for periods of time ranging between 6-12 weeks to permit the establishmentof a fibrous union between the damaged vertebrae. Compression fractures of the cervical spine are also treated by traction using Crutchfield tongs. Where severe malalignment of the longitudinal section of the vertebral column has taken place and traction has not proved successful, surgical procedures and spinal fusion are resorted to.

2.6.2. Prevention of Decubiti

Bed sores, pressure sores or as they are more correctly termed 'decubiti', invariably result from ischemia as a result of continued pressure on soft tissue.

Since the patient is anaesthetic below the level of the spinal lesion he is unable to feel the effects of prolonged pressure and great care and constant vigilance on the part of the nursing staff is necessary if such sores are to be prevented. In many cases plastic surgery is necessary to repair recurrent bed sores.

2.6.3. Respiratory Insufficiencies

Fracture dislocations of the spine often involve (to a lesser or greater degree), the 3rd, 4th, and 5th cervical segments thereby impeding the route whereby the diaphragm is innervated. Further, post traumatic oedema or swelling of the cord may interfere with respiration until such swelling has subsided. The patient is therefore able to accomplish only shallow breathing, and if he is in traction and therefore lying on his back, he is unable to clear his mouth and posterior pharynx of mucus. Respiratory tract infections may develop as a result of this poor drainage and diminished chest excursions and in fact (hypostatic) pneumonia is a major cause of concern during the initial acute stages of treatment.

2.6.4. Bladder and Bowel Functions

Volitional control of both bladder and bowel function is absent in all cases of complete quadriplegia. Bowel function is considered simple to control when compared to the precautions which must be exercised in the care of the bladder.

Constipation is almost the rule in spinal injuries and incontinence of faeces is rare; use of suppositories or enemas of soap and water or glycerine are most commonly employed to effect bowel function control.

Bladder and kidney infections are a major cause of concern to all paralysed spinal patients. The mechanics of infection of the bladder and kidneys are not well understood but it is thought that infection is carried via the bloodstream to the kidneys and bladder from infected foci such as decubitus ulcers elsewhere on the body. In the acute stage of treatment the incidence of bladder infection is highest since continual or intermittent catheterisation is necessary to ensure urinary continence. Also, since patients are confined to bed and immobilised until bony fibrous union of the spinal fracture is complete, calcium imbalance and an osteoporitic condition of the weight bearing bones is common as a result of disuse atrophy. Calcium precipitates out of the system to form kidney or bladder stones. Ultimately these must be removed surgically if they are not to cause obstruction of the urinary tract.

2.6.5. Mass Reflex Spasm

Patients who have suffered spinal lesions i.e. upper motor neuron lesions generally suffer mild muscular spasms. Approximately 65% of quadriplegics, however, suffer mass reflex spasm as a direct result of their injuries. The onset of spasm usually takes place after the initial spinal shock has subsided. Spasm manifests itself as powerful, uncoordinated and grotesque movements of both upper and lower limbs and is usually a source of extreme inconvenience to patients. Sometimes, the spasm completely overrides any volitional function which the patient may attempt to effect thus detracting further from the patient's residual ability. The causes of spasm are not clearly defined but are thought to stem from heightened reflex activity as a result of irritation of the spinal cord at or near the site of trauma. Surgical procedures are resorted to and the spinal nerves are excised where mass reflex spasticity is intolerably high. Differential nerve blocks[5] may be used to dampen spasticity in cases where some volitional function remains and where excision of the spinal roots would result in total or flaccid paralysis. Nerve blocks have to be repeated from time to time if their effect is to be maintained. (It is interesting to note that mass reflex spasticity can be useful in preventing osteoporosis because of the resultant stresses transmitted to the skeleton.)

2.6.6. Disuse Atrophy of the Musculature and Contractures

In the immediate post traumatic condition of patients who have undergone severe spinal surgery flaccid paralysis of the musculature below the affected spinal segment is common. As a direct result thereof muscle atrophy or wastage takes place; as much as 40% weight loss may be recorded[6] within the first 14 days post-accident. Once reflex induced spasticity is present muscles may regain some of their lost weight.

Contractures occur in cases of both flaccid and spastic paralysis and result from immobilisation of the limbs and joints for extended periods of time. Care should be taken to exercise regularly all joints and muscles which are susceptible to contractures and patients' feet are usually propped up using wooden foot rests to prevent flexion contractures of the foot.

2.6.7. Life Expectancy of the Quadriplegic

Tempered optimism is appropriate in projecting the life expectancy of quadriplegics. Provided bed sores, urinary tract and respiratory infections are controlled, quadriplegics after their accidents, can be expected to survive for many years and the cause of death may not even be attributable to the patient's paralytic condition. The most common cause of death amongst all spinal injuries is toxic bed-sores and urinary tract infections resulting ultimately in renal failure.

2.6.8. Mortality in Cases of Qadriplegia

Approximately 10% of spinal injuries die during their acute hospitalisation period. (8% is the latest figure available from Spinal Injuries Centre at Conradie Hospital[7]). Of this figure 60% are cervical spine injuries. Death is most often ascribed directly to injuries of the spinal cord and consequent respiratory involvement or to other extensive injuries sustained at the time of the accident. Death resulting from poor hospital treatment has been minimised by ensuring that spinal injuries are generally removed to specially equipped nursing centres.

2.6.9. Prognosis of Recovery

The extent to which the patient recovers functional movement is dependent entirely on the extent of the damage to the spinal cord. Complete transection of the cord results in total and irreversible loss of motor and sensory function while partial damage to the cord may permit varying degrees of recovery of function once oedema has subsided. In instances of incomplete transections of the cord, months may elapse before return of function is evident. Thus it is wise to wait until several months have passed after the accident before considering a patient's functional capacity as having stabilised.

2.7. POST-ACUTE TREATMENT

Once the immediate post traumatic treatment of the quadriplegic has been resolved i.e. once the spinal fracture has stabilised, and respiratory, urological and bowel functions are adequately controlled, the patient passes from the acute stage where his life was very much in the balance, to a convalescent stage where medical attention is reduced to a schedule of routine maintenance usually effected through specially trained nursing personnel. The paramedical personnel are now called upon to make a more significant contribution to the patient's well-being.

2.8. PARAMEDICAL SERVICES ASSOCIATED WITH TREATMENT OF QUADRIPLEGIA

2.8.1. Physiotherapy

The chief function of the physiotherapy staff is to preserve the range of movements of the patient's joints and muscles and thereby prevent the incidence of contractures. Further, exercises to promote the maintenance and strengthening of the patient's residual functional ability are applied. Once the patient is no longer confined to bed, part of the physiotherapy programme requires the patient to stand upright while strapped to a tilting table. This is carried out in an attempt to arrest calcium precipitation by placing stresses on the patient's weight-bearing bones (any beneficial effect of such treatment however is dubious[8]).

2.8.2. Occupational Therapy

While the patient is still confined to bed, the occupational therapist's efforts are directed mainly at involving the patient in diversional and recreational activities. Muscle strenghtening is also attempted using the techniques described in Chapter 3. Once the patient is wheelchair bound (6-12 weeks post-accident), the occupational therapist instructs him how best to cope with the activities of daily living within the limitations of his residual functional ability; for example, the patient is taught how to feed himself, and how to push his wheelchair, etc.
The role of the occupational therapist in teaching patients to use equipment designed to augment residual voluntary functions is most significant. After assessing the patient's capacity for work he is encouraged to take part in work orientated activities with a view to finding suitable employment, or if the patient is still school going, he is encouraged to continue with his studies.

2.8.3. Social Services

State and local welfare organisations are informed by the social worker of the admission to hospital of the spinal injury patient, and should the patient qualify for state or institutional aid, arrangements are made to acquire wheelchairs, bio-engineering equipment and appliances, and where necessary to effect any structural changes to the patient's home in preparation for his home-coming.
Further, it is the task of the social worker to investigate the patient's background and home circumstances to determine whether in fact it will be possible for the patient to return to live at home at all. If the home circumstances are unfavourable, suitable arrangements must be made for the patient's after-care on being discharged from hospital.

During the course of the Rehabilitation Programme, the social worker, in close conjunction with the occupational therapist, investigates what possibilities exist for placing the patient in gainful employment.

2.8.4. Psychological Observations

Accident rates have reached such alarming proportions that attempts have been made to categorise the type of person most often involved in serious accidents. The majority of spinal injuries have a history of being accident prone. It is thus not uncommon to find that quadriplegics have suffered many minor accidents prior to having undergone spinal trauma. (In a number of cases splinting of the hands has been impaired and even rendered impossible by the patient having lost a distal phalanx or a complete finger or two in a previous accident.)

After having investigated a series of accident victims, Dunbar[9] describes a typical accident prone person as having a shallow character and being somewhat introverted. Such persons are not of very high educational standards, are intensely interested in sport and gambling and have little respect for authority. Sociological problems are also common to accident prone persons. In fact, the writer's personal experience tends to indicate that a severe social problem is almost a prerequisite for a quadriplegia. In general the foregoing description typifies the spinal injury patient. The mental trauma that accompanies the sudden loss of function is of catastrophic proportions and can result in the patient withdrawing into himself or becoming overtly aggressive and non-cooperative.

While physical trauma is viewed with the utmost concern, the emotional trauma accompanying total and permanent paralysis receives scant medical attention. It is distressing to note that there are those (medical personnel and others) who today still underestimate the contribution that the trained psychiatrist and/or psychologist is able to make to the treatment of the severely paralysed.

2.8.5. Bio-Engineering Personnel

Having assessed what functional movement the quadriplegic is able to effect and having considered the problems detailed in Section 2.7 of this Chapter, the bio-engineer's tasks are clearly defined. He must determine how best to apply his scientific knowledge and the skills of his technicians to:

i) supplement the residual motor capacity of the patient to maximise and optimise patient-environment control and,

ii) to reduce and simplify patient treatment and after-care wherever possible.

2.9. INTERDISCIPLINARY CO-OPERATION - THE REHABILITATION TEAM

From the foregoing it is evident that a close degree of co-operation must exist between the protagonists of the different disciplines involved in providing a balanced treatment and rehabilitation programme for quadriplegics. Round table consultations and discussions between medical specialist, paramedical staff, social worker, psychiatrist and bio-engineer, where each contribution is as important as the other, is to be commended and encouraged. Absolute co-operation and consultations at all levels are essential to the success and efficiency of the rehabilitation programme. The realisation of this concept of a team approach to the rehabilitation of quadriplegics is however difficult to achieve in practice. Para-medical staff have been trained to accept, to a large extent unquestioningly, instructions from their medical superiors in much the same way as technicians carry out the instructions of engineers. Consequently, the doctor is unaccustomed to discussing patients problems with his paramedical staff but prefers to prescribe treatment based on his own views of the particular case.

The problem unfortunately does not end here, the doctor often tries to extend his authority to disciplines about which he has little knowledge.

This attitude, unacceptable to any professional engineer and no doubt to other members of the rehabilitation team, must lead to friction and the creation of a pecking order or, alternately to the total abrogation of the doctor's interest, either of which situation is to the ultimate detriment of the patient. It is time for all involved with patients having as severe medical, sociological and technological problems as those facing quadriplegics, to stop paying lip-service to the "team approach" of rehabilitating the severely disabled and for team members to realise the importance of each discipline's contribution to the overall well-being of the patient. (It should be stressed that the writer is not advocating that nurses, physiotherapists or occupational therapists should be placed on a par with doctors, or that technicians and engineers be considered as equals, but that each discipline should enjoy the status and professional etiquette that his separate speciality entitles him to). The doctor should at no time attempt to extend the authority he has over the paramedical staff to the engineering personnel. Direct interdisciplinary consultations at all levels cannot but contribute to the smooth functioning of the rehabilitation programme.

It is often necessary for one discipline to modify its particular rehabilitation programme to accommodate factors considered beneficial to the patient by another discipline. For example, the bio-engineer must consider the advice of the social worker or psychiatrist in recommending what aids should be utilised to the utmost in the patient's home circumstances.

2.10. CO-ORDINATION OF THE INTERDISCIPLINARY ACTIVITIES

The question of who should co-ordinate the activities of the rehabilitation team is one that requires careful attention. Traditionally, the role that the doctor plays as healer in the eyes of the patient and his family is so firmly rooted that it would seem most inappropriate to expect anyone but a medically trained person to lead such a team. A more important consideration is that we are dealing with a living system and although the contributions from other disciplines to the system's well-being and its optimum independent existence might indeed be significant, there can be no doubt that a doctor should be responsible for the supervision of the patient's progress in the broadest sense. Moreover, from a legal standpoint, the doctor is the only member of the rehabilitation team who may carry the responsibility of the patient's health on his shoulders. From which speciality of medicine should the Programme Co-ordinator be drawn? It is difficult to decide from a medical point of view, whose role is most significant; specialist neurosurgeons, orthopaedic surgeons, urologists, psychiatrists and plastic surgeons are generally all consulted when a patient suffers severe spinal trauma. To ensure that too much stress is not laid in one particular area it is most prudent to choose neither of the above mentioned specialists but to rely on one who has a broader and more general approach to the quadriplegic and his problems. Although little light has been focussed on Rehabilitation Medicine in the past, recent reports from the United States of America indicate that rehabilitation is receiving greater attention and that doctors are specialising in the field. It is from the ranks of these specialists that the Programme Co-ordinator should be appointed. Amongst the obvious qualities that this person must possess, is the ability to dovetail and co-ordinate the efforts of the various team members efficiently and maintain communication links between the patient, his family and specialists of all the fields attending to him.

2.11. THE ROLE OF THE BIO-ENGINEER IN THE INITIAL REHABILITATION STAGES

The bio-engineer should be consulted soon after damage to the spinal cord has been assessed and once the patient has recovered from the initial trauma or from any major surgical procedures that might have been necessary.

Orthotic devices (Chapters 5 & 6) should be provided as soon as possible and environmental controllers (Chapter 7) should be linked to the patient where necessary. Such procedures should be commenced with while the patient is still undergoing treatment to stabilise his damaged spine. This helps the patient to adjust to himself and to his unfortunate circumstances and gives him an insight into what he will be able to accomplish physically and how he will be able to communicate with the environment about him. It is most important that the patient should not be left alone to contemplate his total loss of motor function.

Once the patient has grown accumstomed to being unoccupied for a number of weeks and has people about him tend to his every need, it is most difficult to persuade him to attempt the activities of daily living within his limited capabilities especially if it requires great physical and sometimes mental effort. Experience has shown that the likelihood of patient-equipment compatibility is greatest if an early start is made in providing the external equipment and appliances which the patient may ultimately require.

It may be felt that one should wait at least until the neurological lesion has been adequately defined or until the patient's physical condition has stabilised so that the efforts of the technicians involved in making the appliances should not be wasted. Even if it might become necessary to modify or even discard an appliance because of additional - muscular atrophy or weight loss, or because of neurological return, the cost of fabricating a few splints is far less than the price which the patient might have to pay for the potential loss of function resulting from an adverse mental attitude to his equipment.

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CHAPTER 3

3.1. MUSCLE TESTING AND ASSESSMENT

The residual functional ability of quadriplegics with complete transection of the spinal cord at different segmental regions has been detailed above. Further, it was noted that considerable time might pass before the patient's neurological condition had stabilised and thus before his ultimate physical capacity might be determined accurately. It is desirable for members of the rehabilitation team to be aware of any recovery of muscle functions by the quadriplegic, and the rate of any such recovery, so that they may amend their rehabilitation procedures and their projection of the patient's prognosis. Since techniques for grading muscle function do exist but are generally qualitative and thus not scientifically accurate, diagnoses of a patient's prognosis vary from clinician to clinician.

3.1.1. Strength Duration Techniques for Muscle Testing

One of the more scientific muscle testing procedures in common use and an exception to the above statement is the Strength-Duration Test[1]. By means of this technique the electrical excitability of the muscle and its innervation may be determined. The test procedure finds particular application in instances of lower motor neuron involvement and may thus be used to determine whether nervous pathways other than those of the spinal cord have been damaged. (Muscles whose nerve supply have been abolished at some point between the spinal root and the myo-neural junction i.e. muscle that has suffered disruption of the peripheral nerve supply is described as having been affected by a lower motor neuron lesion). Such muscle will not respond (contract) to electro-stimulation by Faradic currents i.e. when pulses of current having a duration of less than 1.5 m.secs are applied to the muscle.

Provided that there is no pathology associated with the muscle itself, the degree of its excitability is dependent on the extent of innervation of the muscle via the peripheral nerve supply. As peripheral nerve supply is re-established, the amount of current necessary to elicit a muscular response is reduced. Graphical representation relating the excitability of the muscle to currents of differing strengths and of different time durations of current may thus be used to determine quantitatively the rate of regeneration or degeneration of the peripheral nerve supply to a muscle.

In instances where the peripheral nerve supply is intact and the muscle being tested is non-functional because of an upper motor neuron lesion affecting the spinal cord, the strength-duration test will provide results displaying features characteristic of normally innervated muscle. This technique cannot therefore be applied in determining the degree of innervation or re-innervation of muscles affected by upper motor neuron lesions. As far as the quadriplegic patient is concerned, the Strength-Duration curve is useful only in assessing whether any peripheral nerve damage was sustained at the time of trauma to the spine.

3.1.2. The Oxford Standard of Grading

Following a recommendation in a memorandum released by the British Medical Research Council in 1943[2] that a standardised method of muscle grading be adopted, muscle condition and function have been related to a scale ranging from 0-5. The method suggested, known as the Oxford Standard of Muscle Grading has been adopted throughout the British Commonwealth countries, and categorised muscle movements in the following way:-

Grade 0 - no contraction whatever

Grade 1 - flicker, or minute trace of contraction

Grade 2 - active movement of joint controlled by muscle being assessed with gravity eliminated

Grade 3 - active movement against gravity

Grade 4 - active movement against gravity plus some resistance

Grade 5 - normal muscular function.

While this method of grading might be satisfactory as far as grades 0-1 are concerned, it is evident that there are many intermediate muscle gradings which are not explicitly described. Assessments of muscles as 2+ or as 4- are thus common and since the grading is based on human judgment, different gradings by different people of the same muscle are to be expected.

3.1.3. Electromyography as a Diagnostic Medium

While there are numerous references in the literature to the use of electro-myography in lower motor neuron diseases and pathologies of the muscle[3,4], no definite indications as to its application in upper motor neuron lesions are presented. Lenman[5] has shown that electromyograms of upper motor neuron lesions do not exhibit any marked variation from normally innervated muscle, except that the muscle tension is diminished and thus both the amplitude and high frequency content of the myo-electric signal is diminished. Further, specialist knowledge of electromyography as regards technique and interpretation of results is necessary if it is to be used as a diagnostic tool. Changes in myo-electric signal intensity which may be attributed to improved muscular innervation monitored when using either surface or needle electrodes are difficult to detect unless these changes are comparatively gross in nature.

3.2. THE DEVELOPMENT OF A USEFUL DIAGNOSTIC AND THERAPEUTIC AID

3.2.1. Introduction - Muscle Physiology

Muscles are comprised of numbers of motor units grouped together. These motor units in turn consist of numbers of muscles fibres; the numbers of fibres per motor unit varies from muscle to muscle. By definition, a motor unit is considered to be made up of the muscles that are innervated by a single motor neuron (nerve) and it is the smallest unit of muscle that can be voluntarily activated. The innervation ratio of muscle fibres to motor neurons may vary from 5:1 to more than 5,000:1[6] and is related to the

fineness or degree of control that the muscle can develop.
For example, the extrinsic occular muscles, which are required to position the eyeball very accurately, have a low innervation ratio while the gluteus maximus muscle responsible for the more gross movements of the leg and thigh have a much higher innervation ratio.
The innervation ratio is also determined by the inertia of the body part which is to be moved; the leg would require many muscle fibres contracting simultaneously to move its mass and consequently one would expect a higher innervation ratio. The anatomical distribution of the muscle fibres throughout a particular muscle varies.
The fibres may be grouped together in a whole unit, in several sub-units or they may be scattered randomly throughout the muscle. (It is assumed by most authors in the literature, that each motor unit is supplied by only a single neuron. The concept of polyneutral innervation is mooted(7), but there is no positive information proving or refuting either assumption.
The aphasic or polyphasic myo-electric signal is derived from the electrical activity associated with the asynchronous contraction of many motor units in a muscle. The time sequence and intervals between firing of the different motor units of a muscle has been examined by many workers in an attempt to establish if there is any periodicity associated with the composite myo-electric signal pattern. Indications are that no such periodicity exists(8) and that the myo-electric output from a contracting muscle is best described as a random signal.

3.2.2. The Piper Rhythm or Myo-Electric Signal Carrier Frequency

While no periodicity has been established for the amplitude and frequency characteristics of the myo-electric signal, as early as 1886(9), a rhythmical tendency associated with the activity of motor units, was reported. The phenomenon, termed the Piper Rhythm (after one of the early workers to have observed this rhythm), has attracted the attention of a number of workers notably Lippold, Redfarm and Vuco[10]. Extensive investigations were undertaken by Lippold et al to define the nature of these rhythms and to determine the factors which influence them. They found that in general motor units contracted at approximately 9 cps and confirmed that the motor units scattered throughout the muscle contracted asynchronously. The effect of increased tension of the muscle and fatigue was to increase synchrony of firing throughout the muscle; cooling the muscle had the effect of slowing the basic firing rate throughout the muscle.

The physiological reasons for the existence of the Piper rhythm are not clear; however Lippold suggests that it may be the result of the finite time constant associated with the muscle feedback control loop operation. Kadefors et al[11] state that the Piper rhythm frequency associated with the myo-electric signal derived from surface electrodes is between 40 and 50 cps. It may thus be concluded that although there is no periodicity or predictability as far as the complex myo-electric signal waveform is concerned, there does seem to be a "carrier signal" of approximately 40-50 cps on which the aphasic myo-electric signal rides.

3.2.3. The Mechanism of Muscular Contraction

It is generally accepted[12] that as the volitional tension in a muscle increases, more motor units are recruited to contribute to the muscle power output, and the frequency of firing of motor units that are already actively participating in the muscle contraction, is increased. Further, during extended periods of constant muscular contractions, more motor units are recruited while the frequency of contraction of those already involved in the contraction is reduced[13]. At near maximum levels of muscular contraction, a degree of synchronism of motor unit firing is observed and at absolute maximal contraction tetanic or synchronous contractions take place resulting in muscle tremor.

3.2.4. Amplitude Characteristics of the Myo-Electric Signal

It has been found[14] that there exists a degree of proportionality between the myo-electric signal amplitude output and the tension being developed in a muscle. The absolute amplitude value of the myo-electric signal output however, varies from patient to patient and is dependent on factors such as the type of electrodes used to monitor the myo-electric signal, the distance between electrodes if bipolar electrodes are used, and the geometrical configuration of the electrodes. When surface electrodes are used, subject's skin condition and the nature of the interposing tissue between muscle and skin surface has considerable influence on the monitored electromyographic readings. Thus, while it is possible to compare normalised myo-electric signal amplitude output versus muscle tension relationships, from subject to subject, no absolute value tables relating myo-electric signal output to muscle tension may be deduced.

3.2.5. Frequency Composition of the Myo-Electric Signals

Qualitative changes in the myo-electric signal wave-form accompanying certain muscle and lower motor neuron pathologies have been documented (Lenman 1959); frequency analysis of signals derived from such muscles were investigated to determine whether such procedures might be significant in confirming and supplementing present diagnostic procedures. In an investigation described by Johannsen et al (1970)[15] small co-axial needle electrodes were inserted into the biceps brachii of a number of subjects to monitor myo-electric signal output for constant moderate contractions. After having been amplified, the myo-electric signals were passed through 4 separate pass band filters having centre frequencies at 50, 200, 800 and 1,600 cps. The resultant output signals from the filters were passed through short time amplitude integrators and their outputs were recorded, tabulated and compared to provide a quantitative evaluation of the myo-electric activity in each pass band. It is interesting to note that the results of the investigation reveal (amongst other things), that there exists a relationship between the readings obtained for the percentage frequency content of myo-electric activity in each pass band (cf Table 3.1). Variations from the mean percentages obtained in the different frequency bands - with the exception of one reading - do not exceed 10%. This is considered to be quite accurate for physiological measurements.

Since different muscle groups contain different numbers of motor units, it might be expected that percentage spectral content from muscle to muscle would be different. Johannsen does not present any comparative muscle group studies however, nor are any clinical or diagnostic application of this particular signal processing procedure suggested.

3.2.6. Power Density Spectrum of the Myo-Electric Signal

Scott[16] presented curves of the smooth power density spectrum (i.e. continuous power spectrum) of the electromyogram for frequencies up to 300 cps. (Three hundred cps is chosen as the upper limit for Scott's graphical presentations since he maintains that the power spectrum of myo-electric signals do not contain any significant components above this frequency).

In most instances the chief component of the power spectrum lay in the 50-60 cps. range. Comparative studies of different muscle groups however do indicate general differences in power spectra associated with different muscle groups. For example, the biceps muscle (cf fig. 3a) show much less high frequency power content than do the muscles flexor carpi radialis. Further, analysis of the power density spectra indicates that there is a shift to higher frequency power increase, with increase in muscle tension. Unfortunately, as was the case in the foregoing section, no clinical application of power density spectrum analysis is suggested, probably because the assembly of the necessary input data for the digital computer techniques associated

Subject	Passbands 50	200	800	1600
1	45	34	14	7
2	32	46	16	6
3	42	38	14	6
4	36	42	15	7
5	40	42	13	5
6	36	43	15	6
Mean	38.5	40.8	14.5	6.2

Table3.1 Myo-Electric Percentage Content in Passbands 50,200,800,& 1600 cps. (after Johansson et al)

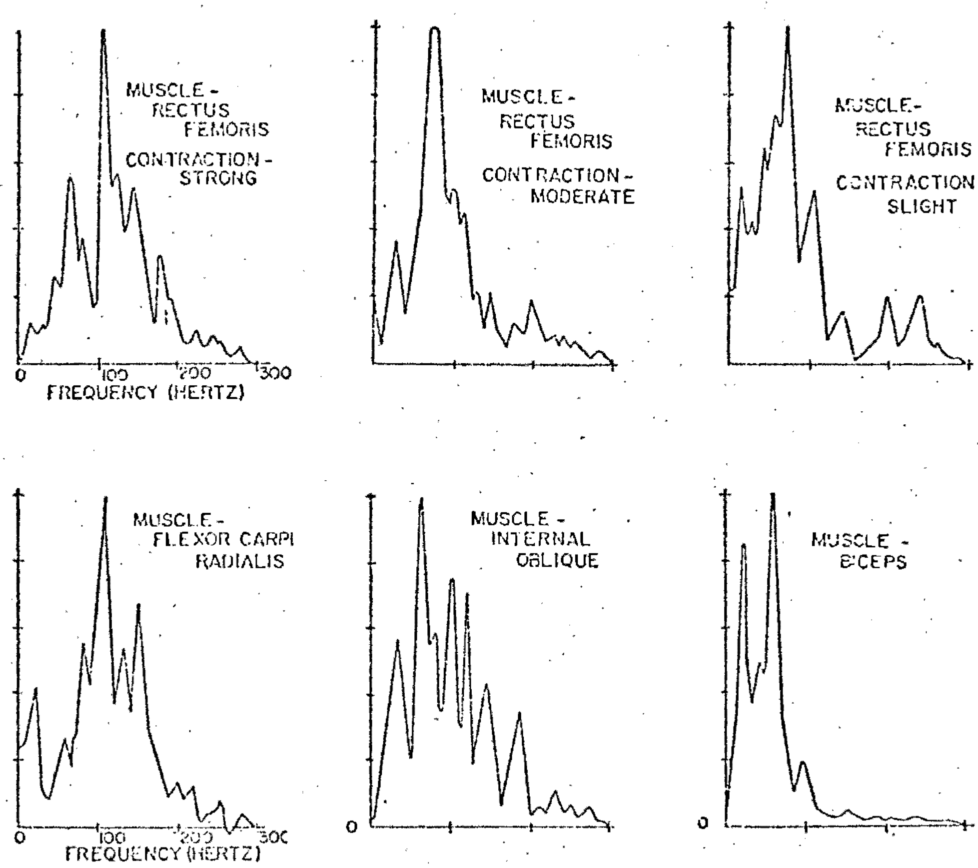

Fig 3a (i) Frequency Characteristics at Different Levels of Contraction
(ii) Frequency Characteristics of Different Muscle groups
(after Scott)

with continual power density spectrum analysis, is extremely tedious.

3.2.7. The Differentiated Electromyogram and Zero Crossing Counts

Differentiation of the myo-electric signal provides an indication of the number of peaks or inflections in the myo-electric signal waveform and the rate at which transitions from peak to peak take place. Direct readings of the zero crossings per second of the differentiated waveform and short time amplitude integration of the differentiated signal renders a measurement of their time rate of occurrence. Fursfield (1972)[17] attempts to correlate normal and pathological muscle zero cross counts of the undifferentiated (raw), first derivative and second derivative myo-electric signals and has presented a series of cases to compare results obtained experimentally from a number of subjects with certain clinically observed pathologies.

In general there is good correlation between the two and Fursfield suggests that the zero cross counting procedure of myo-electric signal processing may be extended to be of use in the diagnosis of other myopathic states.

3.2.8. Zero-Crossing Counts of the Raw Myo-Electric Signal

Consider a single motor unit contracting; it is accepted that the number of peaks of spikes associated with the contraction is indicative of and proportional to the degree of activity of the motor unit. Since the occurrence of peaks in firing motor units is random and since the firing of motor units takes place asynchronously, it is not unreasonable to postulate that the number of peaks monitored from a group of motor units is related to the contractile activity of the group as a whole. The number of peaks or spikes of a group of motor units is not linearly proportional to motor unit population since summation of the randomly occurring spike potentials takes place. Twice the number of motor units taking part in a contraction results in approximate $\sqrt{2}$ increase in the muscles electrical output[18]. Bergstrom[19] compared the short time amplitude integrated electromyogram with the number of spikes in the myo-electric wave-form and was able to demonstrate almost linear proportionality between the two. An increase in the number of spikes is thus indicative of an increase in the motor unit population taking part in a contraction.

If the number of spikes in a myo-electric wave-form is indicative of the degree of activity in a muscle and, if one assumes that the number of minor inflections or minor peaks (Fig. 3.2) in each half cycle of the myo-electric signal waveform is approximately constant, i.e. if the ratio of major to minor peaks in the random type myo-electric interference pattern is constant, then counting the number of times that the myo-electric signal passes through zero volts provides a direct quantitative way of assessing muscle activity. Further, if a tetanic muscular contraction is elicited or if the contraction is of such magnitude that tetanus is nearly approached, then

i) the majority of motor units in the muscle will be contracting and,

ii) they will be contracting in near synchronous fashion.

Therefore, the number of zero crossings counted when a muscle is undergoing maximal contraction, and is approaching a state of tetanus, is directly related to the total number of innervated motor units in the muscle.

On the basis of the foregoing hypothesis, the writer set up an experiment to measure the zero crossing count of signals derived from muscles of normal subjects. The subjects were required to contract their muscles isometrically and maximally for short periods of time and the results derived from four different muscle groups were compared to see if any average value for a zero crossing count associated with a particular muscle group could be established.

3.2.9. Experimental Procedure

Ten healthy subjects between the ages of 7-50 years volunteered for the series of experiments. None of the volunteers could recall having suffered any pathology of the muscles or of their nerve supply. Surface electrodes

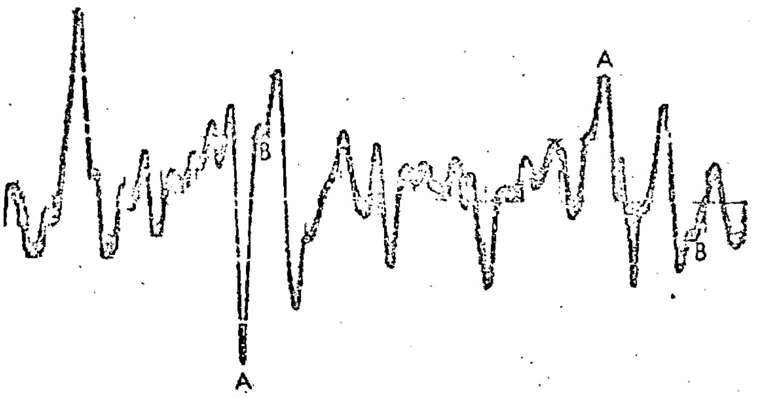

Fig. 3.2. Electromyogram showing Major (A) and Minor (B) Inflections in Waveform.

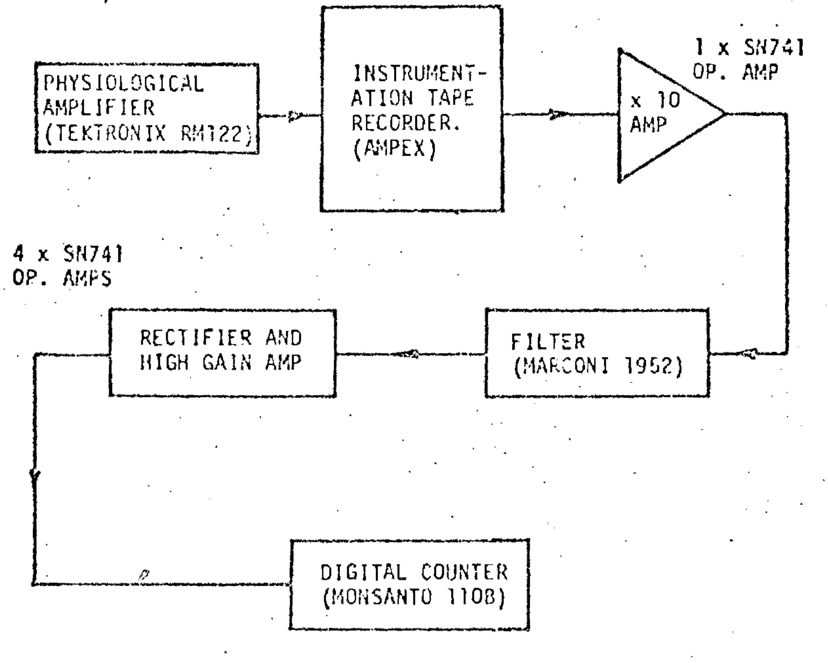

Fig. 3.3. Experimental Arrangement for deriving Zero Crossing Counts

(type Becton-Dickinson BD Disposal) were used throughout the investigation and electrode spacing was kept constant at 1" between electrode centres. The electrodes were attached over the belly of the muscles monitored and were connected to a high input impedance physiological amplifier (Tektronix type RM 122).

The output signals from the amplifier were recorded on magnetic tape on an Ampex instrumentation tape recorder at 7½ i.p.s. (frequency response d.c. to 20 kcps) so that the signals could be processed by a number of different methods if required and at any convenient time. The biceps, extensors of the wrist, flexors of the wrist, and quadriceps muscles of both left and right hand side of each volunteer were investigated. Each subject was requested to contract his muscle against a fixed resistance for about 30 secs. while the muscle activity was recorded.

The signals were processed in the following way:

The tape recorder output was fed to a high input impedance amplifier with a gain of 10 times. Thereafter the signal was fed directly to a Marconi universal filter (type Marconi 1952). The output from the filter was half-wave rectified and thereafter greatly amplified to obtain saturated output signals in square wave form; each square wave corresponded to a positive excursion of the myo-electric signal above the zero volts line. This amplifier output was connected to a digital counter (Monsanto type 110B) and a numerical display of the zero crossing count was obtained. The electrical arrangement is shown in figure 3.3 in block diagram form.

The tape recorder output signal was processed using three different band passes - 60-1,000 cps, 75-1,000 cps, and 100-1,000 cps. Rejection at the extremes of the pass bands for the Marconi filter is 30dB per octave. Since there is little myo-electric activity above 1,000 cps. the filters are effectively high pass filters. Low frequency components of the myo-electric signal were rejected for the following reason: The myo-electric signal was being examined for its spike content, and since the spikes themselves are not of a low frequency nature, summation of a number of spikes occurring asynchronously must have given rise to the low frequency components of the myo-electric waveform. The exclusion of lower frequencies would thus tend to breakdown the electromyogram into its constituent components. Further, possible Piper rhythm effects and mains interference were eliminated using the high pass filters. (Measures to minimise mains interference were necessary when readings of muscles of low activity were made - particularly of quadriplegics' muscles - for comparative study purposes).

3.2.10. Results

A table of readings obtained for the four different muscle groups is presented in figure 3.4 and histograms showing the relative distribution of results in the 100-1,000 cps region is shown in Fig. 3.5. Initial indications are that there is a particular average zero crossing count associated with each of the four muscle groups investigated. (It is stressed, however, that the figures presented here are to be considered only as results of an initial investigation and that more precise and more extensive researching is necessary to confirm these preliminary results). Since there are differing numbers of motor units associated with each muscle group, it is to be expected that higher zero crossing counts should be registered for muscles having a greater population of motor units. As mentioned elsewhere (section 3.2.1.) muscles with low innervation ratios are associated with the finer controlled movements of the body. The wrist extensors and wrist flexors muscle groups exhibited highest zero crossing counts of the four muscle groups investigated. On the basis of the theory presented above, this was to be expected since these muscles are associated with fine hand (wrist) movement. The quadriceps zero crossing count however, was unexpectedly higher than that of the biceps muscle. The contribution of the quadriceps muscles to the comparatively gross movements of locomotion did not indicate zero crossing

	WRIST FLEX			WRIST EXTEN			BICEPS			QUADRICEPS		
	a	b	c	a	b	c	a	b	c	a	b	c
	149.9	133.8	150.0	130.6	148.6	173.2	110.9	120.5	151.6	145.8	160.6	188.1
	132.1	144.2	172.2	144.1	160.6	184.6	115.8	130.1	156.7	155.3	151.1	183.0
	151.5	171.2	195.6	158.7	168.6	189.6	100.5	133.6	158.1	131.2	147.9	181.2
	176.3	184.2	198.8	151.6	163.5	195.4	88.7	115.3	145.7	131.2	147.9	181.2
	183.1	187.1	205.2	177.7	181.2	197.1	127.1	140.5	161.5	140.8	149.8	170.3
	151.1	163.3	186.2	171.1	183.5	209.1	113.7	126.4	150.5	144.4	130.0	161.8
	163.2	184.8	209.1	137.2	148.9	171.1	97.0	132.2	176.2	130.9	152.6	170.0
	166.4	140.6	173.5	100.7	135.7	160.3	118.9	157.7	198.0	125.8	164.0	190.1
	163.3	184.1	199.3	169.5	173.8	201.3	103.5	122.6	150.5	137.9	158.6	205.8
	181.5	176.5	210.6	124.9	161.2	181.9	102.6	124.3	166.7	143.6	165.9	201.2
	133.2	195.7	211.6	165.9	174.8	190.5	112.3	113.0	166.1	117.9	141.7	173.5
	145.7	157.7	177.3	128.8	140.6	166.3	100.2	120.3	159.1	113.9	129.9	152.2
	191.6	209.9	227.9	104.6	148.9	185.3	93.2	113.3	154.2	124.0	145.8	174.7
	161.6	129.5	195.3	124.4	150.4	209.0	81.4	119.1	159.1	135.5	164.2	188.8
	150.1	198.9	220.6	144.4	163.3	187.1	105.9	125.6	150.1	134.8	174.9	195.0
	203.5	212.3	225.3	130.4	174.3	186.8	93.6	117.8	156.9	124.3	163.0	190.9
	138.2	159.3	194.4	130.3	141.5	175.2	103.8	123.5	155.5	145.1	159.1	176.0
	172.7	183.5	201.2	152.2	171.8	198.4	131.3	148.7	173.3	141.2	153.1	175.2
	147.5	147.9	198.0	110.5	149.2	170.3	76.1	106.5	160.5	60.4	107.1	173.7
	147.5	187.8	205.0	147.6	159.5	178.9	80.3	112.2	152.3	121.7	163.0	190.9
Mean	160.5	172.6	197.9	140.8	160.2	186.0	107.3	125.2	159.5	130.3	151.5	182.2
Std. Dev.	19.5	24.6	13.1	22.5	14.4	13.3	24.5	12.6	10.3	19.6	15.5	13.0
% Var.	9.9	11.9	7.0	13.2	7.4	5.6	15.1	7.4	6.7	9.5	7.4	5.6

Fig 3.4 Zero Crossing counts for 4 Different Muscle Groups.
(Freq. Range c=100-1000cps boxed.)

FREQ. RANGE a = 50-1000cps.
b = 75-1000cps.
c = 100-1000cps.

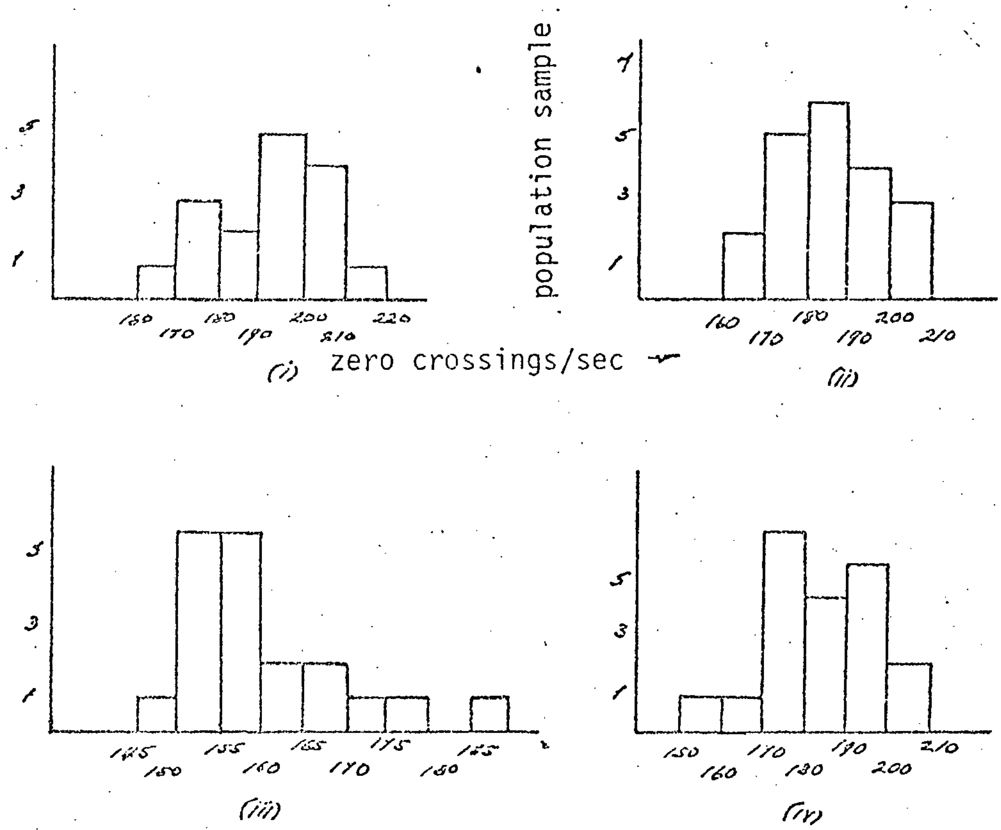

Fig 3.5 Histograms of Zero Crossings of:

(i) Wrist Extensors
(ii) Wrist Flexors
(iii) Biceps
(iv) Quadriceps

in the 100-1000cps range.

readings of such magnitudes. However, the quadriceps do contribute to the upright postural maintenance of the body and therefore these muscles are responsible for fine movements which are necessary for small displacements of the body centre of gravity. Of the four muscle groups investigated the biceps exhibited the lowest zero crossing figure representing the muscle of grossest movement.

The measurements derived from readings of the biceps muscle are the most consistent of all. The reason for this is possibly because this muscle is most clearly defined anatomically and in general there is little interposing tissue between the muscle and the skin surface.

3.2.11. Application of the Zero Crossing Count to Quadriplegics' Muscles

The object of the above investigation was to determine:

i) if the zero crossing count of muscles undergoing maximal volitional contractions differed for different muscle groups,

ii) if the zero crossing count for muscles affected by upper motor neuron lesions could be used to determine the extent of innervation of a muscle, and,

iii) if improvement of such innervation could be indicated by corresponding change in the zero crossing count.

If the above objectives could be realised, then using surface electrode techniques, daily or weekly assessments of muscle nerve supply could be made.

To this end, twenty patients suffering from upper motor neuron pathologies were examined and a total of sixty six readings of zero crossing counts from these patients were made and compared with muscle evaluations based on the Oxford 0-5 Standard Method of Muscle Grading. Wherever possible, patients whose lesions were asymmetrical i.e. whose muscles were better innervated on the one side (left or right side) than on the other, were chosen as subjects. This was done so that muscles of the same group but of different strengths could be evaluated in the same person.

3.2.12. Analysis of Results

In general it was found that with patients having Oxford ratings between 3- and 4+, the zero crossing count did display lower readings for lower

Oxford assessments. This was evident when muscles of different strengths of patients with asymmetrical lesions were examined. On no occasion was a greater zero cross count obtained for weak muscles than for stronger muscles. Most of the muscle groups examined, i.e. wrist extensors, wrist flexors, and biceps exhibited zero crossing counts consistently within the limits determined for muscles of healthy subjects.

There were occasions where muscles of patients having incomplete lesions exhibited abnormally high zero crossing counts - in these instances the patients were quadriplegic as a result of stab wounds and it is suspected that lower motor neuron damage was also present. Lenman[5] has recorded an increase of myo-electric signal high frequency content for lower motor neuron pathologies.

Muscles having been assessed as 2-, 2 or 2+ displayed higher zero crossing counts in the 100-1,000 cps range than might have been expected. The 60-1,000 cps band reading however, were more consistent with their Oxford Standard rating. Unfortunately not many patients having muscles of this strength were available for assessment - only 7 readings were obtained - and thus readings cannot be considered to be sufficiently representative to be quoted as reliable. Table 3.6 summarises the results obtained for quadriplegic patients.

3.2.13. Implication of the Results obtained from Zero Crossing Signal Processing Techniques

Initial indications are that for muscles undergoing maximal or near maximal isometric contractions, different zero crossing counts for different muscle groups exist and that the zero crossing count may be related to the degree of innervation of the muscle and/or to the number of motor units taking part in the contraction. The preliminary figures obtained above cannot be considered to be sufficiently accurate to supercede the existing method of grading muscle strength. Much more data needs to be collected by examining many more patients before any such

Frequency Range a = 60-1000 cps
b = 75-1000 cps
c = 100-1000 cps

o.s. = Oxford Standard

Subject	Diagnosis		WRIST FLEX				WRIST EXTEN				BICEPS			
			a	b	c	o.s.	a	b	c	o.s.	a	b	c	o.s.
L.B.	Syringa Myelia	R	129.9	142.0	167.5	4	113.5	127.2	146.2	5	106.1	133.6	164.6	5
		L	123.0	141.1	161.3	4	107.4	138.3	165.1	5	117.8	141.1	162.6	5
G.M.	$C_{6,7}$ complete	R	75.0	115.8	155.7	3								
		L	82.3	110.2	145.2	3								
M.S.	$C_{6,7}$ incomplete	R	58.3	91.0	150.8	3+								
		L					79.5	127.3	156.9	4				
M.P.	$C_{6,7}$ incomplete	R	100.2	123.0	140.6	3	87.6	119.3	146.5	5				
		L	120.9	140.1	165.2	5-								
L.S.	$C_{4,5}$ complete	R									85.8	107.4	150.8	5
		L									56.6	89.9	142.2	3+
K.M.	$C_{5,6}$ complete	R					112.1	124.0	148.3	4	105.6	116.3	142.3	4
		L					146.5	159.9	175.0	5	104.5	118.6	138.6	4
R.K.	C_5 incomplete	R	129.9	152,3	170.6	3								
		L	139.9	157.0	175.3	4	145.9	159.9	188.3	5				
W.T.	$C_{6,7}$ incomplete	R	128.3	145.0	165.8	3+	152.7	178.2	194.8	5				
		L	162.8	184.6	199.7	5	120.0	133.3	156.0	5				
H.Z.	$C_{4,5}$ incomplete	R					94.6	131.0	149.3	3-	88.1	105.5	130.2	4
		L					120.7	139.4	160.8	3+	95.3	116.5	144.0	4+
J.F.	$C_{6,7}$ incomplete	R	144.1	154.5	164.8	3+	122.9	140.0	163.8	4+				
		L					124.7	135.0	154.4	4				
M.P.	$C_{6,7}$ incomplete	R	145.0	154.9	173.2	4+	158.1	173.4	192.9	5				
		L	128.1	134.2	156.7	3+	135.0	149.6	166.8	5				

Figure 3.6(i)

Readings of Muscles of grading greater than 3-

Subject	Diagnosis		WRIST FLEX				WRIST EXTEN				BICEPS			
			a	b	c	o.s.	a	b	c	o.s.	a	b	c	o.s.
H.v.Z.	$C_{4,5}$ complete	R									102.7	123.3	155.3	2
		L									95.8	113.2	158.8	2-
E.K.	$C_{5,6}$ incomplete	R					60.3	81.2	157.7	2	92.3	137.1	157.3	2+
L.S.	$C_{4,5}$ incomplete	R		64.2	148.9	2-	-	59.8	137.9	2-				
R.K.	$C_{5,6}$ incomplete	R					153.1	162.5	173.8	2+				

Figure 3.6(ii)

Readings of Muscles of grading less than 3-

claims can be adequately substantiated.

3. 3 THE APPLICATION OF ZERO CROSSING COUNT SIGNAL PROCESSING IN THE INITIAL TREATMENT OF QUADRIPLEGICS

An instrument known as the Myo-Electric Signal Monitor (Ruch 1966,[20]) has been developed for use by Occupational Therapists in

their early rehabilitative treatment of quadriplegics. The instrument operates in the following way: Surface electrodes (similar to the Beckman type bipolar electrodes) are placed over the muscle whose activity is being monitored. Care is taken in locating the electrodes over the same sites on the skin at successive treatments and to maintain consistent inter-electrode spacing in an effort to eliminate the influence that changes in these parameters might have on the myo-electric signal readings. The myo-electric signals generated when the patient contracts his muscle, are fed to a high gain, high input impedance differential amplifier and processed to obtain a reading on a meter on the front panel of the instrument. The reading is proportional to the zero crossing count of the myo-electric signal. Experience has shown that the zero crossing count is proportional to the tension in the muscle in much the same way as tension and myo-electric signal amplitude are inter-related. The patient's effort may thus be gauged by observing the meter reading Fig. (3.7.)

Once the zero crossing count of the monitored myo-electric signal reaches a preset value which is determined by the Occupational Therapist using the patient's previous performance as a guide, an indicator lamp is illuminated to indicate that the patient is contracting his muscle sufficiently. If the contraction is maintained at this level for approximately ½ second, a pulse count is logged on a counter. In accordance with a regime developed by the occupational therapists[21] the patient is required to elicit contractions in this muscle at present intervals and at a level consistent with a preset zero crossing rate. To provide incentive to the patient so that he will in fact contract his muscle when required, a timing device is

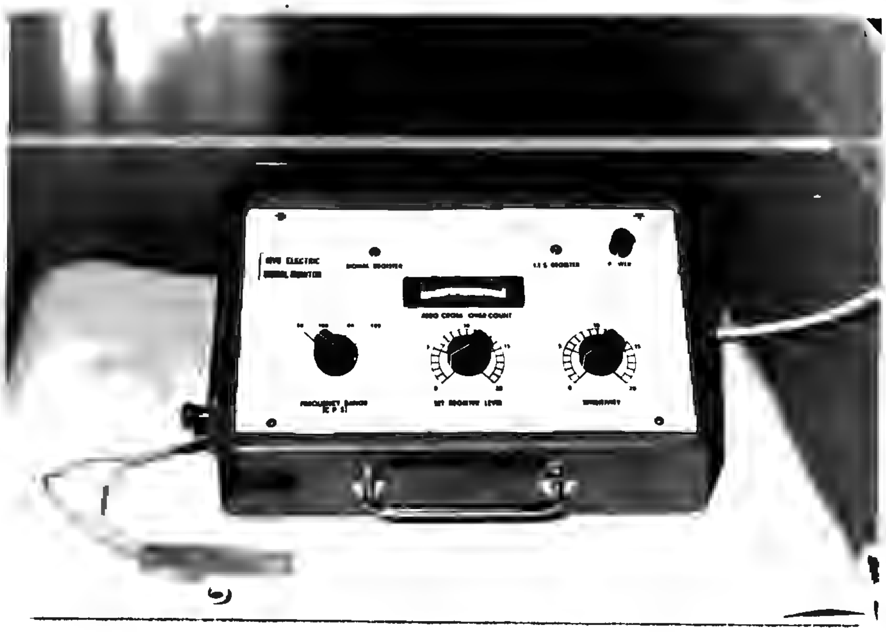

Fig. 3.7. The Myo-Electric Signal Monitor.

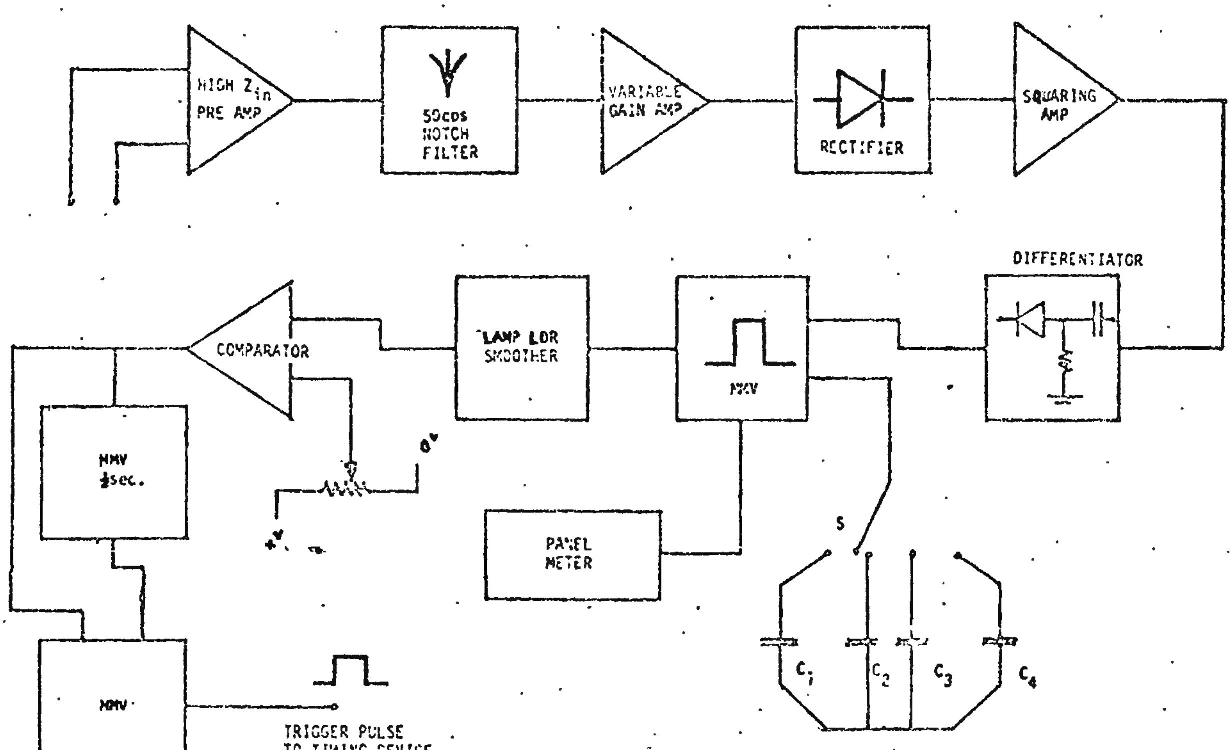

Fig. 3.8. Block Diagram of Myo-Electric Signal Monitor

triggered by the Myo-Electric Signal Monitor output. Power is supplied via this timing unit to slide projectors, record players or other suitable electrical appliances; non-contraction of the muscle being monitored in strict accordance with the prescribed regime will result in interruption of the power supply to the appliance.

The occupational therapists are required to note the values of the zero crossing readings from treatment to treatment and to log the total number of contractions that the patient was able to effect. Records gathered from two spinal injury centres in South Africa indicate the following:-

i) It is possible to gauge muscle strength increase even on a day to day basis by noting a corresponding increase in the zero crossing reading, and

ii) the zero crossing readings obtained from muscles that are considered to have stable innervation i.e. muscles that are not improving nor degenerating, do not differ more than $\pm$ 5% from the average of readings obtained previously.

When used with quadriplegics the Myo-Electric Signal Monitor finds particular application in the specific treatment of weak muscles which are expected to improve and for maintaining existing muscle strength and mobility. It is also a means whereby patient's muscle contractions may be monitored, improvements noted and where muscle contractions of just Oxford 1 grading may be put to functional use in the early stages of patient treatment. There are a number of Myo-Electric Signal Monitor instruments in widespread use in all three spinal injury centres in South Africa; two units in Australia are also experimenting with this instrument. There does not seem to be any direct correlation between results obtained from different patients as regards readings for similar muscle gradings. This does not in itself indicate that no such correlation exists. Experimental procedures and processing techniques using perhaps different pass bands might well show that quantitative muscle comparisons and gradings are possible. On the strength of the above preliminary results, further investigation using larger populations of both volunteers and patients would be worthwhile to determine more conclusively the value of the zero crossing count method of signal processing in muscle performance evaluation.

3.4. CIRCUITRY CONSIDERATION OF THE MYO-ELECTRIC SIGNAL MONITOR

A block diagram illustrating the operation of the Myo-Electric Signal Monitor is presented in fig. 3.8 A high input impedance, differential pre-amplifier is used to monitor the myo-electric signals derived from the muscle being exercised. To eliminate the interference described in 3.2.9. above, a 50 cps notch filter is inserted in the circuit. (By capacitive coupling much of the low frequency signal below 50 cps is excluded). The notch filter output is further amplified using a variable gain amplifier and the signal is then half-wave rectified. The rectifier output is amplified to provide a square wave (saturated) signal for each half-wave of the myo-electric signal. The square wave signals are differentiated and the positive going spikes are used to trigger a monostable multivibrator. The monostable multivibrator (MMV) therefore puts out a pulse for every positive going zero crossing of the myo-electric signal. The MMV time constants are switch selected (4 positions) and determine the full scale reading of the front panel meter. Larger capacitors providing larger time constants are switched in if the muscle is weak and if as a consequence low zero crossing counts are expected. The meter is connected directly to this monostable multivibrator and the inertia of its moving coil acts as a low pass filter. The amount of current per zero crossing of the myo-electric signal is controlled by means of a series resistor thus permitting meter calibration. The meter scale factor is changed by selecting the different MMV time constants.

The Monostable Multivibrator also feeds an incandescent lamp driver circuit and pulses of light related to both the frequency and duration of the MMV output are generated. These are directed to a light dependent resistor (Philips type LDR - 08). Both the incandescent lamp and the resistor are slow operating devices and their intrinsic time constants are used to smooth (short time integrate) the direct current analog signal representative of the zero crossing count of the electromyogram. The d.c. signal thus obtained is compared with a locally generated preset voltage and should the processed myo-electric signal output exceed the preset value, a second monostable multivibrator of ½ second time constant is triggered. A "Signal Register" lamp is illuminated for as long as the myo-electric intensity results in a processed signal that is greater than the internally generated preset voltage. Should the "Signal Register" lamp still be illuminated after the ½ second MMV has returned to its stable state, a third MMV is set. This MMV provides the output signal for the timing device described above in Section 3.5. The ½ second myo-electric signal maintenance requirement is included in the design specifications to eliminate the effect of mains transients, generated by appliances being switched on or off in the immediate vicinity of the Myo-Electric Signal Monitor. The instrument thus reacts to signals of time occurrence greater than ½ second. The reader is referred to Appendix B for a full description of the instrument operating procedure and for circuit diagrams and component specifications.

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CHAPTER 4

4.1. MAN AND THE MACHINE

From the beginning of time, man used rough implements of stone, bone or wood to extend, increase and replace his functional capabilities within the environment in which he lived. Technological advances have long since superceded the crude instruments of prehistoric man, however the criteria by which the degree of usefulness of modern day appliances and tools are measured, are much the same as those of days gone by. These criteria may be enumerated in general terms as follows:-

i) The design and construction of the tool should be such that it is optimally suited to performing the task for which it is intended.

ii) The decision making capabilities of the human operator using the appliance should not be taxed beyond his intellectual capacity.

iii) The degree of skill required in the operation of the appliance should be within the operator's physical ability.

iv) Information regarding the success with which the appliance is being used must be relayed simply and effectively to the controller. This is necessary so that the operator may modify his actions to maximise the use of his appliance.

v) The effort (both physical and mental) involved in accomplishing a task must be less than that involved in accomplishing the same task by other means.

vi) The cost in labour, components and time to manufacture and maintain the appliance must be consistent with its degree of usefulness.

vii) The equipment must be psychologically compatible with the human controller. He should be able to integrate fully with such equipment to visualise its function as a convenient and logical extension of himself.

All of the above requirements must be adequately catered for if a successful man-machine system is to be synthesised.
This applies equally to the quadriplegic and any orthotic equipment designed for his use. Because of the severe physical limitations of bodily function accompanying quadriplegia, the criteria enumerated above are extremely difficult to satisfy.

4.2. THE PARAPLEGIC, HIS MACHINE AND HIS ENVIRONMENT

The paraplegic who is mildly disabled when compared to a quadriplegic, must use a wheelchair or crutches in order to move around in his environment. These are the main machines which the paraplegic uses constantly. Only with extreme difficulty can paraplegics who ambulate using crutches negotiate a staircase, while those who are wheelchair bound would not attempt such an ostacle unaided. Environmental considerations, therefore, determine the spatial limits in which a paraplegic may move.
The paraplegic's independent range of access may be extended by either acquiring a wheelchair that can negotiate staircases - regrettably no wheelchair that can traverse both steps and flat surfaces has yet been successfully designed - or, by building graded ramps to eliminate staircases in places frequented by the paraplegic. This example illustrates two distinctive approaches which are employed in dealing with severely handicapped persons. These are:-

i) the use of adaptive(') machines, i.e. multifunction machines, and,

ii) the imposition of constraints on the independent activities of the disabled person by requiring him to confine himself and his machine to an existence in a specific or modified environment.

Wherever possible the former approach is preferred.
Other environmental modifications that are considered for paraplegics include the raising of table surfaces to accommodate wheelchair arm rests, and constructional modifications in the bathroom and toilet.

(') The term adaptive is used in a different context in section 4.3.4. of this Chapter

Resorting to the approach of having to confine the patient's independent activity to a specific environment should not be viewed solely as an admission of failure in being unable to design sufficiently versatile and adaptive machines but it should be viewed also as an acknowledgement of the magnitude of the technological problems associated with even modest return of function to the severely disabled.

The man-machine interface between the paraplegic and his wheelchair is quite simply accomplished. Since the patient has full use of his hands, internal body power is available to propel the wheelchair and at a speed comparable with walking. Further, speed and direction of movement are under the patient's control. Since there is no interposition of power amplifiers or delays introduced by assistive externally powered mechanisms, the man-machine system is extremely stable.

4.3. THE QUADRIPLEGIC, HIS MACHINE AND HIS ENVIRONMENT

4.3.1. The $C_{6,7}$ Quadriplegic

The $C_{6,7}$ quadriplegic, while being able to propel his wheelchair, is unable to exercise fine wheelchair control. He has diminished power in his upper limbs and generally experiences greater difficulty than does the paraplegic in propelling his wheelchair. Additional constraints are thus placed on the patient's independent movements by requiring an environment with ramps of minimum gradient to be provided so that these may be negotiated by the patient. Knobs are attached to the wheel rims of the wheelchair to enable the quadriplegic to facilitate the man-machine interface.

The added disability of loss of hand function requires some attention. As detailed in sections 2.6.3. and 2.6.4. the $C_{6,7}$ quadriplegic generally has both active wrist extension and flexion but no useful finger movements. External appliances in the form of splints or ortheses must therefore be provided to augment existing hand function.

The most efficient functional hand splint used for the $C_{6,7}$ quadriplegics, the tenodesis or flexor hinge hand splint, makes use of the remaining active wrist extension and/or flexion to provide driving power for the splint. Flexion of the wrist causes the levered component part of an exo-skeleton fashioned about the fingers, wrist and forearm to move so that the forefinger and index finger are opposed against the thumb to provide a 3 point pincer grip. Since body power is used, and since $C_{6,7}$ quadriplegics do have moderately good sensation in their hands, bilateral transfer of information between both man and his machine is facilitated, i.e. patient can modulate the intensity of his grip at will and is also fully aware of how his machine aided hand is operating.

More advanced flexor-hinge splints permit patients to control the degree of wrist extension required to oppose finger and thumb. This adaptive facility permits efficient gripping of both small or large objects. The three point type of grasp is however the only grip that the orthesis affords. There are no adaptations which permit an operator to change from the 3 point grip to a total finger flexion or fist type grip. Constraints are therefore placed on the type of functions which the splinted hand may perform and the environment in which the patient exists must be adapted or modified if maximum and efficient patient control therein is to be obtained. Eating implements, combs etc. must be modified so that they can be grasped more easily by the patient. There are activities such as unscrewing lids off jars which the patient will have difficulty in accomplishing; wherever possible the necessity of having to effect such operations should be excluded or minimised in the patient's environment.

A battery of splints far less efficient than the flexor hinge ortheses described above, have been devised. These will permit the patient to effect specific tasks or to hold specific objects. For example, it is not uncommon to see a $C_{6,7}$ quadriplegic who has a splint to facilitate writing, a smoking splint and a splint with which to eat. These splints may be described as non-adaptive type appliances and are classic examples of devices which, because of their low level of functional variety, place inhibiting restraints upon a patient who still has (potential) multi-function ability. The use of such inhibitive equipment should be discouraged at every opportunity.

4.3.2. The $C_{5,6}$ Quadriplegic

Innervation of the biceps and its muscle output power is diminished to a degree in the $C_{5,6}$ quadriplegic, however adequate residual function is available to permit the patient to manoeuver and propel his wheelchair. The remarks made regarding the $C_{6,7}$ quadriplegic and his wheelchair are thus applicable also to the $C_{5,6}$ quadriplegic. Also, the flexor hinge hand splint may still be used although diminution of sensation in the patient's hands degrades the degree to which the operator may gauge directly how much pressure he is exerting on an object within his grasp. Since visual feedback, and proprioceptive feedback as a result of the splint being body powered, is present splint operating proficiency is not affected to any marked degree.

The $C_{5,6}$ quadriplegic does not have the use of wrist flexors and thus aside from the environmental constaints placed on quadriplegics of lower lesions,an additional constraint is placed on tasks which the controller may confidently expect to carry out. In the case of the $C_{6,7}$ quadriplegic who had active wrist flexors, the fingers and thumb of the splinted hand could be actively opposed (wrist extensors) and active disengagement of grip could be effected (wrist flexors). Since the $C_{5,6}$ quadriplegic has no wrist flexion, he must rely solely on the effects of gravity to release an object from his grasp.

Efficient man-machine interface of low lesion quadriplegics who still have multi-functional ability is relatively simple to achieve. The degree of proprioceptive feedback which is afforded the patient by his being able to use residual body power to operate his splint is the most important single factor contributing to the success that has been achieved in efforts to supplement functional use of the hand.

4.3.3. The $C_{4,5}$ Quadriplegic

The man-machine system for quadriplegics with $C_{4,5}$ lesions is far more complex both from the actual hardware and interface considerations than are systems for quadriplegics with lower lesions. In most cases the $C_{4,5}$ quadriplegic still retains useful biceps and does not have greater difficulty propelling his wheelchair than does the $C_{5,6}$ level quadriplegic. There are instances, however, where the $C_{4,5}$ quadriplegic is unable to propel his wheelchair. In such cases motorised wheelchairs may be used to extend the limits of the patient's independence. The man-machine interface is accomplished by joystick control which may be directed either manually (by a suitably splinted hand) or by using chin or head controls. (Chin or head control is only resorted to where there is insufficient biceps power to position the hand).

Usually the $C_{4,5}$ quadriplegic is able to position his hand in space in front of him; he is unable to extend or flex his wrist however and therefore cannot use the tenodesus type hand splint described above. External power must be provided to articulate the fingers. Further, little or no sensation remains in the patient's fingers and thumb and he is thus quite unaware of the pressure at his fingertips nor has he any proprioceptive indication of the damaging effect of excessive pressure or the prolonged maintenance of such pressure. A functional hand orthesis for a $C_{4,5}$ quadriplegic must permit two degrees of freedom of movement; it should

i) facilitate prehension (externally powered) and

ii) permit changes in the amount of wrist extension and flexion to afford optimum wrist attitude in accomplishing a required activity.

The wrist movements may be either passive or active i.e. manual adjustments of wrist attitude (by the patient himself or by an attendant) may be provided for, or such movements may be externally powered.
There are few constructional difficulties that must be overcome to produce efficient ortheses having only two degrees of freedom of movement; the obstacles preventing the synthesis of efficient man-machine systems are not associated with hardware per se but revolve around the control of such hardware. The patient should be able to generate sufficient control signals to operate the orthesis and at a rate acceptable to himself as approaching normalcy. The $C_{4,5}$ patient's man-machine interface is inefficient since he does not have proprioceptive feedback channels and must rely solely on visual feedback to provide both position and force information to his central nervous system. (Visual extrapolation of force output is gained by observing the effect of the grip on both the object being grasped and on the splinted fingers).

4.3.4. Quadriplegics with Lesions above $C_{4,5}$

1. Body Aided Systems

The quadriplegic with lesions higher than level $C_{4,5}$ has minimal use of his biceps (at best a 2 or 2+ grading on the Oxford Standard). He is thus unable to lift his forearm and wrist to position his hand in space unless externally aided. Ortheses which do facilitate arm movements for such patients have been developed. (cf. Chapter 6). The orthesis comprises a forearm channel mounted on a spring loaded swivel mechanism. The mechanism is attached to the patient's wheelchair on a free moving axis which permits friction free movement in the horizontal plane. The spring loaded channel is so adjusted that the weight of the patient's forearm is counter-balanced by the effect of the springs. Thus gravity is eliminated as far as the forearm is concerned, and the remaining biceps activity is sufficient to permit the lifting of light and small objects. Horizontal movements are effected using the remaining shoulder girdle muscles. Naturally, external power must be provided to control prehension and, if required, wrist extension and flexion. Since the degree of elbow flexion is still related to the effort elicited by the patient's biceps, proprioceptive feedback is present for forearm movements.

'Ball race feeder mechanisms' as they are termed, may also be used to facilitate arm movements for the $C_{4,5}$ quadriplegic. These devices are also gravity operated and consist of a forearm support attached to a mechanism which permits friction free movement in the horizontal plane. The forearm support is centrally situated on a pivot which permits the hand to tilt forward and downward as the patient elevates his shoulder; depressing the shoulder has the opposite effect - that of lifting the hand. The patient uses weak biceps and shoulder girdle muscles to operate this system. Although range of movement is somewhat limited using these devices, proprioceptive position and force feedback is available to the controller and patients are reported(1) to have achieved great proficiency in their use.

2. Powered Multidegree of Freedom Devices

To extend the range of movement and power output capabilities of patients with movement only in the shoulder girdle muscles, complex orthotic devices have been designed and developed. Machines having up to seven degrees of freedom (cf. Chapter 6) are available. Unfortunately the extent of the man-machine interface problem increases as the complexity of the ortheses is increased. Beside the demands of stringent design and technological sophistication needed to produce mechanically sound multi-functional appliances, complex patient operating procedures are required to exercise control over the orthesis. Since no proprioceptive feedback is possible with such a device, patient control is effected using visual feedback only. Further, the bit rate of information transfer from man to his machine is low since tongue switches, head switches or myo-electrically operated controls with low information rate outputs are the only means whereby control signals can be generated.

The above is an example of a low variety of movement system - the C_4 quadriplegic - inhibiting another system with multi-function capabilities - the complex orthesis. The nett effect of such a combination is an inefficient man-machine system and, as in the parallel example of a low variety type splint adversely affecting a $C_{6,7}$ and $C_{5,6}$ quadriplegics' man-machine system, the integration of such mismatched systems is ill-advised. Practical experience (cf. Chapter 6) has shown that the use of multidegree of freedom ortheses is not well tolerated by high lesion quadriplegics. These patients elect not to use their appliances and prefer to make use of the services that healthy people around them are prepared to offer.

The rejection by the quadriplegic of the complex mechanical orthesis and its substitution by a 'human machine' may be considered as an extension of the quadriplegics man-machine system. The healthy person who has responded to the quadriplegic's request for assistance, may be viewed as an improved 'machine'. Such a 'machine' is as multi-functioned and as adaptive as the quadriplegic may require, and the quadriplegic may communicate with the machine using conventional speech channels. The 'machine' may communicate with the controller in a similarly efficient way. The quadriplegic is no longer limited by his low variety of physical function and may convey his intellectual multi-function capabilities via an efficient two-way communication medium to a 'machine' of multifunction physical capacity; two such multifunction ability sub-systems matched together constitute an extremely efficient man-machine system. It is small wonder, therefore, that high lesion quadriplegics do all within their financial means to acquire help in the form of a full-time attendant.

As a consequence of the above statements the following question is no doubt raised: If engineers have failed to produce efficient man-machine systems for quadriplegics and, if such naturally occurring 'machines' may be acquired, why is so much effort being directed at developing a man-machine system that will be expensive to purchase and maintain and that cannot conceivably (at the present time) be more efficient than that which is already available? The answer lies simply in the psychological make-up of man; man guards his independence zealously and will strive to maintain his independent existence even in catastrophic circumstances. Further, man might accept dependence on inanimate objects but absolute and total dependence on other people is an affront to human dignity and selfrespect. The efforts being made throughout the world by researchers in the field of orthotics should thus be viewed not only as being directed toward minimising disfunction of a damaged system but as an effort to provide a means whereby self-respect and human dignity, which go hand in hand with independent existence, may be placed within the reach of the severely disabled person.

Special purpose computers have been used to extend the functional capacity of the inefficient man-machine system described above (cf. page134). Since the patient is unable to put out high information rates, his low bit-rate output is used to control machines which operate largely in automatic mode. The patient has merely to initiate a desired action and the machine will effect the required movement as stored in the memory of a special purpose computer. Adaptive machines able to 'learn' body movement patterns and reproduce them with the controller being required to provide only a rough guide as to what movement path is required, are also being developed. While adaptive and computer aided operation of ortheses is presently being used under experimental conditions it is logical to expect that with the advent of large scale integration of micro-electronic components the use of computer aided control techniques in functional rehabilitation systems will become more widespread.

4.4. ENVIRONMENTAL MODIFICATIONS FOR HIGH LESION QUADRIPLEGICS

The environmental modifications which may facilitate the $C_{4,5}$, and higher, lesion quadriplegics' independent existence deserve consideration. For such patients it is not sufficient to modify minor aspects of the patient's environment as was the case for quadriplegics with lower lesions. Extensive environmental modifications are necessary to permit efficient interface between the quadriplegic and his environment. The quadriplegic is surrounded by equipment (non-orthotic) which he may efficiently and easily operate even with his low capacity of information output. The equipment is controlled by a preprogrammed special purpose computer which interprets the quadriplegic's input signals and permits automatic mode operation of equipment (cf. Chapter 7). Appliances which the patient might wish to use in his day to day activities are adapted for use with this type of machine. These appliances include tape recorders, telephone and other intercommunication systems, radios, television etc. Environmental controllers as these special purpose computers are called, have found extensive application in the rehabilitation of quadriplegics and have proved to be both functionally useful and well tolerated by the patient.

4.5. MAN-MACHINE INFORMATION REQUIREMENTS

The inability of high lesion quadriplegics to generate sufficient control information to operate multidegree of freedom ortheses has been outlined in the sections above. It is necessary to determine what the information output capacity of the quadriplegic is, and what the control requirements of a multivariety system are, so that a more precise measure of the mismatch of the sub-systems of the man-machine complex as a whole may be assessed.

4.5.1. Human Information Output Capacity

Pursuit or compensatory tracking is a popular method employed by psychologists to determine the rate of transfer of information from man to a machine under his control[2]. The results obtained from various experimental procedures, are processed according to the classical information theory techniques as presented by Shannon and Weaver[3] and a value for human information output for a particular set of circumstances is obtained in terms of bits of information.

Crossman (1960)[4] postulates the existence of at least two distinct parts in the human sensori-motor apparatus,

i) the decision or D mechanism, and

ii) the effector or E mechanism.

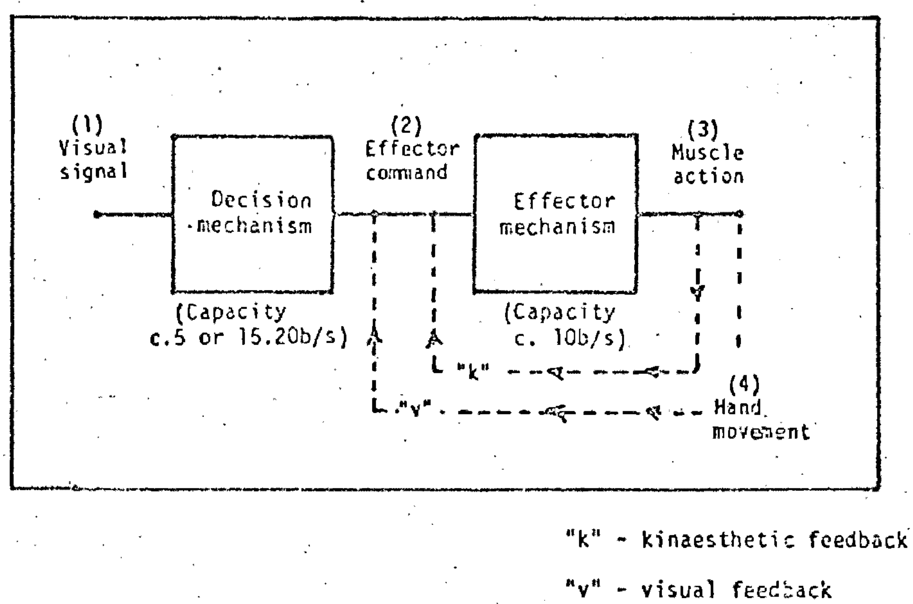
The interaction between the two is illustrated in the figure below.

He further suggests on the basis of results obtained from pursuit tracking experiments that the D-mechanism has a capacity of 5 bits/sec in most cases and of 15-20 bits in highly practised tasks, while an E-mechanism has an output capacity of 10 bits/sec for hand movements. Quastler[5] suggests that a skilled and practised piano player (using both hands) is capable of generating 15-20 bits/sec.

Thus training and practice are seen to be most important factors influencing information output capacity. Kreifeldt[6] considers the human operator in a control system as operating in a sample data fashion rather than operating in a continuous data processing mode. The operator sampling frequency, therefore, determines the rate at which changes in course correction in pursuit tracking tasks will be made. Measurements of response spectrum characteristics after Craik[7,8] display a predominant frequency component of approximately 2 cps, while Freedy[9] quotes references indicating that 80% of the wavelengths of correcting responses of trained pursuit trackers ranged between 0.2 and 0.6 seconds. The frequency of operation of the human controller is thus within the range 1.0-5 cps.

The general expression for the information of a system is:-

$$C = B \quad Pi \log_2 Pi \text{ bits/sec}$$



A Schematic Representation of Information Flow in the Human Perceptual-Motor System.

The Decision mechanism translates perceived signals into instructions for the effector system.
The Effector mechanism controls the muscular activity needed to carry out the instructions. It may use visual feedback, "v", and or kinaesthetic feedback "k".

(after Crossman[4])

where Pi = probability of occurrence of the i th level in a series of n levels

and B = bandwidth of the system.

If the number of different levels occur with equal probability, i.e. if transitions from one position to another are totally unrelated, then,

$$C = B. \log_2 \text{ bits/sec.}$$

For the purpose of calculating the information output capacity of a human controller, consider the value of 2 cps for B.

The expression for C then becomes

$$C = 2 \log_2 n \text{ bits/sec}$$

$$= \frac{1}{0.5} \log_2 n \text{ bits/sec.}$$

In the pursuit tracking experiments from which the value of B above was deduced, all authors referred to used tracking apparatus which was hand operated. The degree of control over movements of the hand is greater than that of limb or trunk movements. Thus when considering signals other than those that are hand generated, allowances must be made for the increased reaction time of that body in calculating its information output capacity. The results of the calculations of the following pages should thus be considered as optimistic since no corrective adjustments to the value of B have been made.

4.5.2. The Quadriplegic's Control Sources

The high lesion quadriplegic does not possess many signal sources through which he is able to effect control over an externally powered appliance. Head switches and shoulder switches which are operated directly by physical displacement of these body parts have been used to provide control signals as have switches operated by tongue movements, and by sucking or blowing on pneumatic transducers. Since the patient employs most of his residual functional capacity to maintain his posture in his wheelchair, remaining trunk muscles cannot usually be utilised for control movements.

Switches mounted on halo type headbands have not proved successful as an information output medium for two reasons:

1) constraints on patient's head movements must be imposed if the switches are not to be triggered inadvertently by the patient while talking or looking about, and

2) cosmetically, the quadriplegic patient finds this arrangement unacceptable.

Chin switches may be used with some success to provide low level information output. (Examples of such use are presented in Chapter 6 for both wheelchair and orthesis control). Shoulder switches are generally unsuccessful since the precise positioning of the switch above the patient's shoulder is critical. The patient does not remain stationary in his wheelchair throughout the day and with each new position that the patient adopts, the switch must be re-adjusted. The tongue has been used as a most versatile control medium, it being able to operate as a multifunction output device because of the degrees of freedom of movement that it possesses. The most serious drawback in using the tongue as a control means is that it interferes with talking and eating and it is also cosmetically unacceptable. Myo-electric signals derived from muscles that are considered to be redundant (i.e. are not required for normal body activities on a continuous basis) have also been employed for orthesis control, and much hope is centered on its use as the ultimate and most efficient means whereby information may be relayed across the man-machine interface.

4.5.3. Information Output of Quadriplegic Signal Sources

The number of discrete levels n, that may be independently generated using the control media enumerated above should be examined to arrive at a value for the bit rate of patient information output. For the myo-electric signal, Vodovnik and Kreifeldt(10) have shown that as many as 30 different levels of myo-electric signal output are attainable. This is however only possible if long time constants are associated with the myo-electric signal processing circuitry. Lowering the system time constant results in a reduction of the number of discernable levels of myo-electric signal output.

In developing the mathematics whereby the 30 levels of myo-electric signals were predicted, Vodovnik and Kreifeldt conclude that the most efficient myo-electric control systems contain only 3 possible levels of discrimination of signal. As they point out, there are a number of researchers who have used 3 state myo-electrically controlled systems with success.

The expression for C for a three state myo-electric system is:

$$C = \frac{1}{0.5} \log_2 3 \text{ bits per second}$$

$$= 2 \log_2 3$$

$$= 3.16 \text{ bits/sec.}$$

Bidirectional pneumatic switches i.e. pneumatic switches which are able to detect both positive (blowing) and negative pressure (sucking) signals also provide 3.16 bits/sec. of information.

Using head, shoulder, or uni-directional pneumatic switches which provide on-off output signals controllers are able to generate only:

$$C_{\text{on-off}} = \frac{1}{0.5} \log_2 2$$

$$= 2 \text{ bits/seconds/switch.}$$

Tongue movements have been used to control banks of up to 7 bidirectional switches. Assuming that it takes 0.2 seconds for a skilled operator to change from one switch to another in a 7 way bank of tongue switches, the information capacity of such a switch may be estimated as follows. The effective bandwidth of the system is determined by the time taken to sample the possible alternative switches in the tongue switch array. T is thus

$$7 \times 0.2 \text{ secs} = 1.4 \text{ secs}$$

The total number of discreet levels N, of the tongue switch array is

$$N = 7 \times 3$$

$$= 21$$

Thus

$$C = \frac{1}{T} \log_2 N \text{ bits/sec}$$

$$= \frac{1}{1.4} \log_2 21 \text{ bits/sec}$$

$$= \frac{4.32}{1.4} \text{ bits/sec}$$

$\approx$ 3.16 bits/sec. which as is to be expected, is the same as the result derived for a simple 3 way switch. A bank of tongue switches may be used to advantage however, when a number of switches are operated simultaneously.

4.5.4. Information Capacity of Speech Communication

The average number of bits per word in speech communication using the English language based on

1) the average information content per letter, and
2) an approximate formula for word frequency distribution is estimated by Quastler[(5)] to be

6.25 $\pm$ 25% bits/word.

There are 2.1 words per minute transmitted in normal speech thus such communication gives 2.1 x 6.25 $\pm$ 25%

i.e. 11-17 bits/second.

In a face to face conversation, words are not the only means of communication; contributions in the information capacity as a result of facial expression, voice intonation and gesticulation enhance the quality of transfer of information.

Compare the information outputs of the above signal sources with that of a regular speech communication channel. It is small wonder that quadriplegics reject their orthotic appliances and prefer to elicit the aid of an attendant to accomplish their tasks.

4.5.5. Orthesis Information Input Requirements

Consider an orthotic arm system having three degrees of freedom of movement in the x, y and z rectangular co-ordinates. Three separate sets of input data must be relayed to the orthesis motor control to locate a specific point in space. Let the range of movement in the x, y and z directions be 90 cms, 50 cms and 30 cms respectively. This corresponds roughly to the extent within which a quadriplegic might require to situate his hand in front of him. Let the accuracy with which position location is required be 1 cm, i.e. $\pm$ 1 cm in each x, y and z direction. The total number of discrete target locations is thus:

$$N = \frac{30}{2} \times \frac{90}{2} \times \frac{50}{2} = \frac{13.5 \times 10^4}{8}$$

The number of bits required to specify any one position is $\log_2 N$

$$= \log_2 \frac{13.5 \times 10^4}{8}$$

$$= \log_2 1.69 \times 10^4$$

$$= \log_2 (1.3 \times 10^2)^2$$

$$= 2 \times \log_2 (1.3 \times 10^2)$$

$$= 2 \times 7.022$$

$$= 14.044 \text{ bits}$$

A total arm orthesis would have 4 more degrees of freedom; wrist extension-flexion finger prehension and control of rotational attitudes of the hand and forearm. The normal amount of shoulder rotation required in a functional orthesis would be approximate π radians, and that of forearm rotation $\frac{\pi}{3}$ radians.

The range of movement of wrist extension-flexion is also $\frac{\pi}{3}$ radians; a prehensile range of movement of $\frac{\pi}{5}$ radians is considered adequate. Assuming that ten different angular positions for each of the above movements are sufficient for adequate positioning of the hand and for prehension, 10^4 different discrete locations are available. A total of $\log_2 10^4$ bits must therefore be made available to specify hand position in the planes of movement available to the patient. This is equivalent to:

$$2 \log_2 100 \text{ bits}$$
$$= 2 \times 6.64 \text{ bits}$$
$$= 13.28 \text{ bits}$$

A total of 13.28 + 14.04 = 27.32 bits of information are required to position a complete arm orthesis in space.

Assuming that the human controller would be satisfied with a speed of operation that would completely specify a point in say 5 secs. the continuous bit rate of information transfer to the orthesis would have to be

$$\frac{27.32}{5} \approx 5.5 \text{ bits/sec.}$$

Seven separate distinguishable channels of information would have to be used to specify the hand attitude and throughout the duration of orthesis movement a number of channels would have to be activated simultaneously. Complex multidegree of freedom tasks requiring simultaneous control of only two functions, taxes the mental capacity of even normal persons. It is thus quite unrealistic to expect a high lesion quadriplegic to be able to derive satisfactory use from a man-machine system that requires a control information rate that is incompatible even with healthy persons.

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CHAPTER 5

STATIC AND DYNAMIC BODY POWERED SPLINTS

5.1. INTRODUCTION

Appliances which are employed to:

i) provide assistance to under-powered body segments

ii) substitute for absent motor function

iii) provide support for body parts requiring positioning, stretching or immobilisation

iv) facilitate existing body movement patterns so the net overall effect of the movement is functional

v) facilitate the attachment of devices,

are known as splints, ortheses or braces. The prime objective of using any type of splint is to change a body part from a condition of non-function or limited function to a condition of optimal function. The splinting of the upper limbs of quadriplegics include techniques for accomplishing the manifold functions of the splints enumerated above. Splints may be categorised into two different types namely, static splints and dynamic functional splints. The static splint limits any movement of the splinted body segment which the patient might ordinarily be able to move. These splints are used primarily for immobilising a joint in the course of treatment. Dynamic splints, as their name implies, permit functional movement of the splinted body segment. This type of splint may be either body powered, body powered and gravity assisted, body powered and assisted by springs or elastic components, or externally powered using hydraulic pneumatic or electrically powered actuators. This Chapter deals primarily with static and body powered dynamic splints as applied to quadriplegics; externally powered devices are described in the following Chapter.

5.2. EARLY COMMENCEMENT OF SPLINTING PROGRAMME

The splinting of upper extremities, particularly of the hand and wrist, should be commenced as soon as practicable after the patient's admission to hospital. The primary function of splints at such an early stage is prophylaxis i.e. to prevent the occurrence of contractures which might adversely affect any functional recovery in the use of the wrist and hand or impede the function of the splinted hand. In the quadriplegic's hand there is no innervation of the lubriacles and interossii muscles which provide the characteristic hump shape of the metacarpal arch. Flexion contractures of the fingers are common in such instances, as are contractures of the web space between the first and second metacarpal joints. Further since wastage of muscle is maximal in the immediate post traumatic period of the quadriplegic's existence, contractures can be expected to be most easily sustained during this period. To maintain good functional shape of the hand, rolls of material or cottonwool are placed within the patient's palmar surface to support the palmar arch and the fingers and thumb are flexed around the roll. It is sometimes necessary to hold the digits in place by pulling a suitable piece of stockinette over the patient's fist or by strapping the fingers in place. The writer advocates the use of plastic moulded hand cuffs which are individually moulded and fitted to the patient's hand to provide palmar support for the metacarpal arch and to maintain the thumb in an opposition attitude. Velcro straps which pass over the dorsal side of the hand hold the cuff in place and permit the splints to be put on and removed with a minimum of bother. These hand cuffs, which form the central component of the Engen type functional hand splint(1), is the most convenient method of preventing flexion contractures of the fingers and maintaining the web space between the thumb and index finger. For patients who do not have effective residual wrist stabilisers, it is important to splint the wrist joint to prevent stretching of muscles and tendons. Any increase in the length of muscles and tendons - which is primarily due to continued flexion of the wrist because of gravitational effects - will result in inefficient functional capacity of the wrist should return of movement take place at some later stage. Further, if the wrist is in flexion, the tendons of the digits are under tension and this is likely to cause contractures of the fingers to develop. According to Bunnell[2] the wrist should be splinted in a slightly dorsiflexed position, the position of balanced functional use for both wrist extensor and flexor muscles. Where return of function of wrist flexors is not expected ($C_{5,6}$ quadriplegic) the writer considers that it would seem judicious to splint the hand in a greater degree of dorsiflexion than is present practice. The slight shortening in muscles extensor carpi radialis that might result from this procedure, would contribute to the more efficient utilisation of this muscle in driving the tenodesis hand splint described below.

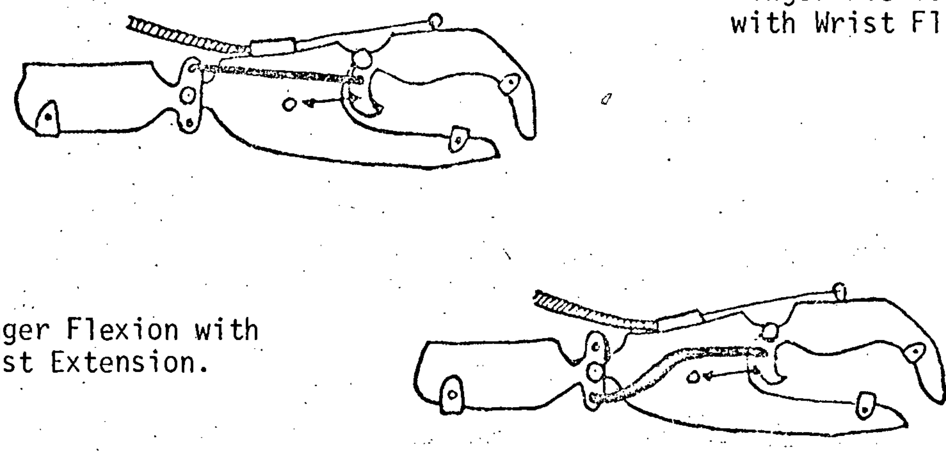
Cock-up splints, i.e. appliances to immobilise the wrist in a dorsiflexed attitude, consist basically of a palmar forearm channel from which protrudes a moulded hand attachment. Support for the metacarpal arch is provided in a well designed cock-up splint. A cock-up splint may be simply constructed by attaching one of the plastic moulded hand cuffs described above to a suitable shaped forearm channel[3]. The splint is held in position using leather or velcro straps.

5.3. TENODESIS TYPE HAND SPLINTS

The tenodesis type hand splint is so called because it has a similar functional effect to the surgical tenodesis procedure. This procedure, whereby the long flexor tendons of the fingers and thumb are detached from their muscle and inserted at a distal position on the radius, is claimed to be useful in cases of flail hands with active residual wrist extension[4]. Dorsiflexion of the wrist automatically causes the fingers and thumb to flex so providing a grasping action of the hand. A mechanical device which utilised residual wrist movement to obtain active finger movement is described by Schottstaedt[5]. The "Handy hand" as this type of functional splint was called, consisted of a forearm cuff and a dorsal hand piece which extended over the fingers of the hand and the thumb. The hand piece was constructed to permit free movement at the metacarpal-phalangeal joint. The hand piece and forearm were connected together at a hinged wrist joint. Adaptations of this splint permitted it to be used in a number of different ways; elastic band assisted finger extension or flexion, or cable controlled finger extension and/or flexion could be easily facilitated. By connecting levers as shown in fig. 5.1 active wrist extension or flexion could be used to effect active finger extension and/or flexion. This configuration of the "Handy Hand" was the forerunner of the tenodesis or flexor hinge hand splint. Nickel et al[6] described a more advanced type of flexor hinge splint consisting of a metal exo-skeleton which is less cumbersome than the "Handy Hand" (fig. 5.2) In this splint the first two fingers are opposed toward the stabilised and stationary thumb to provide a three point grip. Although tenodesis splints have been used for polio, neuro-muscular diseases and arthritis sufferers, this type of splint finds particular application in providing return of hand function to $C_{5,6}$ and $C_{6,7}$ quadriplegics.

The $C_{5,6}$ quadriplegic usually has good residual functional ability in the extensor carpi radialis muscle - one of the muscles associated with wrist extension. This muscle may be inspanned to provide active finger flexion when the patient extends his wrist. The residual musculature innervation of the $C_{6,7}$ quadriplegic permits active wrist extension and flexion; thus both finger flexion and extension are available to the quadriplegic. Referring to figure 5.2 it can be seen that the length of the lever which links the movement of the wrist and metacarpal-phalangeal joints determines the degree of wrist extension at which the fingers and thumb are opposed. The longer the lever, the greater degree of wrist extension is required to attain opposition of thumb and forefingers. Engen[7] of the Texas

Finger Flexion
with Wrist Flexion.



Finger Flexion with
Wrist Extension.

Fig. 5.1. 'Handy Hand' After Schottstaedt

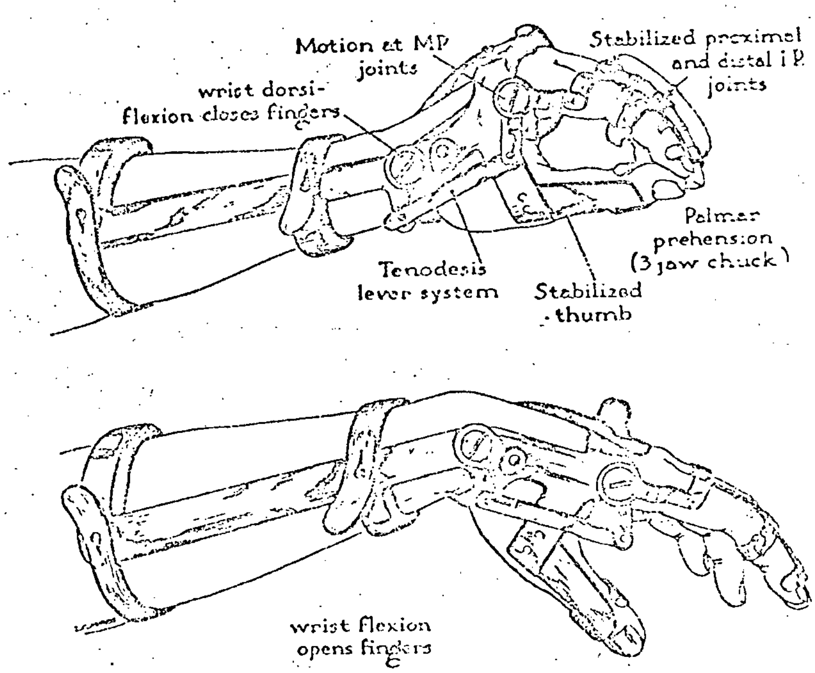
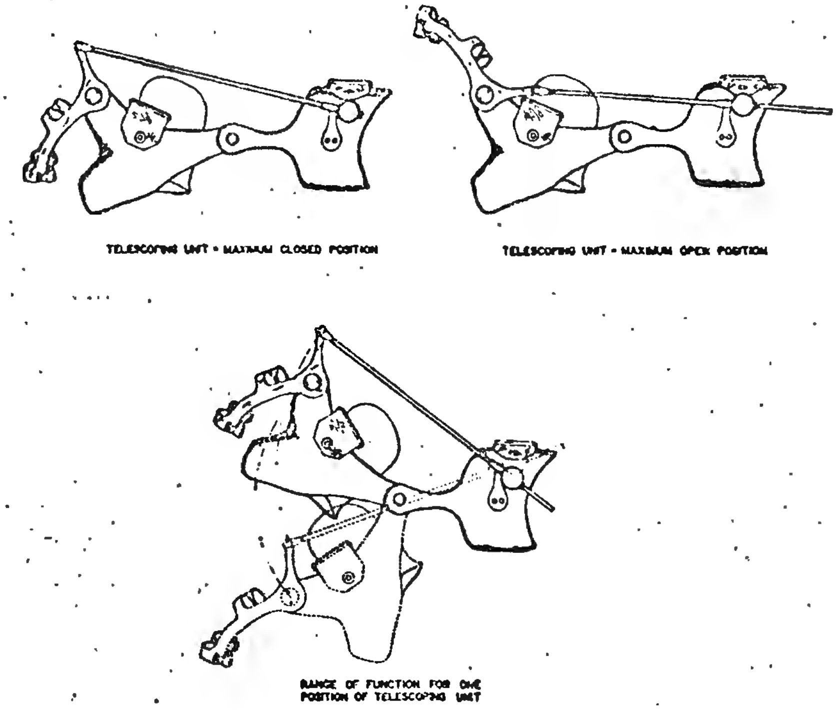


Fig 5.2 Flexor Hinge Splint (after Nickel et al)

Institute of Rehabilitation and Research was the first to provide a mechanism whereby the effective length of the inter-linking lever could be simply and easily adjusted (fig. 5.3a). Engel et al[8] also described a tenodesis hand splint with adjustable connecting lever (fig.5.3.) The advantages offered by the incorporation into the splint of an adjustable lever length extend to a marked degree the usefulness of the flexor hinge hand splint. The wearer is able to grasp objects and hold them at attitudes of wrist extension most convenient to himself. Further, by changing the length of the lever, he is permitted to pick up and hold both small and large objects. These splints are good example of 'adaptive' devices.

The basic differences between the Engen and Engel type flexor hinge splints lies in the materials used for their construction. The Engel splint is constructed solely from metal components; stainless steel and aluminium being used throughout. The metacarpal arch support and finger and thumb pieces have to be individually fitted to each patient and since all these components are made out of metal, it takes up to 40 hours of a skilled orthopaedic technician's time to fabricate a hand splint after the design suggested by Engel.

The simplicity of design, and the ease whereby fitting may be accomplished using an Engen type hand splint, make it the splint of choice in almost all instances where active wrist extension and/or flexion is to be harnessed to provide finger movements. The splint consists of a plastic moulded hand cuff which provides palmar support for the metacarpal arch, also a thumb support is integrated into the hand cuff, the thumb being held in a "posted" position against which the 3 jaw chuck grip is stabilised. Web space is preserved by the inherent construction of the hand cuff. The cuff is so fashioned that it extends laterally over the wrist joint and the metacarpal phalangeal joint. It is fibreglass reinforced at these locations to permit the inserting of aluminium joints about which a simple forearm



(a)

(b)

Fig. 5.3. Tenodesis Hand Splint after (a) Engen[3] and (b) Engel et al.[8]

piece and a finger piece may swivel. The forearm piece is fashioned from aluminium and provides a stable component onto which the adjustable length connection lever or telescoping rod may be mounted. The finger pieces, hand cuffs and forearm cuffs are commercially available(') in four different sizes. The size which best fits the patient is thus chosen from a stock of components - this greatly facilitates fitting. Fitting of the forearm cuff and finger pieces are the most time consuming procedures; any adjustments of fit that need to be made to the hand cuff are simply effected using a heat gun. The total length of time taken to fabricate an Engen orthesis should not normally exceed four hours.

The splint is light in weight, requires little maintenance and if properly finished off is cosmetically quite acceptable. Further, even $C_{5,6}$ quadriplegics are able to put on their ortheses unaided. Velcro fasteners are used to stabilise and position the forearm and hand cuffs, and anchor the digits in the finger piece.

5.3.1. Splint Acceptability

Because of the excellent function available to the $C_{5,6}$ and $C_{6,7}$ quadriplegics who are fitted with flexor hinge splints, the rate of patient rejection of this equipment is extremely low. In the writer's experience gained in having directed nearly 90 Engen tenodesis hand splint fittings, only a hand full of patients elected to do without their appliances completely. Of those patients who did reject their equipment, most were fitted after extended periods of time had elapsed after having suffered quadriplegia and none was able to manage more efficiently without his splint. Prior to 1969 a number of patients were fitted with stainless steel flexor hinge hand splints. To the best of the writer's knowledge not one of these splints is in use today.

5.3.2. Splint Modifications and Adaptations

Because quadriplegics who must use a tenodesis type hand splint usually have only extensor carpi radialis with which to power the splint, wrist

(') Orthotic Systems Inc., Houston U.S.A.

movement is sometimes accompanied by excessive radial deviation of the hand as the wrist is extended. This movement if restrained, inhibits the power output of the wrist extensors and consequently reduces the efficacy of the splint. Allowance must therefore be made to facilitate radial deviation in wrist extension. Such adaptations are not possible if Nickel or Engen type designs are used for splint construction. With the Engen type orthesis however, insertion of a spring steel link of about 2" long between the forearm and hand cuffs and the mounting of the extension rod on a swivel mechanism permits adequate radial movement. About 10% of quadriplegic patients who may benefit from the use of flexor hinge splints require this kind of adaption.

Writing attachments are usually provided on the splint to facilitate maintenance of grip on a pen or pencil. A metal, plastic or rubber ring is attached to the finger piece and the pencil or other writing implement is passed through the centre of the ring. Plastic or rubber rings are recommended since such a ring that is slightly undersized will stretch to accept pens or pencils of a somewhat larger diameter and will thereby provide extra stability of grip. Further, metal adaptations do not permit movement of the pen or pencil in the longitudinal plane. This might be required in order to provide the patient with a more comfortable grip; plastic or rubber holders will permit this movement. Orthoplast('), a commonly used splint making material, is admirably suited to this purpose. The photographs in figs. 5.4 and 5.5. indicate how such writing rings may be attached.

A serious disadvantage of most tenodesis type hand splints is that patients are unable to push their wheelchairs efficiently whilst wearing their splints. Since all of the splints described above have components which extend over the palmar surfaces of the hand, there is diminished traction

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(') Manufactured by Johnson & Johnson

Fig. 5.4. and Fig. 5.5. Writing ring attachment to Splint.

between the metal or plastic orthesis components and the wheelchair rims or wheels. If the patient requires to move some distance in his chair, it is thus advisable for him to remove the splints to effect more efficient wheelchair propulsion.

Attempts to increase traction between splint surfaces and wheelchair rims were made by vulcanising the palmar surfaces of the hand cuff segments of the Engen type flexor hinge orthesis. While a successful bond between rubber and plastic was accomplished (using the technique described in section C of the Appendix), wheelchair dexterity though much improved with splints having rubberised forearm cuffs, was not of such quality as to completely satisfy patient needs.

For patients who were required to handle sheets of paper in their day to day activities, vulcanising of specific areas on the thumb support section of the Engen orthesis proved very useful. The lateral part of the thumb-piece is rubberised so that papers may be gripped and sorted with greater ease and speed.

5.3.3. Flexor Hinge Splints for Weak Extensor Muscles

Figure 5.6 illustrates how an Engen type hand orthesis may be adapted to permit functional finger movement by wrist extensors that are little more than 2+ grading (Oxford Standard). The particular patient for whom this splint was made did not have full range of movement against gravity of the extensor carpi radialis muscle, and was able to lift her wrist from a position of total flexion to the neutral position only. No active dorsi-flexion of the wrist was possible. A coil spring was inserted between the forearm cuff and the hand piece to provide supplementary movement and power to the driver muscle. The tension of the spring was adjusted so that when the wrist extensor muscles were totally relaxed, and the forearm was pronated the effect of gravity was just sufficient to cause the splinted wrist to be flexed, thereby extending the fingers. The residual wrist extension movement could thus be utilised to dorsiflex the wrist

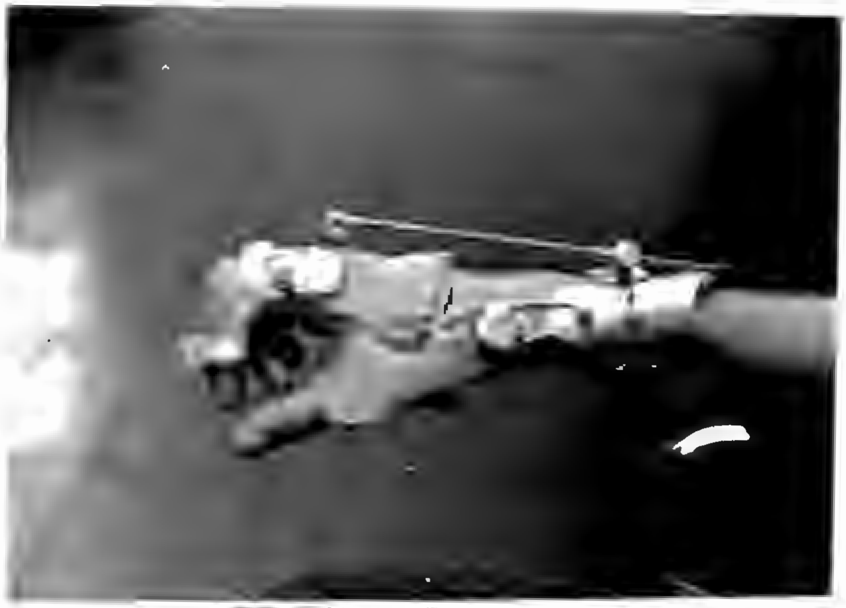

Fig. 5.6. Spring Assist Adaptation of Flexor Hinge Splint

Fig. 5.7. Stiff Metal Wire Writing Splint

since gravity was effectively 'eliminated' by the spring tension. Provided gravity is used to extend the fingers, functional movement is available even if weak extensor carpi radialis muscles are present.

5.4. STATIC HAND SPLINTS

A large variety of static type hand splints have been devised over the years. These splints are used to accomplish specific tasks where movement in the body segment is not required. For example, splints made from stiff metal wire are constructed to permit the quadriplegic to hold a cigarette. The wire is bent around the patient's fingers and a loop is formed through which the cigarette is held; figure 5.7 shows a patient using a writing splint constructed after this fashion. Shaving splints, eating splints and host of many other unsophisticated appliances may be made for the quadriplegic. For the quadriplegic who has at least residual active wrist extension the devices described above are strongly contra-indicated. As pointed out elsewhere, the low functional nature of these splints inhibit the multifunctional capacity of the patient, since by their very nature they are designed to facilitate the execution of a specific task to the exclusion of all others. It is far more efficient to make minor adaptations to a dynamic functional orthesis, i.e. to add attachments to the basic orthesis, to facilitate activities which the patient might find difficult to carry out. Where there is no active wrist extension or flexion, and where the patient does not use a powered splint, the use of passive type splints is recommended. Their use cannot further inhibit the patient's low residual capacity.

5.5. ORTHESIS FOR EXTENSION AND FLEXION OF THE ELBOW

The $C_{4,5}$ or higher lesion quadriplegic is most likely to require the assistive properties of orthesis developed to facilitate elbow extension and flexion. These splints find application where there is insufficient residual function in the biceps to effect elbow flexion. The forerunner of the body powered orthesis used presently to supplement weak elbow movements, was probably the Barker feeder (after the patient for whom it was devised) developed at the Georgia Warm Springs Foundation in June 1936[9]. The device consisted basically of a forearm channel mounted on a hinge on which the forearm could pivot in see-saw fashion. The mechanism was mounted on a table or onto the patient's lapboard and was operated by the patient elevating or depressing his shoulder. This resulted in the elbow being extended or flexed. Subsequent variations in the design of the splint included suspending the forearm channels from trapeze like yokes attached to an overhead suspension mechanism extending from a mounting on the back of the wheelchair. Since these devices were used mainly for facilitating feeding they were known as 'feeder mechanism'. Figure 5.8 shows the construction of a feeder mechanism(') in common use today. A suspension arm mounted on a suitable friction free joint attached at the back of the patient's wheelchair forms a stable base onto which the hinged forearm trough and its pivot may be connected. Joints A and B are constructed using ball races to minimise friction and permit freedom of movement in the horizontal plane. Aside from see-saw vertical movement the trough may also swivel in the horizontal plane. An elbow back-stop is provided to prevent the forearm from slipping out of the orthesis when the elbow is fully flexed. Provision is made to facilitate the positioning of the forearm trough pivot to suit the requirements of different patients.

It is important when using the ball race feeder mechanism that the functional capacity of the patient be correctly assessed and that by correct angular adjustment of the wheelchair mounted pivot A, that the needs of the patient are adequately catered for. The residual muscular strength particularly of the biceps will normally determine whether the trough should be pivoted so that it is 'elbow heavy' or 'hand heavy'.

(') Jaeco Orthopaedic Specialists. Arkansas, U.S.A.

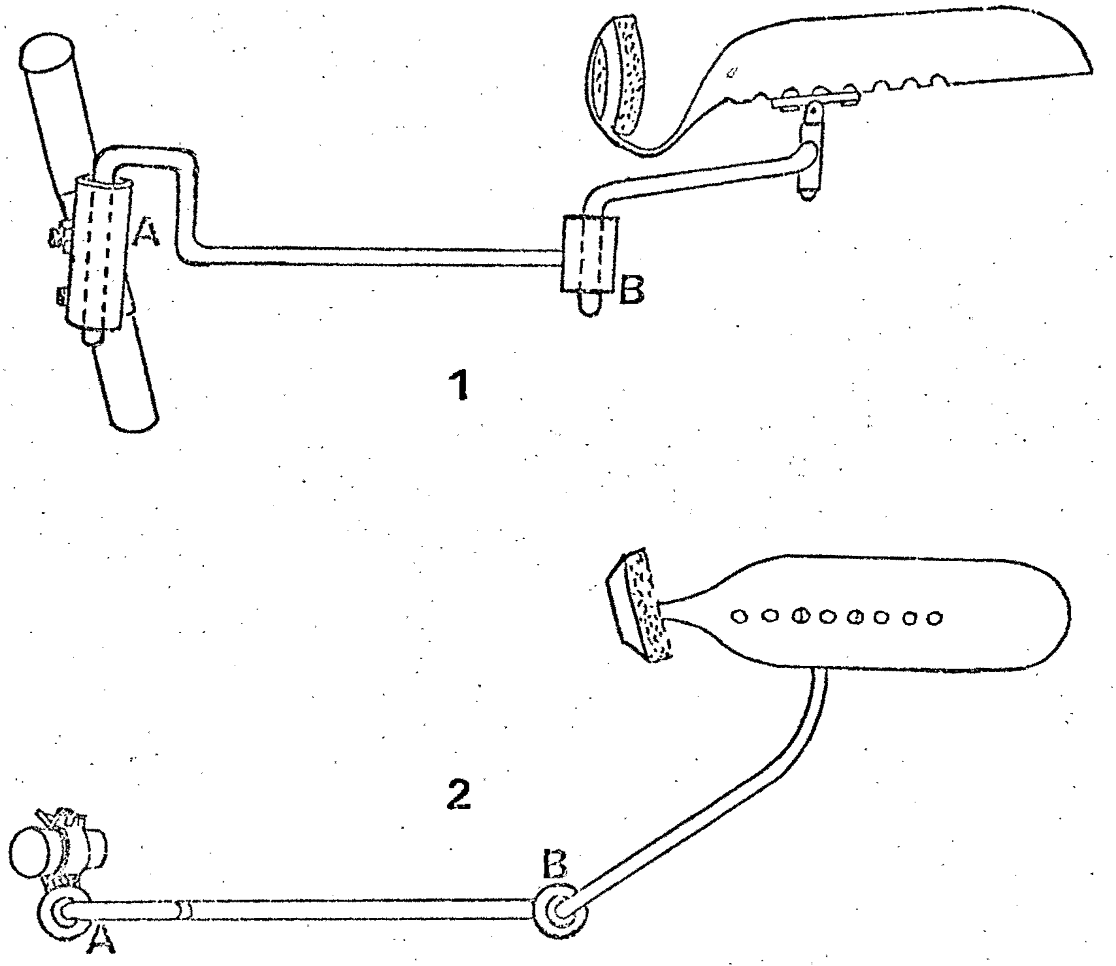

Fig. 5.8. Ball Bearing Feeder Orthesis

The exact criteria whereby ball bearing feeder ortheses (B.F.O.) may be efficiently set up have been well documented elsewhere(10); Kay and Appoldt(11) have reviewed the type of BFO devices available and the reader is referred to the above sources for further information.
While BFO's can be applied extensively to quadriplegics, the writer has not made much use of these techniques for supplementing residual patient movement. A somewhat different appliance is preferred and is described as part of a composite orthesis providing motorised prehension, in Chapter 6 (of page 128).

5.6. ORTHESES USED AS CORRECTIVE MEASURES

5.6.1. Ortheses may be applied to correct deformaties due to contractures in both the fingers and elbow. These splints are usually spring loaded so that traction in a direction which will minimise the effect of the contracture may be applied. In applying traction to joints that are deformed by contractures it is to be noted that less traction over extended periods of time is more efficient than strong traction over short periods of time.(12)
Special care must be exercised with quadriplegics to ensure that the effect of traction is not damaging to the limb since in some cases the patient is unable to record the painfull effects that indicate damage. For the same reason when applying traction splints, care should be taken to avoid excessive pressure at any point to prevent the formation of decubiti.
The splints first suggested by Bunnell(2) are still used for the correction of flexion contractures of the hand. These use elastic bands or spring steel components to effect active traction.
Stretching of flexion contractures of the elbow may be treated by using non-conforming passive orthesis made out of plaster of Paris bandages. The orthesis is non-conforming in that it does not fit the body segment precisely and it is so shaped that when it is strapped onto the patient's

arm it forces the elbow into less of a degree of flexion. As the contracture is diminished, successive splints are made to maintain corrective traction. In another splint designed to correct flexion contractures of the elbow, turnbuckles are used to increase the tension of the corrective traction[5]. Humeral and forearm cuffs are fitted to the patient and the turnbuckle mechanism is anchored between these two segments. The above splints are usually applied at night so that what movement is available to the patient is not inhibited during his waking hours.

5.6.2. An Active Splint for Contractures of the Elbow

Figure 5.9 illustrates a splint designed by the writer to exert active traction on flexion contractures and also to permit active flexion of the elbow. The splint consists of a forearm and humeral cuff which are hinged together at the elbow joint. Velcro fasteners are used to hold the splint in position. The hinge is spring loaded using a heavy coil spring. The tension of the spring may be increased or diminished by tightening or releasing an adjusting screw mechanism on the side of the spring assembly housing. A protective elbow guard (to prevent the formation of pressure sores at the olecranon,is provided so that the patient may rest on his stomach and prop himself up on his elbow if he so desires. Extremely good results have been achieved using this plint and its use can be recommended. Full constructional details of the device are supplied in Appendix D.

The wearer is permitted to retain active use of his arm at all times when wearing the splint and thus may wear the splint continuously, not only at night. Simulated triceps movement is available to the patient by using the spring loaded orthesis movement as antagonist for biceps movement. Motions such as grooming, and holding objects in elbow extension e.g. holding a book in front of ones face when lying supine, are thereby facilitated. When the patient is confined to bed such movements are most useful. Quadriplegics, however, manage adequately without the use of

Fig. 5.9. Splint to Facilitate active Traction of the Elbow

triceps when they are up in a wheelchair; the use of this splint is thus somewhat limited in its application as a method of providing artificial triceps.

5.7. REVIEW OF SOME ORTHESES POWERED BY REMOTE MUSCLES

A number of splints have been designed using body power derived from body parts that are comparatively remote from the splinted body segment. Kabat and Rosenberg(13) describe a hand splint for a $C_{5,6}$ quadriplegic patient who has not more than a 2 grading (Oxford Scale) of muscle power in the wrist extensors but who still have good biceps with which to position their arm. The principle of operation of the splint is similar to that in which the cable and harness controlled prothetic hand operates. Elevation of the scapula or abduction of the shoulder causes retraction of a cable against a spring loaded articulating finger piece of the orthesis, thereby causing finger extension. On relaxing the shoulders, spring tension returns the index and middle fingers to an attitude of opposition with the thumb. The cable control may be attached to a figure of 8 harness about the scapulae or if the cable is mounted on some convenient part of the wheelchair, elevation of the scapula is required to operate the device. Care must be exercised in using an orthesis of this kind since the fingers and thumb are in a continuous state of opposition. A quadriplegic with a lesion as high as to necessitate his having to use an appliance of this nature, has no sensation in his hand and thus pressure sores may develop if the spring tension controlling opposition is excessive. Further, most quadriplegic patients do not have good postural balance in their wheelchairs, and it is thus not uncommon to find a quadriplegic sitting with one arm hooked behind the handle on his wheelchair to supplement his balance. If shoulder harness cable controlled splints are to be used, a prerequisite for good function is controlled and accurate shoulder girdle function. This is not usually possible in quadriplegics of high lesions.

Schottstaedt and Robinson(5) described a technique where prosthetic hooks (of the Dorance type) operated by scapulohumeral forward flexion and abduction was used to provide return of function to a C_6 quadriplegic. The hook was mounted in the palmar part of the hand of a patient who lost the use of wrist extension and passive finger movements as a result of an unsuccessful surgical procedure. Although good results were predicted using this technique, no follow-up information was published.

Jones and James(14) presented an orthesis driven by elbow extension. A leather humeral cuff is strapped around the patient's biceps and with the elbow in about 90^o of flexion a cable is attached from the cuff to the finger piece of a hand splint. The finger piece is spring loaded so that the fingers are held in opposition with the posted thumb. Finger extension is accomplished by extending the arm using gravity or by supinating the arm. Either of these movements causes the cable to be stretched thus extending the fingers. The comments made above regarding the problem of pressure sores when using Kabat and Rosenberg's splints apply equally in this case. Further, since the patient has to rely on gravity to extend his wrist or on supination for splint operation it is difficult to see how accurate grasping of an object is accomplished and it is doubtful if the degree of success reported is consistently attainable in practice.

It is the writer's opinion that unless active wrist extension or flexion is available, body power cannot be utilised to drive prehension ortheses; external power must be provided in such cases.

5.8. SURGICAL PROCEDURES USED TO IMPROVE MOVEMENT IN THE QUADRIPLEGIC HAND

A number of surgical procedures have been suggested to improve the functional capacity of quadriplegics with residual muscular power in the forearm. Arthrodesis of the wrist joint of the $C_{5,6}$ quadriplegic, i.e.

surgical immobilisation of the wrist, in a functional position of slight dorsiflexion, and transfer of the tendons of the wrist extensors to the tendons controlling finger flexion is commended by some(5) . Bunnell(15) considers wrist movement to be too valuable a function to sacrifice for finger flexion and maintains that since there are no finger extensors no real benefit can be derived from wrist arthrodesis and such tendon transfer procedures.

Tenodesis of the finger flexors(15) is by far the most popular and successful surgical procedure applied to the hands of $C_{5,6}$ and $C_{6,7}$ quadriplegics. The tendons of all the flexor digitium profundus together with the flexor of the thumb (pollocus longus) are fastened to the radius (usually beneath a volar cortical flap of bone and secured with the aid of pull-out wires). The wrist is maintained in a flexed position with the fingers extended when the tenodesis is carried out. On extension of the wrist, the fingers automatically flex thereby providing a grasping action for the patient.

To supplement the automatic movement by providing some direct voluntary flexion, the brachio radialis muscle may be attached to the tenodesed tendons at a point just lower than their insertion at the radius. Alternately if the patient only has weak wrist extensors branchio radialis may be used to supplement wrist extension. To provide opposition of the thumb, abductor pollicis breves is attached (by tendon graft) to the ulna (cf figure 5.10).

Nickel and Perry(16) describe a somewhat different procedure to provide a "flexor-hinge hand". A bone block is inserted at the thumb and it is fused permanently in a position of opposition. The interphalangeal joints of the first and second fingers are also fused in functional positions. Standard tenodesis is then performed to provide powered flexion of the fingers. For the C_7/C_8 quadriplegic Bunnell(15) suggests a whole series of tendon transfers to provide flexion of the digits and thumb.

Whilst a measure of hand movement is returned to the patient, it is the

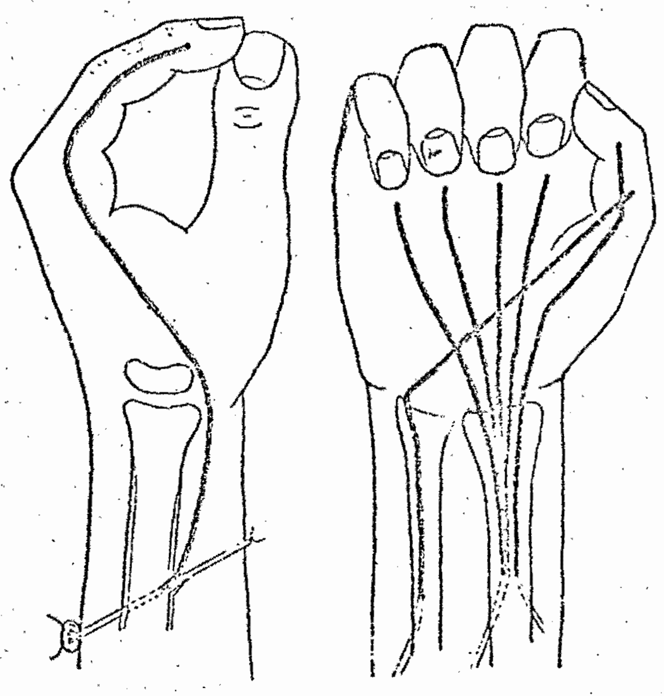

Fig 5.10 Tenodesis of Finger Flexors after Wilson(4)

writer's experience as an objective observer, that for quadriplegics surgical tenodesis procedures are not sufficiently successful to provide efficient hand function. Muscle transplants, such as the use of brachio-radialis to supplement weak wrist extension, are also not usually successful. The measure of added functional capacity obtained when using tenodesis type ortheses by far exceeds the benefit that may be derived from current surgical corrections.

The main objections to surgically facilitated movements are:

1) the movement of the digits are not adequately directed and it is thus not possible to obtain an accurate three jaw chuck or pincer grip by thumb and finger opposition;
2) the degree of wrist extension required to accomplish finger flexion is fixed at the time of surgery and cannot be changed to accommodate more comfortable gripping attitudes;
3) there is a risk that adhesions of transferred tendons may form thus further limiting functional hand movement.

5.9. COMBINATION OF SURGICAL AND ORTHOTIC TECHNIQUES

The writer considers that there is merit in the judicious combination of surgical and orthotic techniques for quadriplegics who are able to dorsi-flex their wrists. Part of the technique suggested by Nickel and Perry(16) could be used to provide improved function of the hand when used together with a flexor hinge type splint. Fusion of the thumb in addition to arthrodesis of the interphalangeal joints would make for more efficient splint function. The thumb should be fused in an attitude of internal rotation to permit grasping of objects with the pulpy surface of the thumb. Support of the metacarpal arch could be provided by using a modified form of handcuff after the Engen design; no thumb support would be necessary since this would be provided surgically. The finger piece and the telescoping rod which permits wrist angle adjustment, could be attached to the arthrodesed fingers to provide prehension in the usual way.

5.10. CINEPLASTIES TO PROVIDE INTERNAL BODY POWER

No mention is made in the literature of the possible functional benefits that may be derived from cineplastic type operations to drive prehension ortheses. Cineplasties have been used in the past[17] to provide motor power for upper limb prosthetic devices. The residual movement in for example, the wrist extensor or flexor muscles of a mid-forearm amputee are inspanned to operate finger prehension in an artifical limb. A tunnel is surgically fashioned through the muscle which is to provide the motor power. This tunnel is lined with skin and once the body has recovered from the surgical procedure, a dowel-pin is passed through the tunnel. This pin moves up and down with the muscle as it changes its length when contracting or relaxing. The movement is transmitted to the prosthesis by means of a Bowden cable or by connecting linkages. It might be worthwhile to use a strong brachi-radialis muscle to provide extension or flexion of the digits in a spring loaded hand orthesis. A device of this nature would be particularly useful for quadriplegics who are unable to operate the wrist driven flexor hinge splint and if successful this technique would provide a measure of proprioceptive feedback which is not available with powered splints.

5.11. USE OF ORTHESIS TO CONSOLIDATE SURGICALLY PROVIDED FINGER MOVEMENTS

A C_6 quadriplegic, underwent surgery to one arm in which the wrist was arthrodesed and action of the extensors of the wrist were transferred to the flexor profundus tendons. The result of the operation was that the patient was able to attain gross finger flexion. The movement was rendered non-functional, however, since there were no active means whereby the fingers could be extended. An orthesis was constructed for the patient using an Engen type hand-cuff to which a finger piece was attached. A coil spring was attached to the finger piece which extended the fingers when the patient relaxed his (flexion)grasp, (fig. 5.11) The patient was satisfied with the results of the combined surgical orthotic procedure and he is reported to have attained good proficiency in the use of his hand.

This particular case provided an opportunity to compare return of hand function provided by surgical means, with that provided using a standard flexor-hinge fitting. The functional capacity of the hand fitted with the flexor-hinge splint was superior in every respect.

In 1956, Schottstaedt and Robinson[5] concluded that "functional bracing of the arm should not supercede reconstructive surgery for upper extremities. A reconstruction if properly perceived and executed is always superior to the use of external appliances. However, functional bracing of the arm will occasionally serve to supplement surgical results." Advances in both functional body powered and externally powered appliances no longer justify the acceptance of these views.

5.12. SOME ADDITIONAL REMARKS ON SPLINT FITTING

5.12.1. Splint Manufacture

All standard splint fittings should be carried out by a certified orthopaedic technician. When more complicated fittings are required, the bio-engineer should be consulted to direct alterations to existing splints or to implement new designs. In many centres throughout the world, the Occupational Therapist has assumed the role of an impromptu splint maker - this practice is to be discouraged since the simplistic techniques that are within the therapist's ability revolve about the provision of low variety type splints. The effect of the use of such devices for a quadriplegic with a comparatively low spinal lesion has been detailed elsewhere. The occupational therapist should be requested to contribute to the actual making of the splint where an adequate bio-engineering service, or where orthopaedic workshop facilities are not available.

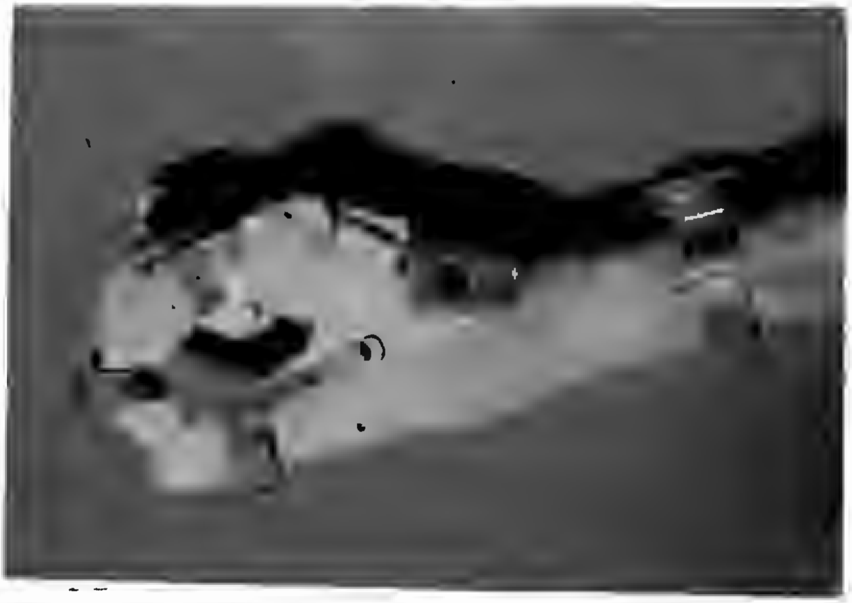

Fig. 5.11.

5.12.2. Pre-Fitting Patient Education and Training

It is most important that the patient be made to realise the extent to which he may benefit from his appliance. Even before he receives his own splint he should be able to make an accurate assessment of his ultimate capabilities. To this end, it is advisable to show the patient how a splint similar to the one he is to be fitted with, operates, and if possible, to have another patient proficient in the use of this equipment demonstrate its function. In this way it is hoped to stimulate the patient and to encourage him to look forward to receiving and using his splint.

For patients who are to be provided with externally powered ortheses, it is considered useful to ensure that the patient is familiar with the method by which the control of his splint is to be effected. If myo-electric control (Chapter 6) is contemplated the patient must be taught how to contract his control muscles correctly and if switch or other transducer mechanisms are to be used, the patient must be able to elicit the appropriate movements with a minimum of effort.

Muscles which are to be used to provide movement for body powered ortheses should be strengthened by both isometric and isotonic exercises to ensure that maximum function will be transmitted to the splinted body segments. The use of the Myo-electric Signal Monitor described in Chapter 3 is most appropriate for this purpose. This instrument is used mainly for muscle strengthening through isometric contractions and is particularly useful for monitoring movement in weak muscles (1-3 Oxford Standard).

Isotonic movements of weak upperlimb muscles may be facilitated by suspending the limb in overhead slings to eliminate the effects of gravity. Strengthening and improvement of movement of the Gleno-humeral joints, shoulder adduction, and elbow extension and flexion, may be effected using this simple procedure.

5.12.3.

Once the patient has received his splint he is to be encouraged to make use of it to as great a degree as possible. If cannot be expected that he will wear his appliance constantly during all his waking hours immediately, as initially he will experience difficulty in adjusting to the way his splint operates; in the words of Long[18] "implicit in increased wearing time is increased use of the splint".

The occupational therapist should devise a training programme to facilitate patient proficiency in the use of his equipment. Early training programmes should be carefully structured so as not to set up goals for the patient that are beyond his present capability. The therapist should thus instruct the patient how to accomplish more of the requirements of daily living at each successive training session.

Amongst the first skills that the occupational therapist must teach the patient, is how to put on and take off his splint unaided. (This is possible only with patients who are able to operate wrist driven flexor hinge splints). This is necessary so that the patient will not be unduly inhibited should he wish to push his wheelchair or carry out other activities which he could more easily effect without the use of his ortheses.

When the patient has mastered the basic functions of his splint, it is propicious to call a round table meeting of all hospital personnel involved with the patient on a day to day basis. The functional capacity of the patient should be outlined at this meeting as well as what the patient is expected to accomplish independently with the use of his splints. It should be impressed upon all those present that if the patient is to derive the maximum benefit from his equipment, he should be encouraged to carry out all tasks that he is technically able to accomplish, without aid from any quarter. He is to feed himself, attend to his grooming etc., provided that these activities are within the limits of his functional capacity.

Those who are directly responsible for patient care should be instructed how the splint is to be put on (if the patient is unable to do so himself) and how to make any non-structural adjustments to the patient's equipment. For example, the nurse who will help the C_4 patient dress in the morning should be shown how to put the patient's splint on, how to switch power to the prehension actuator and how to adjust the gain of the control system. Also, the danger signs which indicate prolonged pressure or poorly fitting splints which may ultimately result in a pressure sore on some part of the patient's anaesthetic hand, should be pointed out. It is vital that the patient's family be advised of his ability and that they too be requested not to provide unnecessary aid and to keep a watchful eye for any causes of pressure sores.

It is necessary to create a congenial and positive, though not authoritarian, atmosphere within which the patient is to be encouraged in the use of his orthesis. Further it is essential to impress upon all those who come into contact with the patient, that they have a direct contribution to make in promoting the patient's independence and his ultimate physical and mental well-being.

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CHAPTER 6

EXTERNALLY POWERED FUNCTIONAL SPLINTS

6.1. INTRODUCTION

The use of external power is indicated where body power is not available for driving functional hand and arm ortheses for quadriplegics. Approximately 15% of quadriplegics have lesions that are sufficiently high to necessitate the use of externally powered appliances for prehension and/or other arm movements.

The limitations of powered orthotic systems have been outlined in section 4.5. above and were ascribed basically to a lack of efficient man-machine communication. Thus, while sophisticated electronic control systems may be devised to provide natural life-like movements of splinted hands, the control information that the patient is able to generate for control. is of such low quality that system operation is severely inhibited.

Practical externally powered orthotic systems, i.e. powered ortheses that are within the financial means of most rehabilitation services, are therefore simplistic in their operation and cannot provide as much return of function to the quadriplegic as is necessary.

A number of different control concepts have been used in powered systems designed to provide return of function to the disabled and some of these will be examined below to ascertain their functional use for quadriplegics. However, it is first necessary to investigate the means whereby quadriplegics are able to generate control signals for orthesis control.

6.2. CONTROL MEDIA AVAILABLE TO THE QUADRIPLEGIC

It is a truism that the more severe the extent of quadriplegia the less control sites are available from which suitable signals may be obtained. Further, the quadriplegic patient who has suffered damage to his spine such that he requires externally powered ortheses, uses much of the residual upper limb and trunk movements to maintain his postural balance in his wheelchair.

Thus the quadriplegic has very little functional capacity to devote to orthesis control; the most that one could hope for would be small excursions of body segments to provide on/off type control signals.

Light beam switches, lever switches, and micro-switches in different housings and mounted in various configurations, and which rely on movement of body parts for their operation have been used to provide control of ortheses.

Much attention has been centered on the use of myo-electric signals as a means of providing orthesis control. Since subjects are able to elicit different levels of myo-electric activity, such a control source might be used to provide continuously variable control for externally powered systems.

6.3. MYO-ELECTRIC SIGNALS IN THE CONTROL OF POWERED SYSTEMS

Early myo-electric control systems were used for mid-forearm amputees(1). In the logical course of events this method of control was extended for use with appliances for above elbow amputees, lower limb prostheses, and for control of orthotic devices for patients who has lost control or effective use of their upper limbs.(2)

The mid-forearm amputee has remaining wrist extensor and flexor muscles from which two separate control channels may be derived. Since generally there is no pathology associated with the muscles themselves, both control sites are of extremely good quality as far as signal to noise ratio is concerned.

Discrimination between channels is excellent because of the anatomical separation of the muscles. Further, once the arm has been amputated, there is no practical use for the wrist extensor and flexor muscle groups. These muscles, which to all intents and purposes are redundant, are ideal for use as control sites for externally powered appliances. Unfortunately there are no such high quality redundant control muscles in the case of the high lesion quadriplegic.

6.3.1. Selecting the Control Muscle.

Opinions vary greatly as to which part of the remaining musculature of the quadriplegic is most suited to providing myo-electric signals for splint control. Whichever muscle is chosen the factors detailed below determine the reliability and efficiency of the control site:-

1) Volitional contraction of the muscle must be easily accomplished and must be such that it is not accidentally triggered by accessory movements of the body.

2. The myo-electric signal output must exceed $\pm$ 100 μv (at maximum contraction) since weaker signals of low amplitude necessitate over elaborate techniques of signal processing.

3) The quality of the signal available from the control muscle should be such that various levels of e.m.g. activity can be volitionally generated thereby permitting the use of level discriminating circuitry in the control system.

4) Artifact noise and spurious signals such as crosstalk from adjacent muscles which are being utilised for movements not associated with splint control, should not account for more than about 30% of the monitored signal at any one time. Interference greater than this amount could lead to a degradation of the reliability of the system.

In an attempt to ascertain which of the remaining functional muscles of a $C_{4,5}$ quadriplegic are most suited for providing control signals, Miller et al[3] investigated three muscles. There were:-

i) the upper trapezius - muscle associated with shoulder elevation,

ii) the frontalis - muscle associated with raising the eyebrows, and

iii) the platysma - muscle associated with depressing the jaw and wrinkling the skin of the neck.

The trapezius was found to be the most unsuitable of all the muscles tested since the patient employs this muscle in maintaining his balance in the wheelchair and in assistive movements of the arm. Control of the frontalis could be effected adequately; however, movements such as tensing the jaw or closing the eyes tightly introduced spurious signals. Also the situation of electrodes over the forehead was considered cosmetically unacceptable. Of the three muscles investigated the patysma was found to be the most appropriate for use as a control site. Although movements associated with swallowing, turning the head, coughing and clenching the teeth did produce signals in the electrodes over the patysma, the magnitude of these signals were so small that they did not impair the reliability of the control muscle. From a cosmetic viewpoint electrode sites may be chosen in close proximity to the clavicle where these can be easily covered by the patient's clothing.

The possibility of deriving myo-electric control signals from weak - too weak to be of any functional use - extensor carpi radialis muscles have been investigated by the writer(4). Brachio radialis and the supinator muscles lie in very close proximity to this muscle and it is difficult to differentiate between their electrical activity when surface electrodes are used to monitor the myo-electric signal. Only when constraints are placed on the arm movements which the patient may carry out - thereby limiting activity of brachio radialis and supinator - is it possible to isolate the electrical activity of the weak wrist extensor. Weak non-functional though electrically active, biceps muscles have also been used with some success as control sites in myo-electric control systems(5).

6.4. SOME MYO-ELECTRIC CONTROL SYSTEMS

6.4.1. Three State Systems

Since there are few sites available for orthesis control, it has been the practice of researchers to make as much use as possible of each control site. One control site would thus be used for bi-directional control of a degree of freedom of movement of the orthesis. For example, in the case of prehension, the control site would control both finger extension and flexion.

The best known and possibly the earliest control system which provided such economic utilisation of a control site was that described by Dorcas and Scott in 1965[6]. In this system, the amplitude of the myo-electric signal output determined in which one of three modes or states the orthesis motor would be found. The myo-electric signal output and the orthesis motor states were related as follows:-

1) Zero to slight myo-electric activity - orthesis motor stopped.
2) Moderate myo-electric activity - orthesis motor rotates to oppose fingers and thumb
3) Strong myo-electric activity - orthesis motor rotates to extend fingers.

The chief drawback of this three state system is that the patient has no control over the speed or force of the motor output and he must confine the activity of his muscle within narrow bands. Subsequent systems[7] have been developed which provide proportional type control over the speed of operation of the orthesis in one direction of motor rotation. As the patient increases the volitional myo-electric output from the control muscle, the speed of the motor is increased in the forward direction. When the control signal magnitude reaches a preset level, the motor is connected so that its armature current is reversed thereby reversing its direction of rotation. The transition from maximum rotation in the forward direction to maximum reverse rotation may be eliminated by the interposition of a dead zone at the transition point to yield an operating characteristic similar to that shown in figure 6.1b.

Because the motor output state changes rapidly when the myo-electric signal reaches a preset amplitude, a 'smooth' or continuously variable control is

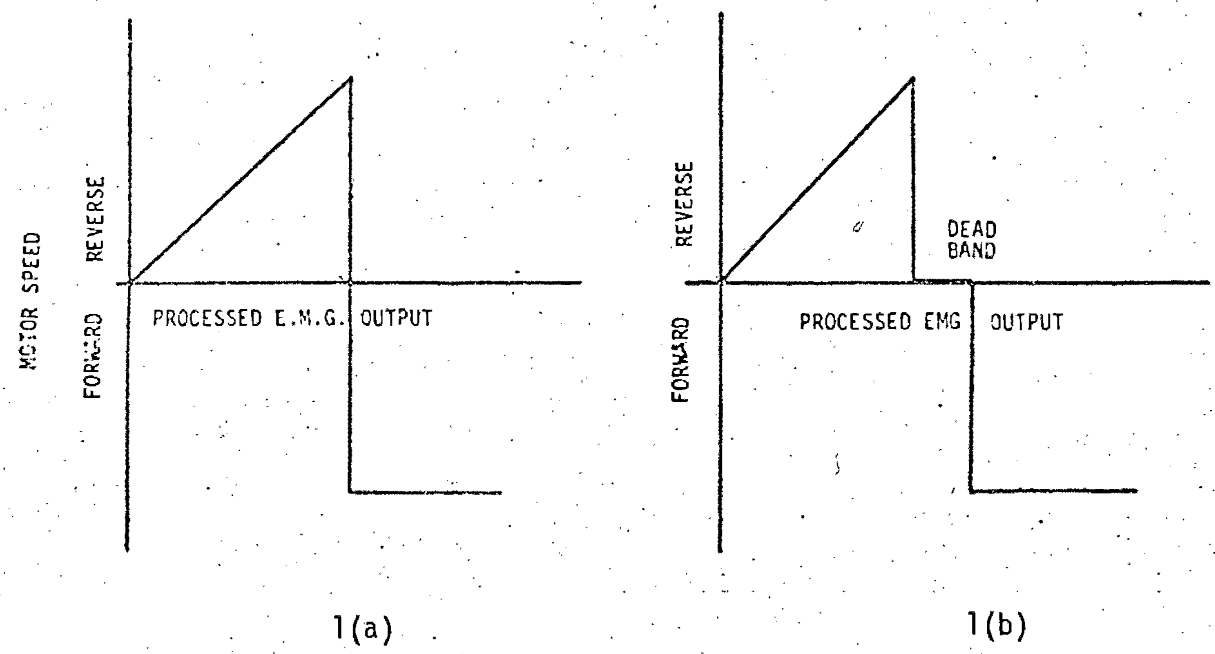


Fig. 6.1. 3 - State Myo-Electric Control Characteristic

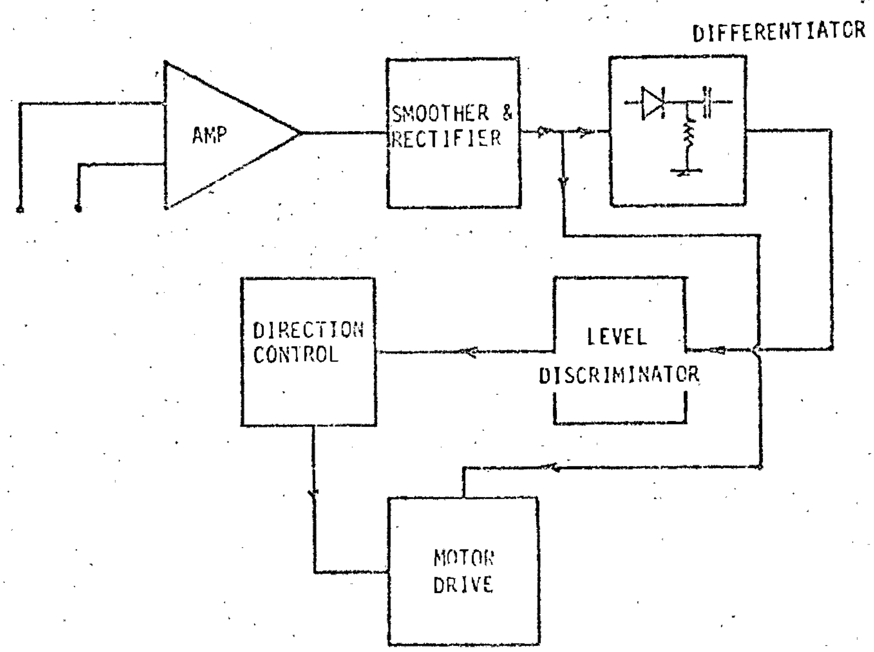


Fig. 6.2. Block Diagram of Improved 3 - State Control System.

not possible throughout the full range of volitional myo-electric signal output. Further the benefits of proportionality that the system affords are lessened somewhat since proportional control is only possible over a diminished band of the control signal output range.

6.4.2. An Improved Three State Control System

The following system was developed by the author to permit the utilisation of the full range of myo-electric signal in both forward and reverse motor directions.(8) System operation is explained with the aid of the block diagram in figure 6.2.

The myo-electric control output is monitored using surface electrodes and is fed to a suitable amplifier. After rectifying and smoothing to obtain a D.C. analogue representation of the myo-electric activity, the signal is passed to a simple differentiating circuit. The differentiator provides an amplitude output signal which is related to the time rate of change of the myo-electric input signal. If the amplitude output of the differentiator is below a predetermined value i.e. if the rate of change of the amplified, rectified and smoothed myo-electric signal is below a predetermined level, then the processor output signal is fed to the motor control to permit the motor operation in the forward direction. Pseudo-proportional control is provided in the forward direction by ensuring that the armature current is proportional to the myo-electric signal input (cf. figure 6.3.)

Should the amplitude output of the differentiator exceed the preset amplitude output level i.e. should the rate of change of the processed myo-electric signal exceed a predetermined value, then the differentiator circuit will channel the myo-electric D.C. analog signal to the motor control in a way as to reverse the motor direction of rotation. (A signal with maximum rate of change is generated by eliciting a quick and strong contraction in the control muscle). Proportional control in the reverse motor direction is a little difficult to achieve, since the patient has to put out a maximal signal to switch into reverse mode, he will thus switch directly into a

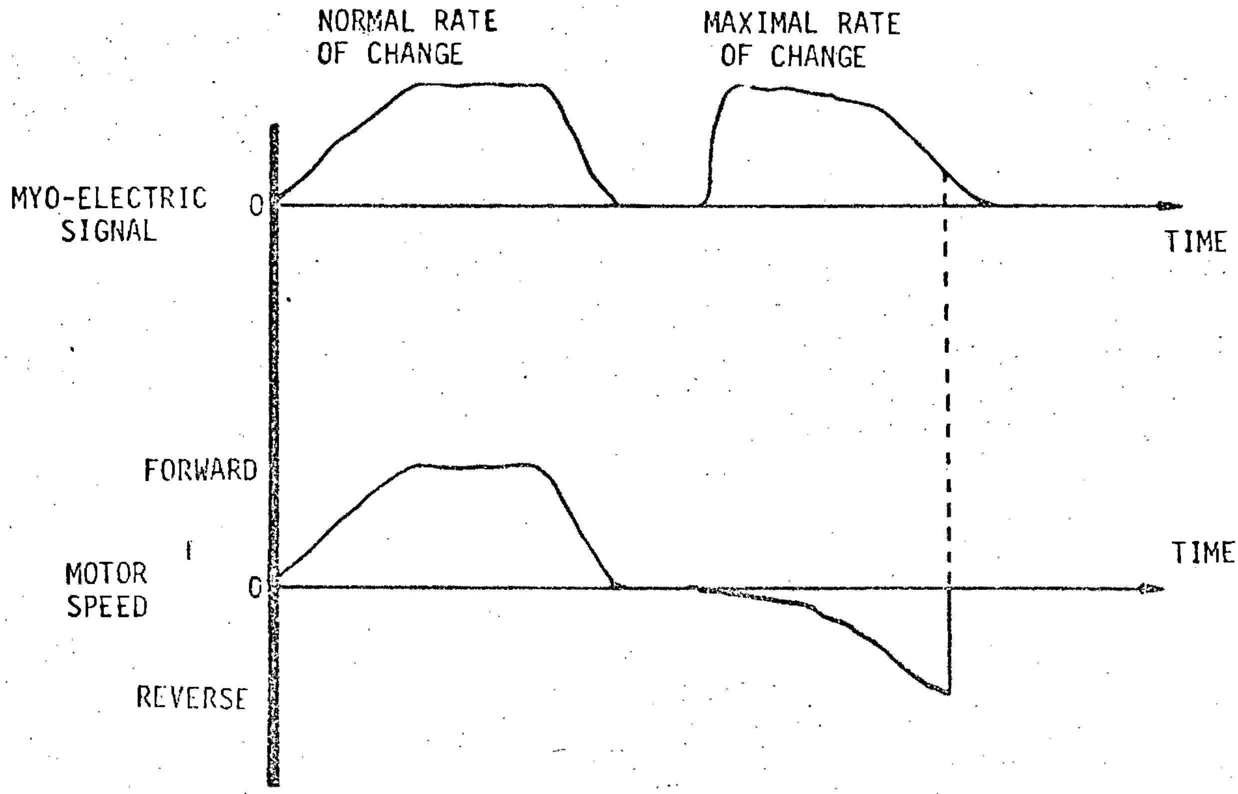


Fig. 6.3. Improved 3-State Myo-Electric Control Characteristic.

condition of maximum speed in the reverse direction. However, by relaxing the control muscle signal immediately after having switched into reverse some proportionality may be made available. To allow for spurious signals generated because of armature commutation noise, or as a result of strong electric fields, a dead band is incorporated into the lower range of the control circuitry; the myo-electric signal must thus exceed a certain minimum value before the control signal will be passed to the motor drive circuitry. Circuit diagrams and component specification are provided in Appendix E. Experience with the above system indicates that patients are able to attain good orthesis control and that they do value the improved proportional facility which the system affords. The success of the system is borne out by it having been adapted for use with externally powered upper limb protheses by Childress[9] and more recently by Silner and Hägg [10].

6.4.3. Sequentially Operated Control Systems

Aside from it being employed in three state control systems, a myo-electric control site may be operated in 'sequential' fashion to provide control over more than one operation. An early sequential system for use in motorised prehension ortheses for quadriplegics was first presented by the writer in 1968[2].

In this system, surface electrodes were connected over weak extensor carpi radialis muscles - Oxford Grading 1+. If the patient wished to initiate movement of his splinted fingers, he contracted the control muscle. The electrical activity associated with this contraction was amplified and used to trigger a four bit cyclical counter. On count '1' of the counter, the orthesis motor was connected in such a way as to begin to flex the splinted fingers. On count '2' the motor was stopped. Pulse three caused the motor to be connected so as to open the fingers. count '4' caused the motor to stop again, and so on.

The Viennatone Orthomot(') [11] also operates in sequential fashion but

(') Viennatone Hörgeräte,Vienna, Austria requires continual myo-electric signal output while the orthesis motor is operating.

Muscles which are capable of more than just a flicker of activity must therefore be used for control of this system. To operate his splint, the patient must elicit myo-electric activity above a preset level. The orthesis motor is then activated to cause finger extension. On relaxing the control muscle, the motor is switched off and the splinted fingers are locked in a stationary position. Further, the control electronics are automatically switched so that when next the patient generates myo-electric activity above a certain level, the ortheses motor is connected for operation in the reverse direction to permit finger flexion. On relaxing the control once the desired degree of finger flexion has been attained, the motor is stopped and the system is switched again so that the next burst of myo-electric activity will once more permit finger extension.

The Viennatone system lends itself to be used in proportional mode, the manufacturers however have not yet incorporated this facility in their design. The most serious drawback of both of the above sequential systems, is obviously the time factor involved in selecting the operating mode. It is seldom that the patient is completely satisfied with the type of grip that he has attained since he is unable to sense the pressure with which he is holding an object (because of diminished sensation in the hand). It may thus be necessary to alter the grip a number of times before the patient is satisfied; this is a time consuming procedure. Further, even though the amplifiers used may be of good quality, spurious signals may cause inadvertent triggering of the sequential control circuitry. This results in uninitiated splint operation in the first system described above, and a change in direction of motor operation in the latter system. Notwithstanding these criticisms, much success has been claimed by workers at the Tobelblad Rehabilitation Centre in Austria[12] using the sequential Viennatone control systems.

6.4.4. Position Control Using Myo-Electric Signals

A further myo-electric control system has been described by the writer[2]. The myo-electric signal output is processed according to the block diagram in figure 6.4. When the volitional myo-electric activity reaches a predetermined level the switch 'A' is activated. The output from switch 'A' is fed to a dual input 'nor' gate. The other input to the 'nor' gate is derived from a micro-switch which is mounted on the hand splint. The micro-switch is so situated that itis triggered only when the orthesis finger piece is extended to its maximum limit. When neither of the two inputs are present, the orthesis motor is commanded to open, that is, $\overline{A}$ or $\overline{\text{micro-switch}}$ = 'orthesis open'.

When either of the 'nor' inputs are present, the circuitry interprets the gate output signal as an instruction to maintain the motor in a stationary position. Should the volitional muscle activity exceed a second preset level greater than the D.C.level required to trigger switch 'A' a second switch, 'B' is triggered. The orthesis motor will then be commanded to rotate in such a direction as to close the splint.

The motor armature current is directly related to the volitional myo-potential output above the D.C. level required to trigger switch 'B'. Consequently, the patient has some control over the speed and force of the orthesis in the closing direction.

When the patient requires the position of his splint and therefore his hand, to remain in a certain desired fixed position, he merely reduces the level of the myo-electric activity in the controlling muscles to that required to trigger switch 'A' only, (and not 'B'), and thereby provide an input to the 'nor' gate. As explained above, this results in the motor stopping.

When the patient requires to open his hand or release his grasp about an

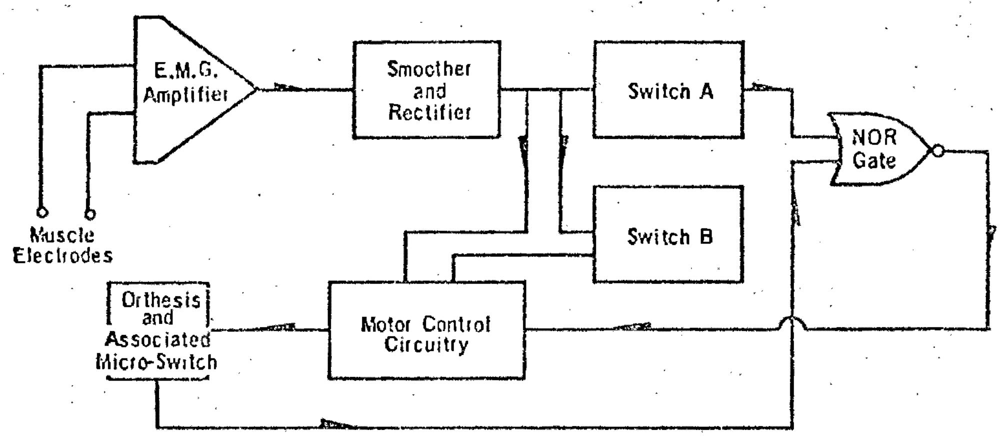


Fig. 6.4. Single Channel Myo-Electric Position Control.

object, he relaxes the control muscle completely. The switch 'A' is now turned off and neither of the two inputs are present at the 'nor' gate. The output from the 'nor' gate now directs the control circuitry to open the hand, and the splint opens to its maximum limit. At this point the micro-switch is triggered, and having provided an input to the 'nor' gate, the reversing action of the motor is inhibited. The orthesis is inactive until an activating signal is once more generated by the control muscle.

In practice it has been found that a great degree of precision of the control muscle, and much concentration by the patient was required. After a few minutes of continual splint use, the patient's concentration flagged and he could not control his device adequately. He was thus unable to maintain a grip about any object.

Position servo control of myo-electrically operated orthotic devices, where the degree of extension-flexion of the splinted fingers is directly related to the intensity of the myo-electric signal output, also requires excessive patient concentration to maintain constant myo-electric signal output. As with the system described above, at best a jerky unsure control is attainable.

Both systems cannot therefore be considered as practical and suitable means of myo-electric splint control.

6.4.5. Myo-Electric Control of Physiological Stimulators

Attempts at providing myo-electric control of orthotic hand splints which used surface electro-stimulation of the existing musculature to provide motor power, were described by Vodovnik et al[13]. Myo-electric signals from the left trapezius muscle were used to modulate a faradic type stimulator positioned over the right extensor digitorum muscles. The fingers of the hand could thus be extended in sympathy with the trapezius muscle contractions. Using a splint which stabilised the patient's wrist and provided a spring loaded finger piece to return the fingers to the normally flexed position when the stimulatior was turned off, patients were reported to be able to attain degrees of finger extension at will. Implanted myo-electric telemetry systems and stimulating electrodes have been investigated by a number of workers(14), (15) (cf. page136) and varying degrees of success have been reported.

The difficulties with such systems, however, do not lie in the technological barriers connected with hardware development, but are associated with a lack of sufficient control sites and the low grade of information output available from such sites.

6.4.6. Additional Remarks on the Use of Myo-Electric Control Systems

The control systems described above have been designed for use solely by quadriplegics who retain some arm movement ($C_{4,5}$) and therefore require only externally powered prehension. No myo-electric control systems have yet been developed for multidegree of freedom ortheses. It is doubtful whether myo-electric controls generally are superior to body movement activated switches. Unless proportional control is available from a myo-electric control site, or the control muscle is too weak to move its body segment and is thus truly redundant there is little point in using a sophisticated control system which does not offer any more than does the simple and reliable on-off micro-switch.

6.5. MECHANICAL CONSTRUCTION OF MOTORISED SPLINTS FOR PREHENSION

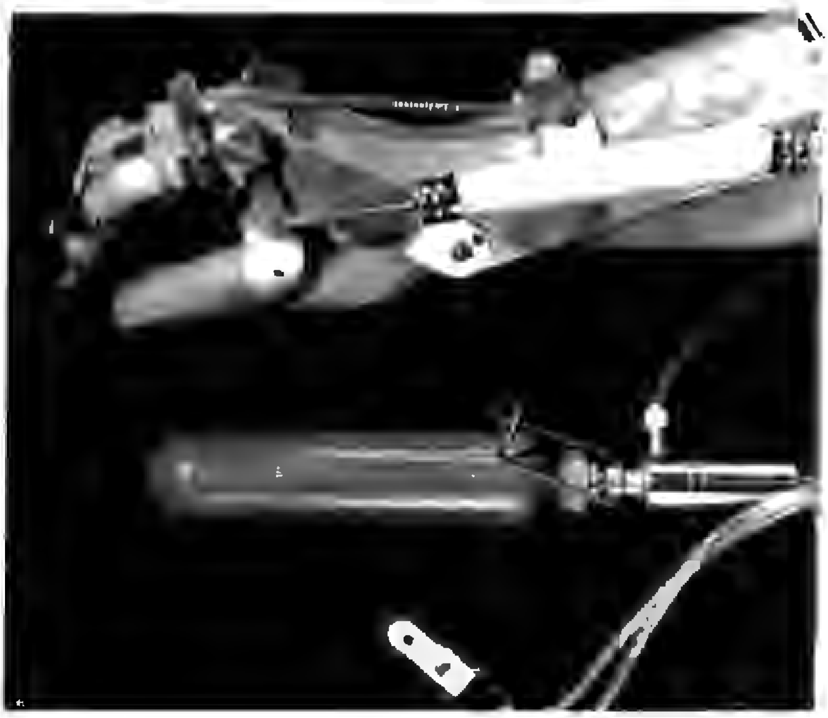
The basic metal hand splint described by Nickel (cf page 77) has been adapted for use with both electrically and pneumatically powered ortheses. Pneumatic motors(16),(17) are not generally used any more today since the use of electrically driven systems is far more convenient. (Engen however, still prefers to use the pneumatic artificial muscle(18) with which to drive his externally powered ortheses). Figure 6.5 illustrates how some externally powered ortheses have been constructed.

The orthesis currently prescribed by the writer is shown in figure 6.6. It consists basically of an adaptation of the Engen type orthesis. The

Fig. 6.5. Powered Ortheses.

(a) Electrically Powered
(b) Pneumatically Powered

(a)



(b)

Fig. 6.6. Powered Ortheses used by the Writer.

standard hand-cuff provides support for the metacarpal arch and/or the thumb piece against which the articulating index and middle finger are opposed. A forearm piece is attached to the hand cuff at the wrist and secured by means of a joint which permits the position of the wrist to be set at any convenient angle. A 'passive' or 'active' wrist joint may be used. The 'active' wrist joint has a spring loaded catch which permits the patient to alter the angle of the wrist unaided. By pushing the lever (fig. 6.7) against the side of the wheelchair arm rests, the catch is disengaged; with the non-splinted arm the patient can then adjust the wrist to the desired angle. The wrist position is locked by the patient removing pressure from the lever. The 'passive' wrist is comprised of a friction joint which permits manual setting of the wrist in any desired functional position. This is usually effected by an attendant.

A D.C. torque motor and associated gearbox, originally developed at the spinal injuries centre at Rancho Los Amigos Hospital(19) provides the power for the splint. The motor is situated remotely from the splint at some convenient location on the patient's wheelchair and power to provide prehension is directed to the orthesis using a Bowden cable system. Finger flexion is provided as the cable is retracted through its outer housing while being wound up on a drum in the motor and gearbox assembly. The finger piece is spring loaded such that as the cable unwinds from the drum the splinted fingers are extended.

When using body powered flexor hinge splints, it is common practice to provide bilateral splints, i.e. both left and right hands are splinted. Unilateral fittings are the rule for externally powered devices since the patient experiences sufficient difficulty controlling only one splint; the provision of two splints would overload the patient's control capacity and thus minimise overall splint operation efficiency.

Fig. 6.7. Patient changing wrist angle of Powered Orthesis.

6.6. MICROSWITCH CONTROL FOR POWERED HAND SPLINTS

The non-splinted arm may be used to provide orthesis control signals by the forearm being either adducted or abducted against a spring loaded control lever mounted on the wheelchair arm rests. The patient seen in the photograph (fig. 6.8.) a $C_{4,5}$ quadriplegic, retained bilateral biceps strength of 4- and was thus able to position his arm in front of him without aid. External power was provided for active prehension. The control lever operated two micro-switches; one as the arm was adducted and the other as the arm was abducted.

Figure 6.9. illustrates the use of a pneumatic switch arrangement for orthesis power control. The patient was able only to move one arm and thus it was not possible to use the contralateral unsplinted arm for control. No attempt at using myo-electric control was made since the patient lived on a farm and it would have been inconvenient to service the unit should any breakdown have occurred.

A pump diaphragm was mounted between two air-tight flanges which were so contructed to permit the mounting of micro-switches on either side of the central metal slug of the diaphragm. Aside from an inlet pipe which was connected to one of the flanges, the whole assembly was air-tight. Blowing into the pipe resulted in the one microswitch being depressed while sucking on the pipe caused the other microswitch to be depressed. These actions corresponded to a signal to flex and extend the fingers respectively. When neither suck or blow signals were present power to the motor was switched off. The pneumatic pipe (plastic) was enshrouded in a metal gooseneck and attached to the rear of the patient's wheelchair. The assembly was sufficiently flexible to allow it to be adjusted in a convenient position within easy reach of the patient's mouth.

For patients who have some biceps movement in the unsplinted arm which may be suitable for splint control, a slide switch mechanism may be used (fig. 6.10). A forearm channel is constructed for the arm which is to

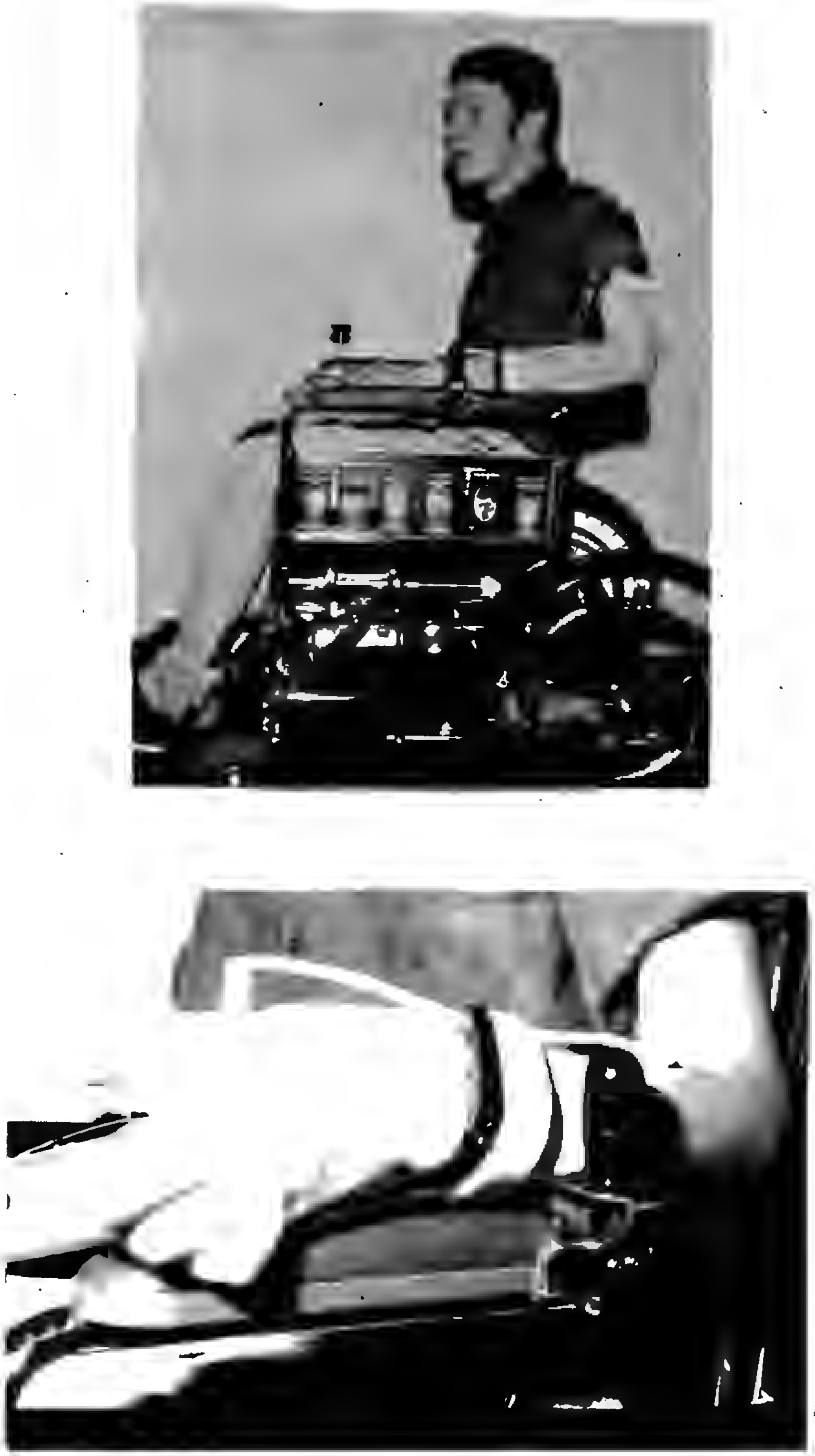


Fig. 6.8. Microswitch Control for Powered Orthesis.

Fig. 6.9. Pneumatic Splint Control

Fig. 6.10 Microswitch Control on Sliding Mechanism

effect control and a moulded elbow stop is provided to position the elbow. The forearm channel and elbow stop are mounted on a ball bearing slide which in turn is attached to the wheelchair arm rest. Using residual biceps and scapular movements the patient is able to slide the forearm piece forward and backwards in the horizontal plane. Microswitches are mounted at the extremes of travel of the forearm trough and are used to provide signals to extend and flex the fingers when triggered. Maintaining the forearm in mid-position between the limits of travel of the slide ensures that power to the orthesis motor is off thereby preserving the degree of extension or flexion of the fingers.

It may be necessary to adjust the height of the forearm slide switching mechanism to the patient's convenience. Also to compensate for functional deficiencies it might be necessary to tilt the slide mechanism vertically either up or down to provide bias in a 'hand heavy' or 'elbow heavy' direction. Further, the patient might wish to maintain his forearm at an angle (in the horizontal plane i.e. with his elbow in a degree of abduction) to the arm rests of the wheelchair.

A multidegree of freedom jig was therefore constructed so that the patient's precise requirements could be ascertained (fig. 6.11). The jig fits into the arm rest retaining holes of the standard Everest and Jennings wheelchair. Once the required height and angles of vertical and horizontal tilt are determined, the moving segments of the jig are locked into position and the slide switching mechanism is constructed directly to conform to these jig positions.

Since the slide switch permits some forearm movement in the intermediate positions where the control switches are not triggered, the patient does not feel inhibited by the movements which he is permitted to carry out. The system has been found to work efficiently and is well tolerated by patients.

Fig. 6.11 Multi-degree of Freedom Jig.

6.7. POWERED HAND ORTHESES WITH ELBOW MOVEMENT ASSIST

Ball race feeder systems have been described above in section 5.5. These devices permit body powered assisted movements of elbow extension and flexion and facilitate movements of the arm. Figure 6.12. illustrates how a similar device[20] may be used to provide improved arm function for patients having a biceps of only 2+ Oxford Grading. The forearm trough support is mounted on a pivot incorporated on a parallelogram lattice work. The parallelogram assembly is mounted on the wheelchair as shown in the figure. A stiff coil spring is attached between the opposite corners of the parallelogram so that its effect is to provide an upward lift to the forearm trough. Patient's range of elbow elevation (shoulder abduction) is greatly enhanced with the use of this device, and biceps function is improved by the effective elimination of gravity due to the combined action of the spring assisted movement and the friction free pivoted forearm trough.

Unless prehension is provided for such a orthesis it is of little functional value. Prehension is provided by attaching a hand cuff to a metal rod extending from the forearm trough. A spring loaded finger piece is attached to the hand cuff and active finger flexion is supplied to the finger piece in the usual way using a remotely situated D.C. torque motor and Bowden cable system. Control for prehension may be derived from a lever switch assembly mounted on the chin control unit of the powered wheelchair (fig. 6.13) or by any of the techniques described above.

6.8 POWERED MULTIDEGREE OF FREEDOM ORTHOTIC DEVICES

Where the effective range of movement afforded by ball bearing feeder or spring assisted devices is insufficient to provide adequate return of function to the patient, total arm ortheses with multidegreeof freedom of movement have been fitted to patients. The Rancho Electric Arm[21], a total arm orthesis developed at Rancho Los Amigos Hospital in 1964, is

Figs. 6.12 and 6.13 Orthesis for Quadriplegic with Biceps of 2+ Oxford grading.

used almost universally where efforts to motorise a totally paralysed upper limb are attempted.

The Electric Arm is powered by electrically driven motors and has seven degrees of freedom providing arm and hand movements considered necessary to accomplish most normal activities of daily living. The splint consists of a basic exo-skeleton with hinges at the shoulder, elbow, wrist and metacarpal-phalangeal joints. Motors are incorporated into the exo-skeleton at the appropriate joints to provide humeral extension and flexion, humeral rotation, abduction and adduction, elbow extension and flexion, and forearm pronation and supination. Power is directed via Bowden cables from motors to provide wrist extension and flexion, and prehension. The orthesis is mounted onto the patient's wheelchair and is so constructed that the paralysed arm may be simply strapped into it. Control over this complex orthesis is accomplished by means of a bank of seven, three position lever switches. The switches are biased so that when they are not activated, they are automatically returned to the centre 'off' position. Pushing a lever forward connects the corresponding motor for operation in the forward direction while pushing the lever backwards, reverses the motor direction of operation. Control of the bank of switches is effected by the tongue and thus the switch array is mounted in close proximity to the patient's mouth.

6.8.1. Case Studies

Two patients were fitted with the Rancho Arm on an experimental basis to gain a first-hand assessment of the device as a clinically acceptable rehabilitation medium.(')

The first patient fitted was a polio quadriplegic of more than 10 years standing; the only movement that the patient could execute was some head and neck movements; he was also able to flex his small finger on the left hand.

(') Electrolimb Corp. Altadena, California

Having been fitted with the orthesis the patient was elated at being able to move his arm about, and within a few days was able to exercise good control over the orthesis. However, the patient soon complained that the device was too slow, and its movement too robot-like. Notwithstanding the patient being above average intelligence, well orientated to self help, and that he soon learned to operate a number of microswitches simultaneously to permit a more natural looking pattern of orthesis movement, the slowness of operation of the device and less important the fact that there were always people who were eager to help the patient, soon resulted in his rejecting his appliance. Further, as the control unit had to be situated almost directly in front of the patient's mouth, the orthesis could not be used for feeding. The patient had to wear a cumbersome breathing assist unit for most of his waking hours; it can thus be safely inferred that his reason for rejecting his appliance was not based on it being cosmetically unacceptable.

An attempt was made to utilise the movement which the patient retained in his finger to provide an extra control channel to compliment the tongue switch control. To facilitate eating, finger movement was used to provide signals to a motor swivel unit onto which the micro-switch control array was attached. A cuff was constructed about the patient's little finger which, when flexed, caused the bank of switches to swivel away from his face; the movement was halted when the patient stopped flexing his finger. On flexing the finger a second time, the current to the motor was reversed and the control unit was again swivelled to a position in front of the patient's face.

Alternately, it was thought that it might be possible to utilise the finger to generate control information in code form by flexing the finger sequentially for longer or shorter time periods. Although much effort was directed to investigate this possibility, it proved unsuccessful as the patient could not enter sufficient information into the control unit before the muscles of the finger fatigued.

The second patient fitted with the Rancho Electric Arm orthesis had suffered traumatic quadriplegia at the C_4 level. Aside from head and neck movement the only movement that the patient could effect was slight shoulder elevation. Further, having suffered quadriplegia as a result of trauma to the spine and not as a result of polio, the patient's hands and most of his arms were anaesthetic. The likelihood of orthesis acceptance was thus diminished when compared to the previous patient because of the loss of proprioceptive feedback.

The patient persevered in the use of this orthesis for some weeks and made a serious attempt to accustom himself to using the device. Despite constant encouragement, and excellent training and supervision in the occupational therapy department, the patient soon elected to do without the aid of the appliance.

6.8.2. Intraoral Transducer Control of the Rancho Electric Arm

To improve on the tongue operated microswitch array, the use of intra-oral transducers mounted on a dental plate are presently being investigated(22). The transducer comprises a number of pressure sensitive areas which are activated by the tongue. To obviate the inconvenience of direct wired connections between the transducer outputs and the ortheses, a radio link is provided to transmit information to the motor control circuitry. It is doubtful however if intraoral control will much improve existing micro-switch techniques since no effective upgrading of the system information handling capacity is inherent in the system.

6.9. APPRAISAL OF THE FUNCTIONAL USE OF POWERED ORTHESES

The quadriplegic's ability to control his powered orthesis directly determines the usefulness of the appliance. Efficient control is dependent on the following:

1) the degree to which the decision making capacity of the patient is loaded.

2) the rate at which control commands may be relayed to the orthesis, and

3) the existence or provision of feedback channels whereby the patient is aware of the performance of his orthesis.

The $C_{4,5}$ quadriplegic who has residual biceps function need only devote his control efforts to operate an orthesis providing one degree of freedom of movement - that of prehension. A measure of success is thus possible in providing some functional return to the patient. This is particularly the case if the patient has retained some sensation in the hand.

Patients who have minimal biceps function - less than 3 Oxford Standard of Grading - are not able to attain much independent and functional movement even when using ball bearing feeders or spring assist devices since there is little power in movements facilitated by these appliances. The prehensile capacity of the patient's splinted hand is thus limited.

As indicated above, powered multidegree of freedom of movement ortheses for high lesion quadriplegics are not well tolerated because of their high control information requirements, and to a lesser degree because of a lack of proprioceptive feedback. Patients who are fitted with total arm ortheses are unable to effect control over fine movement such as writing or handling small objects; they are also unable to feed themselves. Thus patients' activities are confined to lifting objects and relocating them in different positions in space. The effort and frustration involved in accomplishing such mundane tasks are hardly commensurate with the feeling of satisfaction experienced on the successful completion of the task.

From purely an engineering viewpoint, there is really no logic which can justify the use of total arm otheses for quadriplegics. It is utterly senseless to pilot the mass of an anaesthetic arm about in space when more versatile manipulator type prosthetic devices could be used to provide superior functional return of movement to the patient. Since the manipulator would not be confined in its trajectory by the limitations of the ranges of movements of the arm segments, it might operate in polar co-ordinate (r,ø and θ) mode. A grapple could be attached to the end of the telescoping radial arm to provide prehensile function for the prosthesis. While the control requirements of such a device would be less stringent than those of the total arm orthesis, it is doubtful however, whether the patient would be able to identify psychologically with the robot-like nature of the machine. Until such time as more effective appliance control media are developed it would probably be advisable not to complicate further the man-machine interface by compounding the psychological difficulties which the severely disabled patient already faces. In the light of the foregoing it is apparent that excepting for patients with lesions at segmental levels $C_{4,5}$ current techniques for activating paralysed upper extremities are not successful. This conclusion should not be viewed as a pessimistic speculation resulting from the author's (and others') unsuccessful attempts at providing adequate return of function to high level quadriplegics, since theoretical considerations of the man-machine interface detailed in Chapter 4 predicted that using available control modalities, failure to achieve acceptable information transfer rate, and therefore adequate speed of movement, was inevitable.

6.10. COMPUTER AIDED ORTHESIS CONTROL

As early as 1964(23) digital computer techniques were used in attempts to facilitate patient control of multidegree of freedom powered ortheses. The computer was loaded with tapes on which were recorded explicit orthesis control information which could be used in accomplishing movements associated with various activities of daily living. By selecting an appropriate part of the tape, the patient was able to effect a desired movement without having to generate control signals to actuate specific individual segments of the orthesis. Selection of a pre-recorded programme was effected by light beam guidance, controlled by head movements.

The computer aided system was operated in either automatic or autonomous mode, or in manual mode to permit direct patient control of the orthesis motors. This is to facilitate finer adjustments of the arm and hand. In feeding operations therefore, the appropriate tape sequence for locating the hand nearest the food is selected. Then the non-automatic control mode is employed to execute the more precise movements required to actually grasp the food. An autonomous sequence is finally selected to bring the splinted hand and food up to the patient's mouth.

More recently Freedy et al[24] described a system which provided for an adaptive or learning capability in computer aided orthesis control. This control system finds particular application in tasks which have much repetitive movement associated with their execution, as for example tasks such as moving objects from one fixed location to another. The computer detects any repetition of movement which the orthesis makes under direct patient supervision and based on the likelihood of the recurrence of such movements, programmes itself to reproduce these movements in subsequent stages of the task cycle. Ultimately orthesis operation is almost completely autonomous, the patient merely acting as an initiator or inhibitor of an 'acquired' computer controlled movement. Patient override of the computer controlled activity is provided to effect changes in the automatic mode of orthesis operation.

Laboratory tests of computer aided orthotic control systems have demonstrated their capacity for reducing the patient's decision load and thereby reducing the bandwidth requirements of the information channel between the patient and his orthesis. Hopefully the advent of micro-miniaturisation and smaller computers will see the development in the not too distant future, of automatic and/or adaptive functional systems for general clinical use.

6.11. STIMULATION OF EXISTING MUSCULATURE TO ACHIEVE FUNCTIONAL RETURN OF MOVEMENT

The early work of Liberson[25], Vodovnik[26] and others[27],[28], have prompted researchers to investigate the possibility of providing return of movement of paralysed body parts by the simultaneous ordered stimulation of a number of muscle groups. While the practical realisation of the use of such systems particularly for paralysed upper extremities appears to be some time away at this stage, much activity has been centered on the application of electro-stimulation techniques. Milner et al[29] have determined the myo-electric signal outputs from normal subjects legs during walking and have correlated the processed myo-electric signals with the various phases of the walking cycle. They have also demonstrated the feasibility of simultaneously stimulating a number of muscle groups to provide functional movement of the foot. Because of the repetitive nature of the walking movement, computer based programmes for ordered stimulation of the lower limb would be far easier to achieve than for affecting functional electro-stimulated movements of the arms. Most of the work thus far has therefore evolved about aspects of locomotion. However, the techniques which must be perfected to determine parameters such as stimulation electrode placement for optimal contractions, electrode configuration, current pulse characteristics, etc., will no doubt be applicable to all body segments.

The use of electro-stimulation produced movements would permit functional return without having to rely on externally powered motors. Relatively small amounts of power are necessary to elicit limb movements - very much less than what is required to operate even a low-power motor driven hand splint.

Nickel (1972)[30] describes an implanted system of electrostimulators controlled by inductive coupling between an external transmitter and a sub-cotaneous receiver. Large numbers of muscles may be driven by this system by connecting electrodes directly to the nervous pathways associated with these muscles. Provided adequate patient information output rates can be achieved, one may predict exciting and even unlimited possibilities for implementing return of function to the severely disabled. The use of miniaturised computer aided adaptive control of implanted electrostimulators would most certainly be one of the major techniques employed for this purpose.

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CHAPTER 7

ENVIRONMENTAL CONTROLLERS

7.1. INTRODUCTION

Despite the efforts being directed toward finding methods whereby more intimate communication between man and his orthotic machines may be accomplished, there are no indications that satisfactory solutions to this problem are at hand. It would be unrealistic for researchers who find themselves in a situation where they are confronted with high lesion quadriplegics, to wait until such time as the interface problem is resolved before attempting to provide return of function to their patients; an approach other than that of motorising paralysed upper extremities should therefore be considered.

One such approach might be a logical extension of the basic environmental modifications that are already commonly applied to facilitate the activities of daily living of paraplegics. For example, ramps are provided so that inclines may be negotiated and alterations are made in the patient's home to permit easy access to the kitchen appliances, toilet facilities, etc. Attempts are not made to modify the patient by encumbering him with complex orthotic hardware to facilitate patient-environment interface, but the environment in which the patient is to spend most of his time is modelled or tailored so that a patient-(modified) environment interface is efficiently accomplished using the residual functional ability of the patient.

The low bit rate of information output of the $C_{4,5}$ quadriplegic may therefore be used to generate signals to effect control over a drastically modified environment.

7.2. ENVIRONMENT CONTROL SYSTEMS

7.2.1. The Possum

The Patient Operated Selector Mechanism (POSSUM)[1] developed at the National Spinal Injuries Centre at Stoke Mandeville Hospital in the United Kingdom permits control over a number of electrical appliances such as lights, heater, telephone, radio, alarms, etc. To operate the system the patient sucks on a pneumatic switch. This results in a light appearing in the first of a number of compartments of a display unit and then advancing at a preset speed from compartment to compartment. Should the operator require to switch the heater on, for example, he stops sucking on the pneumatic switch as the roving light reaches the compartment marked 'heater'. The heater is then switched on and the machine is reset to carry out a further selection when this is required. To switch an appliance that is already on, off, exactly the same procedure is followed, i.e. selecting the same function repeatedly results in it being alternately switched on and off.

More sophisticated controls have been developed whereby the operator has control of devices that require multiple control inputs, not merely 'on-off' control. The operator might require to select a different station or to modulate the volume or brilliance of a T.V. set. Control is effected in a similar fashion by sucking on the pneumatic switch at which time a light moves downward vertically from compartment to compartment until the required set of functions is reached; the patient then stops sucking thereby locking the system into a sub-programme. When sucking is recommenced the roving light moves along through compartments in a horizontal direction and when the required function is lit up, it is selected by the operator ceasing to suck. The light then returns to the beginning of the sub-programme and the selector unit is reset to carry out another selection should this be required.

To de-select a sub-programme, the controller sucks until the light moves along to a position in the sub-programme marked 'terminate programme'; at this point, if the patient stops sucking, the programme is terminated. Typewriters, dictaphones, calculators etc. have been adapted for use with this type of control.

Most of the Possum devices currently in use are not of the sophisticated complex type since these are still in the experimental stages. Consequently, patients are not afforded multi-choice facilities associated with an appliance, and are able only to switch appliances 'on' or 'off'. Electromechanical relays and uni-selectors are used throughout the Possum control circuitry. It is understood however,[2] that presently efforts are being directed to transistorise the control logic in the interest of more efficient and maintenance free operation. Notwithstanding the incorporation of many electro-mechanical components, the Possum (i.e. the basic 'on/off' type) has proved to be sufficiently successful and useful to patients that the Ministry of Health in the United Kingdom views the provisions of such a system in the same light as it considers the provision of artificial limbs. Consequently, the system is made available under the National Health Scheme to those who require it.

7.2.2. Other Environmental Controllers

1. The "Voiciphone", developed by Telmec Systems Inc. U.S.A.[3] uses the patient's voice to activate telephone answering. By speaking in a louder than usual manner, the telephone handset is effectively lifted to answer the telephone. The conversation is terminated in the same way. The system employs a treshold detector which switches a bistable circuit at each high intensity sound input signal.

2. Light beams are used to operate the Patient Initiated Light Operated Tele-Control (Pilot) environmental controller[4]. A light source is attached to a head band or to the patient's spectacles and by moving his head, the patient directs the light beam onto a number of light sensitive transducers. Each light sensitive device has a particular function associated with it and when triggered by the light beam a bistable circuit is switched on or off. A typewriter control has been developed to operate in a similar fashion.

The disadvantage of the Pilot system is that the patient has to confine his head movements to trigger the device only when he wishes to switch an appliance on or off. Further, the system as a whole operates in on-off mode and does not permit continuously variable control over the patient's modified environment.

3. Recently it has been reported(5) that the National Aeronautics and Space Administration have developed an environmental control system of their own design; to date no detailed information is available on the system operation.

7.3. DESIGN AND DEVELOPMENT OF MULTIFUNCTION ENVIRONMENT CONTROL SYSTEMS

Because environmental controllers available for use by quadriplegic patients were not sufficiently versatile in their functional capacity and operation, patients could not exercise adequate control over their modified environment. While they could switch a radio 'on', patients were unable to modulate the volume, nor could they change from one station to another. To maximise patient-environment control it was necessary to develop versatile environmental controllers which would place within patients' capacity, complete and continuously variable control over a number of appliances which they would most likely require to use in their day to day existence.

Two environmental controllers were developed:(7)

System 1 was signed specifically for use by quadriplegics who have no arm movements whatever (C_4 lesion); environmental control signals are generated by the patient suching and blowing on a pipe. This system is designated as the Suck-Blow Selector System - SBSS.

System 2 was designed for use by quadriplegics who retain some useful arm movements and who are able to position their arms in space. Control signals are generated by the patient touching sensitive switches. This is the Touch Button Selector System - TBSS.

Initial experiences with the systems have proven their reliability and efficacy in providing most versatile environmental control to permit substantially increased patient independence.

7.4. THE SUCK-BLOW SELECTOR SYSTEM

7.4.1. General Operation

A bi-directional pneumatic switch, operated by both sucking and/or blowing provides the input signals to the Suck-Blow Selector System (SBSS). Utilisation of tri-state switching has the effect of freeing system operation from the time factor associated with the sequential access switching programme of the Possum system, where the controller had to wait until the select mechanism progressed in time to a particular function before it could be selected. The access time associated with the selection of all functions in the Suck-Blow Select System is the same.

Should the patient - (henceforth referred to as 'the controller') - wish to select any of the available functions (cf Table 7.1.) a 4 bit SUCK-BLOW code must be entered into the SBSS via the bi-directional pneumatic switch. A numerical display indicates to the controller what code he has entered and, that by having entered 4 SUCK or BLOW bits of information, he has 'primed' a particular circuit for selection. To effect selection of the 'primed' circuit, the controller must generate a SUCK input pulse; the circuit corresponding to the entered code is then switched on. To cancel a 'primed' selection - (due perhaps to having entered a code incorrectly) - the controller generates a BLOW pulse, thereby resetting and clearing the select circuitry. Consequently, the display indicates that the controller may enter a new 4 bit SUCK-BLOW code sequence when he so desires.

Since 4 bits of information are generated by the controller when selecting a function, it is apparent that as many as 16 different selections may be made. However, it has been found that by utilising only 9 of the possible circuits or programmes, sufficient versatility in environmental control

Table 7.1

MAIN FUNCTION	1 LIGHT ON-OFF BISTABLE CIRCUIT	2 CALL ATTENDANT MONOSTABLE CIRCUIT	3 PAGE TURNER MONOSTABLE CIRCUIT	4 RADIO COMPLEX CIRCUIT	5 TELEPHONE COMPLEX	6 TAPE RECORDER COMPLEX	7 INTERCOM COMPLEX	8 TYPEWRITER ON-OFF BISTABLE CIRCUIT	9 HEATER/FAN ON-OFF BISTABLE CIRCUIT
CODE	BBBS	BBSB	BBSS	BSBB	BSBS	BSSB	BSSS	SBBB	SBBS

RADIO

1.	ON-OFF (BISTABLE CIRCUIT)	- BBBS	(1)
2.	CHANGE STATION (MONOSTABLE CIRCUIT)	- BBSB	(2)
3.	VOLUME CONTROL (BISTABLE CIRCUIT)	- BBSS	(3)
4.	TUNE CONTROL (BISTABLE CIRCUIT)	- BSBB	(4)
5.	RESET TO MAIN PROGRAMME	- SSSS	(15)

TELEPHONE DIAL DIGIT

1.	BBBS	(1)
2.	BBSB	(2)
3.	BBSS	(3)
4.	BSBB	(4)
5.	BSBS	(5)
6.	BSSB	(6)
7.	BSSS	(7)
8.	SBBB	(8)
9.	SBBS	(9)
10.	SBSB	(10)
HOLD (BISTABLE CIRCUIT)	SBSS	(11)
RESET TO MAIN PROGRAMME	SSSS	(15)

TAPE RECORDER

ON-OFF (BISTABLE CIRCUIT)	- SBBS	(9)
VOLUME CONTROL (BISTABLE CIRCUIT)	- BBBS	(1)
RECORD LEVEL (BISTABLE CIRCUIT)	- BBSB	(2)
TONE CONTROL (BISTABLE CIRCUIT)	- BBSS	(3)
BALANCE CONTROL (BISTABLE CIRCUIT)	- BSBB	(4)
PAUSE (MONOSTABLE CIRCUIT)	- BSBS	(5)
STOP (MONOSTABLE CIRCUIT)	- BSSB	(6)
RECORD (MONOSTABLE CIRCUIT)	- BSSS	(7)
EJECT (MONOSTABLE CIRCUIT)	- SBBB	(8)
REWIND (MONOSTABLE CIRCUIT)	- SBSB	(10)
FORWARD (MONOSTABLE CIRCUIT)	- SBSS	(11)
RESET TO MAIN PROGRAMME	-	(15)

INTERCOM

SELECT STATION 1	- BBBS	(1)
SELECT STATION 2	- BBSB	(2)
SELECT STATION 3	- BBSS	(3)
SPEAK-LISTEN	- BSBB	(4)
RESET TO MAIN PROGRAMME	- SSSS	(15)

TABLE 1

S - SUCK
B - BLOW

CODE SEQUENCE 1st 2nd 3rd 4th
BBBB

is made available.

Of the nine Primary or Main functions available to the controller, four functions are 'complex functions' i.e. multiple choices are associated with each of these selections; as many as sixteen separate selections are possible in each complex function sub-programme. The remaining five functions consist of 'on-off' circuits. Three of these circuits have bistable switching modes and two circuits operate in monostable mode (fig.7.1) Repeated selection of non-complex functions result in their being:-

i) reselected in the case of monostable functions and

ii) alternately switched on and off in the case of the bistable functions.

To enter a complex function, a SUCK-BLOW code is entered in the normal way. Once the required function has been 'primed', the controller selects the function by entering a SUCK signal. All subsequent codes now entered are channeled to the sub-programme associated with the particular function selected.

To re-enter the main select programme, a code constituted by generating four consecutive SUCK signals is entered; on SUCKING once more, the sub-programme is de-selected and the controller is then free to operate in other programmes of his choice. A flow chart of how the system operates is presented in Figure 7.2 and table 7.1 indicates what selections are available to the controller and details the appropriate codes.

7.4.2. Constructional and Design Details

Integrated circuits are used extensively in the design of the system and all circuitry is assembled using glass epoxy printed circuit board. The circuit boards are mounted on plug-in Vero card frame modules and assembled in 19" racks in a Botley type cabinet 24" high.

The bulk of the logic employed in the Selector Systems signal processors in High Level Logic made by SGS[6]. The systems were initially designed using TTL logic of the 74 Series, however difficulties encountered because

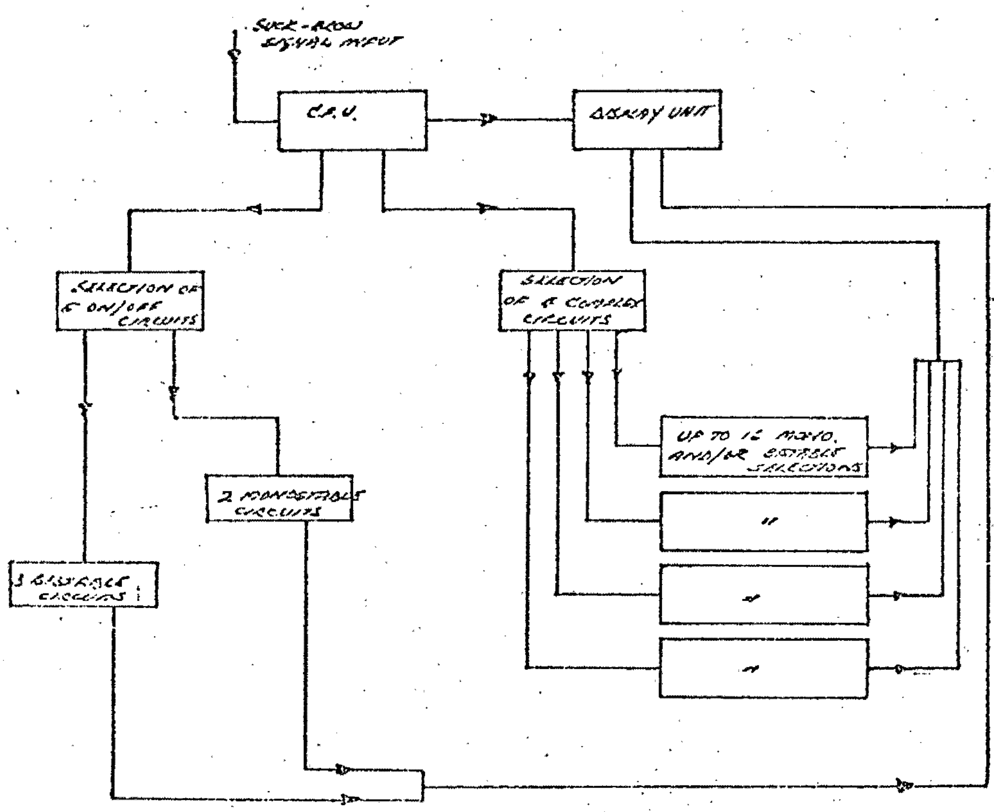
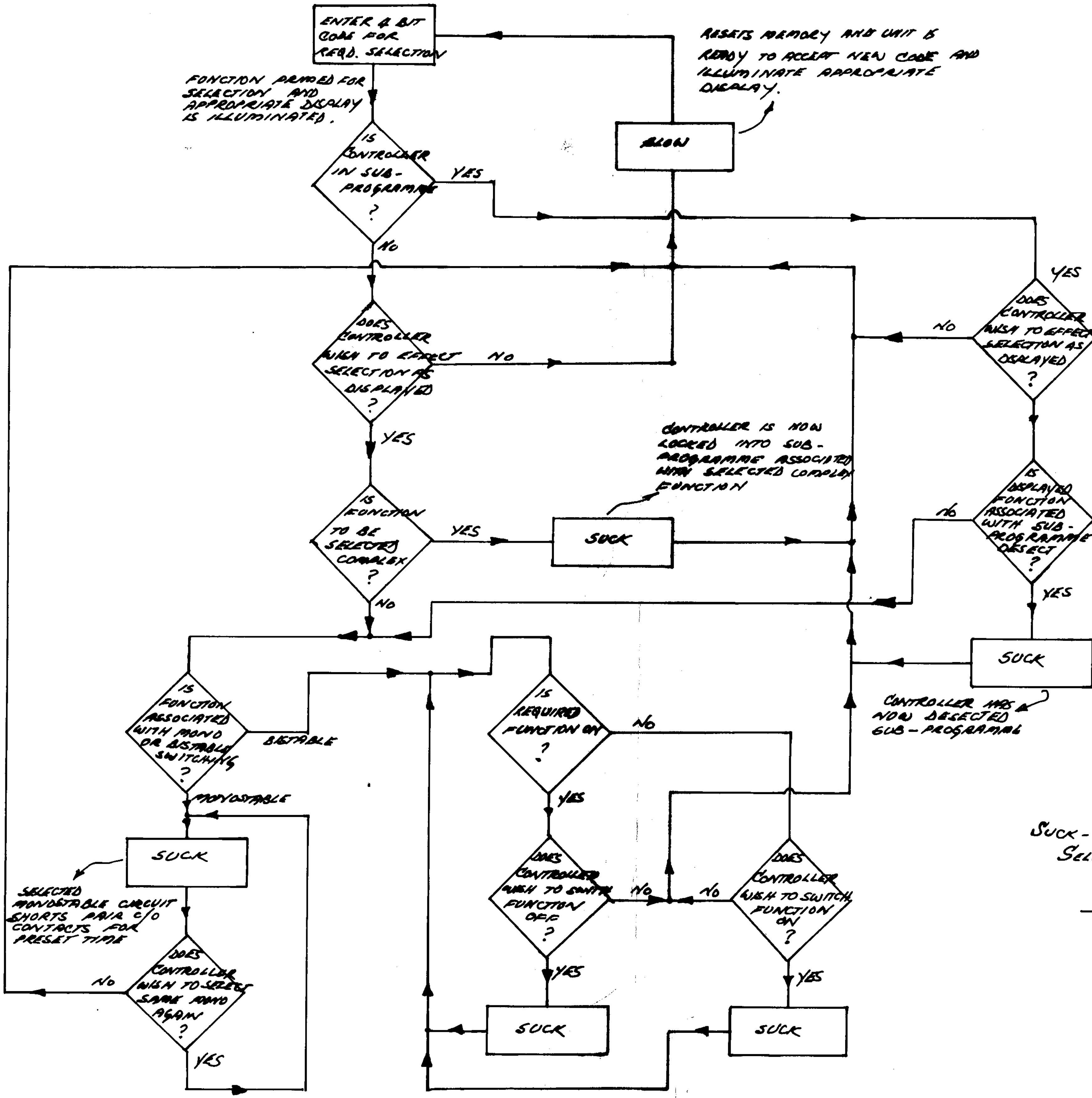

C.P.U.
SELECTION OF 6 ON/OFF CIRCUITS
SELECTION OF 4 COMPLEX CIRCUITS
2 MONOSTABLE CIRCUITS
UP TO 12 MONO. AND/OR BISTABLE SELECTIONS

Fig 7.1.



Suck-Blow Selector System Operation.

of the low noise immunity of TTL - (1 volt) - necessitated going over to High Level Logic (HLL) which has a noise immunity of 5^V minimum. The functions currently available in the HLL family are somewhat limited when compared to the TTL 74 Series, however the circuitry at ones disposal is sufficiently versatile to synthesise the requirements of the Selector Systems.

7.4.3. The Suck-Blow Transducer Unit - General Description

The Suck-Blow transducer unit first constructed, consisted of a diaphragm enclosed in an airtight housing. A metal slug was mounted in the middle of the diaphragm, which made contact with one of two micro-switches respectively when positive or negative pressure was applied to a mouthpiece, connected via an airtight gooseneck to the diaphragm housing. Screw adjustments provided sensitivity control permitting use of the device with small volumes of air.

When patients with low residual respiratory ability tested this mechanism it was found that blowing presented quite some difficulty and thus other more sensitive methods of deriving a Suck-Blow signal needed to be investigated. The system which was finally adopted - (and which has application in most cases where directional detection of gas flow of small quantities is desired), is described with the aid of the block diagram (cf. 7.3).

Two small, bead negative temperature thermistors are placed one behind the other in a perspex - (or other non-metallic) - tube through which the gas flow takes place. The thermistors are connected in opposite arms of a Wheatstone bridge and an electrical current is passed through the thermistors to elevate their temperatures - (by I^2R dissipation) - to a little above ambient. Blowing down the pipe in which the thermistors are mounted causes:-

i) the proximal thermistor bead to be cooled down - (the degree of cooling is related to the volume of air circulating about the bead), and

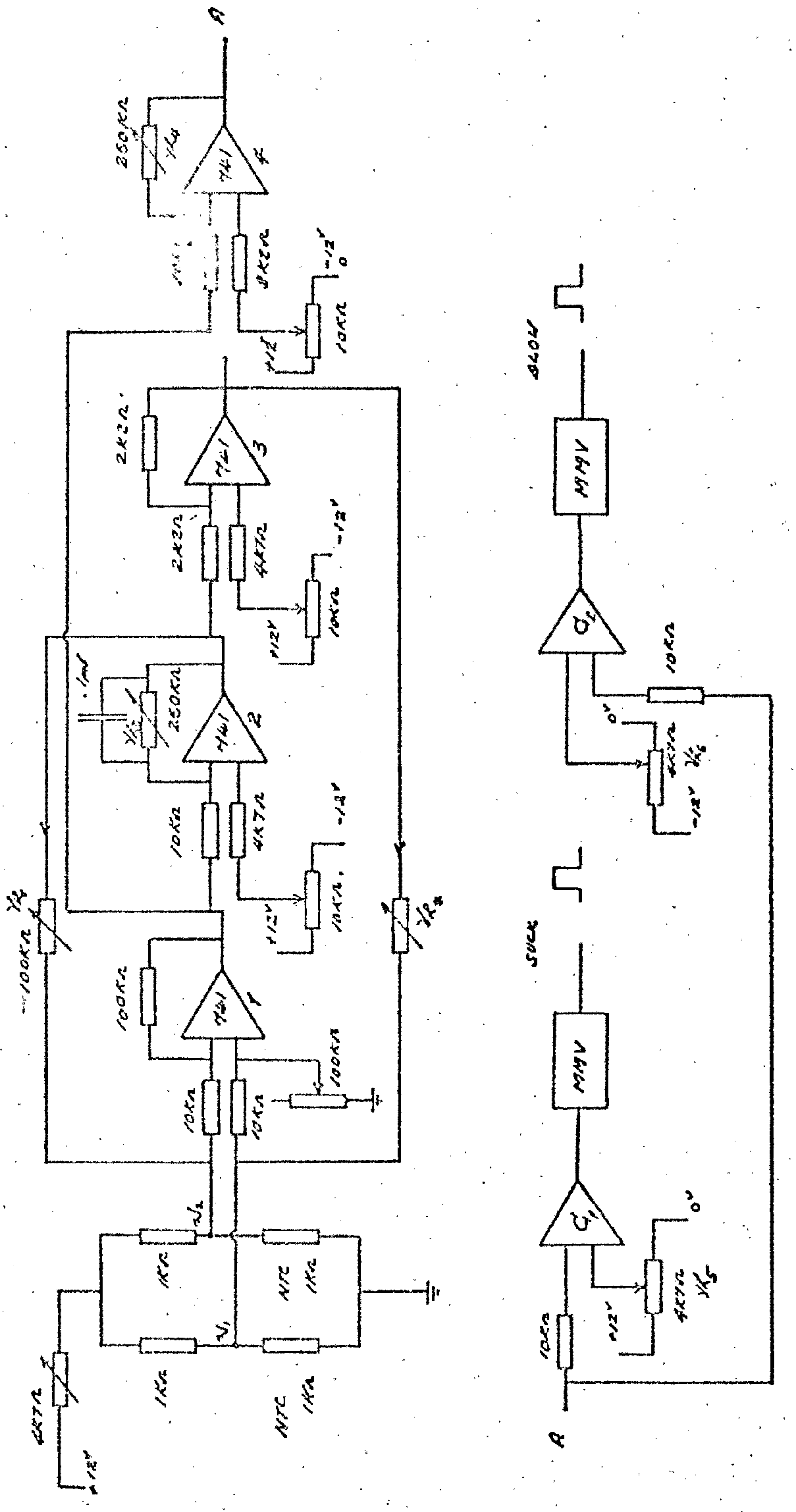


Figure 7.3

ii) the distal bead to be warmed slightly as a result of heat transferred by the air flow from the proximal thermistor.

A corresponding decrease and increase in resistance of the respective thermistors takes place and becomes manifest as a change in the Wheatstone bridge output. Sucking on the pipe causes a reversal of the above effects. Thus, by connecting a suitable amplifier across the bridge output, a signal relating both the volume of air flow and its direction is available. The time constants associated with the thermistor assembly present a problem in that the time taken for the thermistors to cool down and return to their quiescent states has the nett effect of limiting the rate at which input signals may be entered into the Central Processing Unit of the SBSS. However, by applying feedback to the thermistors in the bridge, effectively force heating and cooling the cooler and warmer thermistors respectively, the problem is adequately overcome.

The extent of the improvement in transducer characteristic when feedback is applied in the circuitry is illustrated in Figure 7.4.

Circuitry Considerations

The Wheatstone bridge outputs are D.C. coupled to an operational amplifier connected so that the incoming signal is amplified ten times (cf block diagram 7.3.) The signal is then further amplified (Amplifier 2) and the resultant signal is inverted by a unity gain amplifier. The outputs from the second amplifier and its inverted signal are used to provide the feedback signals necessary for improving system performance. The degree of feedback is set by adjusting the gain of Amplifier 2 and fine adjustments are made to individual thermistor feedback paths by setting series trimmer potentiometers VR_1 and VR_2. These potentiometers are set to ensure minimum system overshoot.

The output from Amplifier 1 provides also the input signal for Amplifier 4. The gain of Amplifier 4 -(adjusted by VR_4) - controls the sensitivity of the transducer circuit as a whole - (but does not influence the thermistor

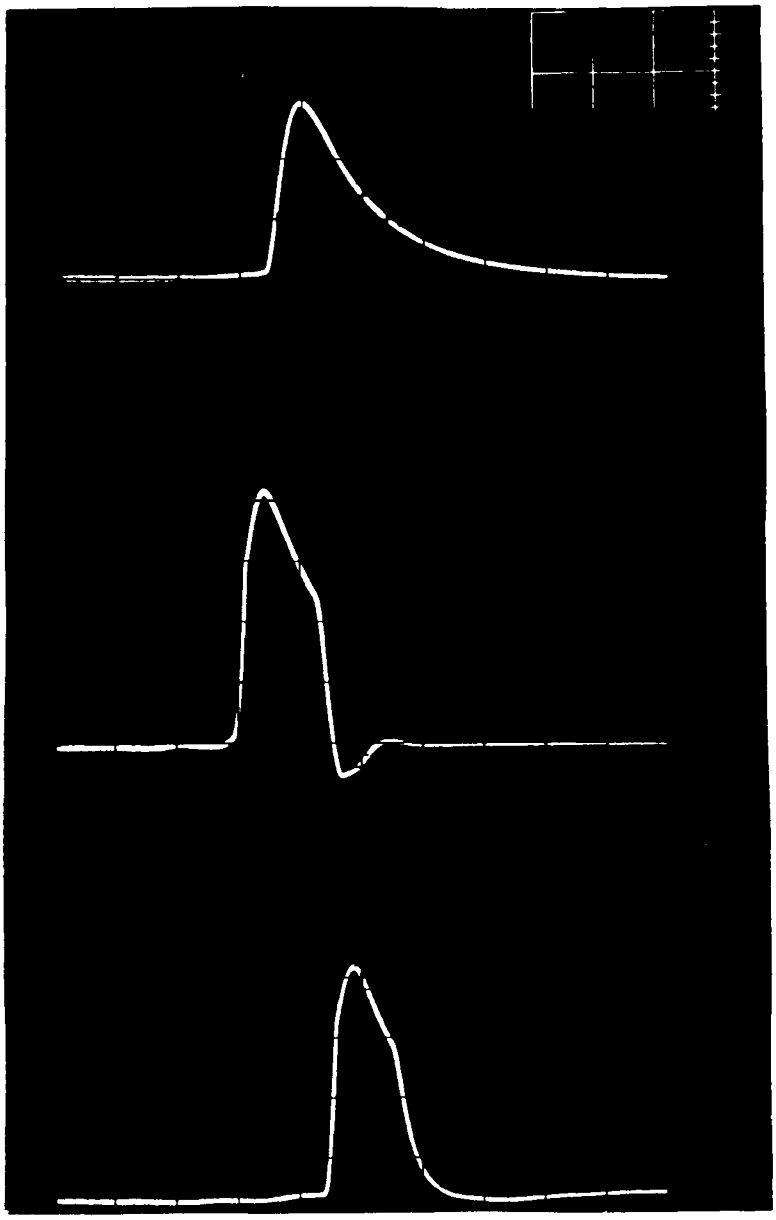


Figure 7.4.

Top Trace - thermistor characteristic without feedback (0.5 sec/div).

Centre Trace - thermistor characteristic with too much overshoot (0.2 sec/div).

Lower Trace - thermistor characteristic with feedback adjusted for minimum overshoot (0.2 sec/div).

characteristics as do Amplifiers 2 and 3).

Amplifier 4 output - (node A, block diagram 7.3) - is fed to two comparitor circuits C_1 and C_2 which provide trigger pulses to two monostable multivibrators. If the output at A should exceed a preset positive voltage - (set by potentiometer VR_5) - a SUCK pulse is made available to the Central Processing Unit and conversely, if output A is less than a preset negative voltage - (set by VR_6), a BLOW pulse is generated. VR_5 and VR_6 are adjusted independently to accommodate for the variations in patients' ability to suck and blow.

The comparitors (Figure 7.5) consist of suitably buffered Schmidt trigger circuits with adjustable trigger levels. The trigger circuits differ only in the type of transistor used in their construction. That which switches on positive going signals uses largely NPN transistors and is connected between earth and the positive supply, while that which switches on negative signals uses complementary PNP transistors and is connected between earth and the negative supply. Light emitting diodes (LED's) indicate when the comparitor circuits are in the triggered state.

The outputs from the Schmidt trigger circuits are coupled to respective SUCK and BLOW monostable multivibrators. Further LED outputs are provided to indicate when a SUCK or BLOW signal has been successfully accomplished. SGS type H 117 integrated circuits monostable multivibrators with time constants of $\pm$ 150 m.secs. are used as the SUCK-BLOW signal generators.

Power Supply

+12 volt as well as -12 volt power supplies are required to power both the Amplifier and Comparitor circuitry. The positive power supply may be taken from either of the two MAIN POWER supplies (cf) or, if desired, provision has been made for independent +12 volt and -12 volt supplies in the design of the SUCK-BLOW TRANSDUCER printed circuit board itself. The supplies are constructed using integrated circuit regulators type LM 036 together with the appropriate bridge rectifiers and smoothing capacitors (Figure 7.6).

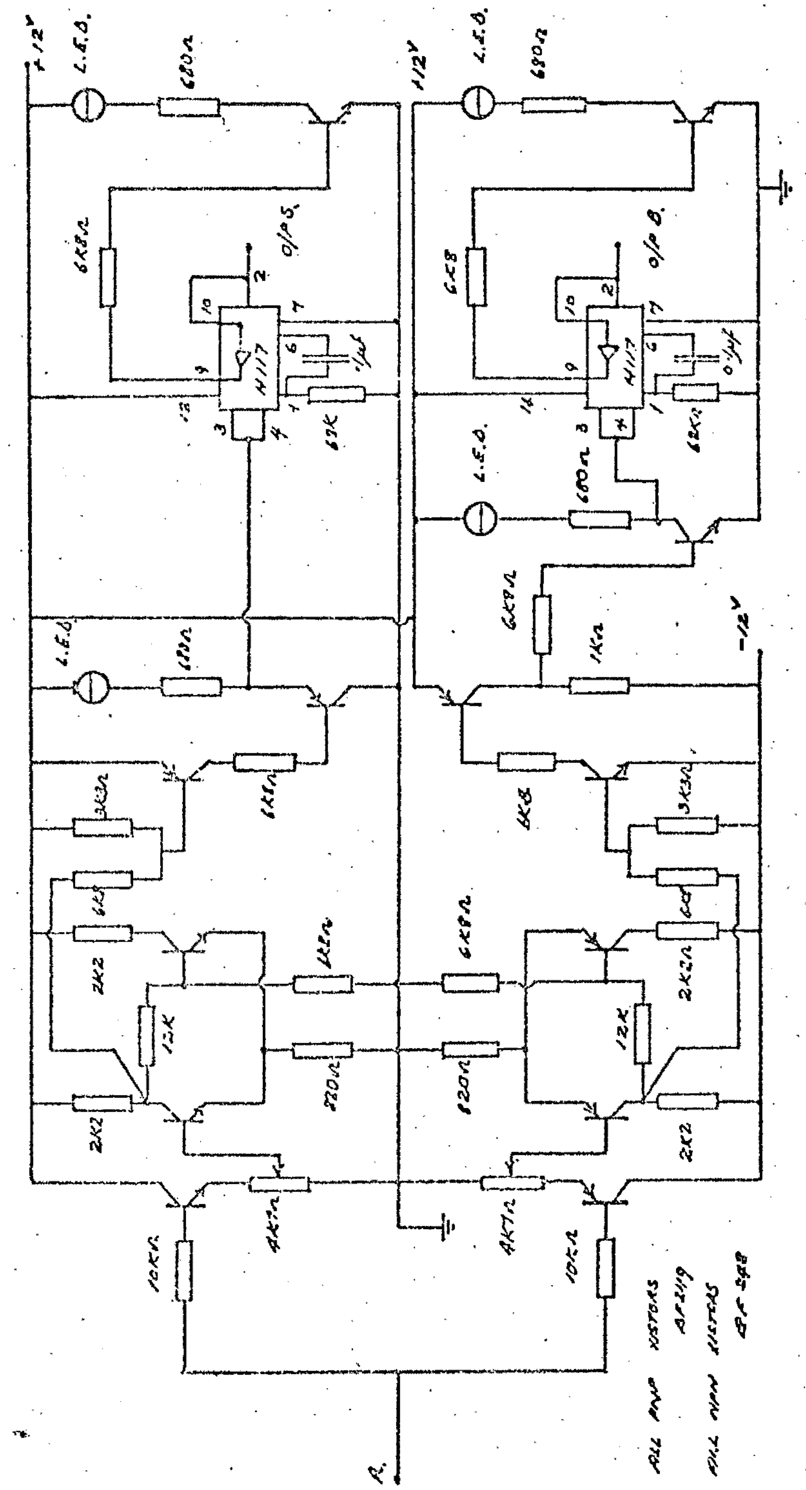


Figure 7.5

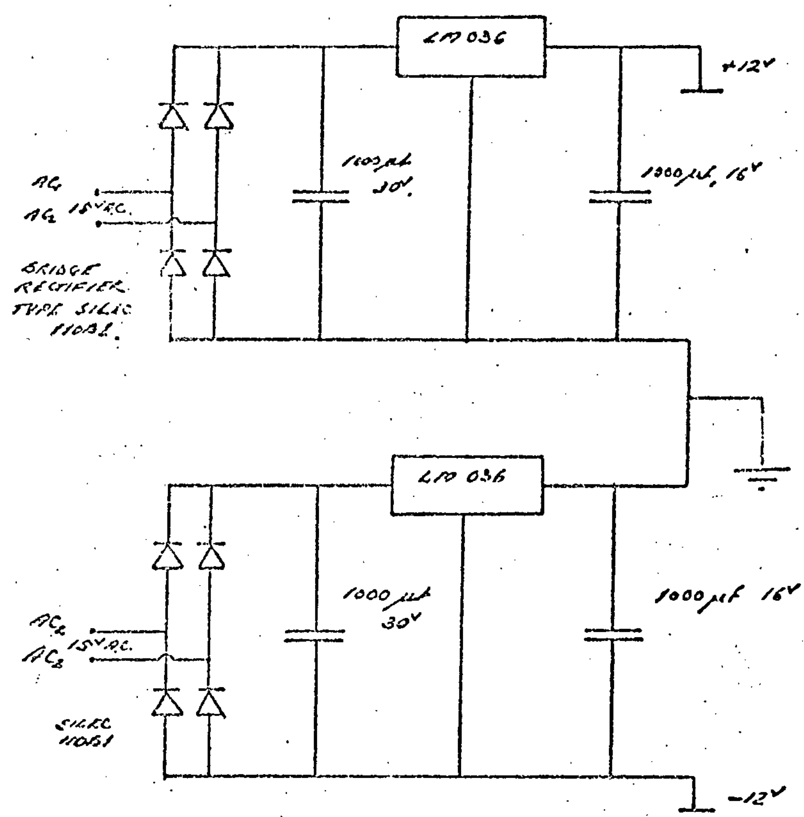

LM 036
+12V
1000 μf 30V
1000 μf, 16V
AC1
AC2 15V AC.
BRIDGE RECTIFIER TYPE SILEC 110B1.
LM 036
1000 μf 30V
1000 μf 16V
AC3 15V AC.
AC4
SILEC 110B1
-12V

Figure 7.6

The Pipe-Thermistor assembly is mounted in the base of a microphone stand. As was the case with transducer A, plastic tubing enshrouded in a metal gooseneck, connects the mouthpiece with the transducer itself. (For component layout and p.c. board details see Appendix F).

7.4.4. The Main Select Unit (Figure 7.7)

The 'SUCK' and 'BLOW' signals generated in the flow transducer unit are reshaped by feeding them directly to respective 'SUCK' and 'BLOW' monostable multivibrators (cf Figure 7.7) and, assuming that node Q of the MAIN BMV is high, the signals are nanded to provide SUCK (S), BLOW (B) and SUCK or BLOW (S + B) signal. The S + B signal is directed to two monostables where it is delayed by about 1 m.sec. before being passed on to a decade counter. This counter logs the number of S + B pulses generated by the controller. If the counter '0' output is high - which indicates that the select sequence has not yet been initiated - and a SUCK pulse is generated by the controller, the SUCK pulse and the '0' output are nanded to provide a signal which will set BMV REGISTER 1 to the high output state. If the controller generates a BLOW pulse, no signal to set REGISTER 1 is generated and its output will remain low. In either of the above instances the SUCK or BLOW (S + B) pulse is passed on to the counter after being delayed for 1 m.sec. and node '1' of the counter is then set to a high output. REGISTER 2, 3 and 4 outputs are determined in exactly the same way as is the output of REGISTER 1. Also after each register has been set, a S + B pulse is logged by the counter. Once four such SUCK-BLOW codes have been entered, the counter is set so that node '4' is high.

All further input signals to the COUNT port of the COUNTER are now inhibited, i.e. the counter can no longer log S + B signals.

Should the controller now generate a BLOW pulse, the BLOW signal and the output from node 4 of the COUNTER are combined in a nand gate and its output resets REGISTERS 1 - 4 and resets the COUNTER to 0 and the system is primed

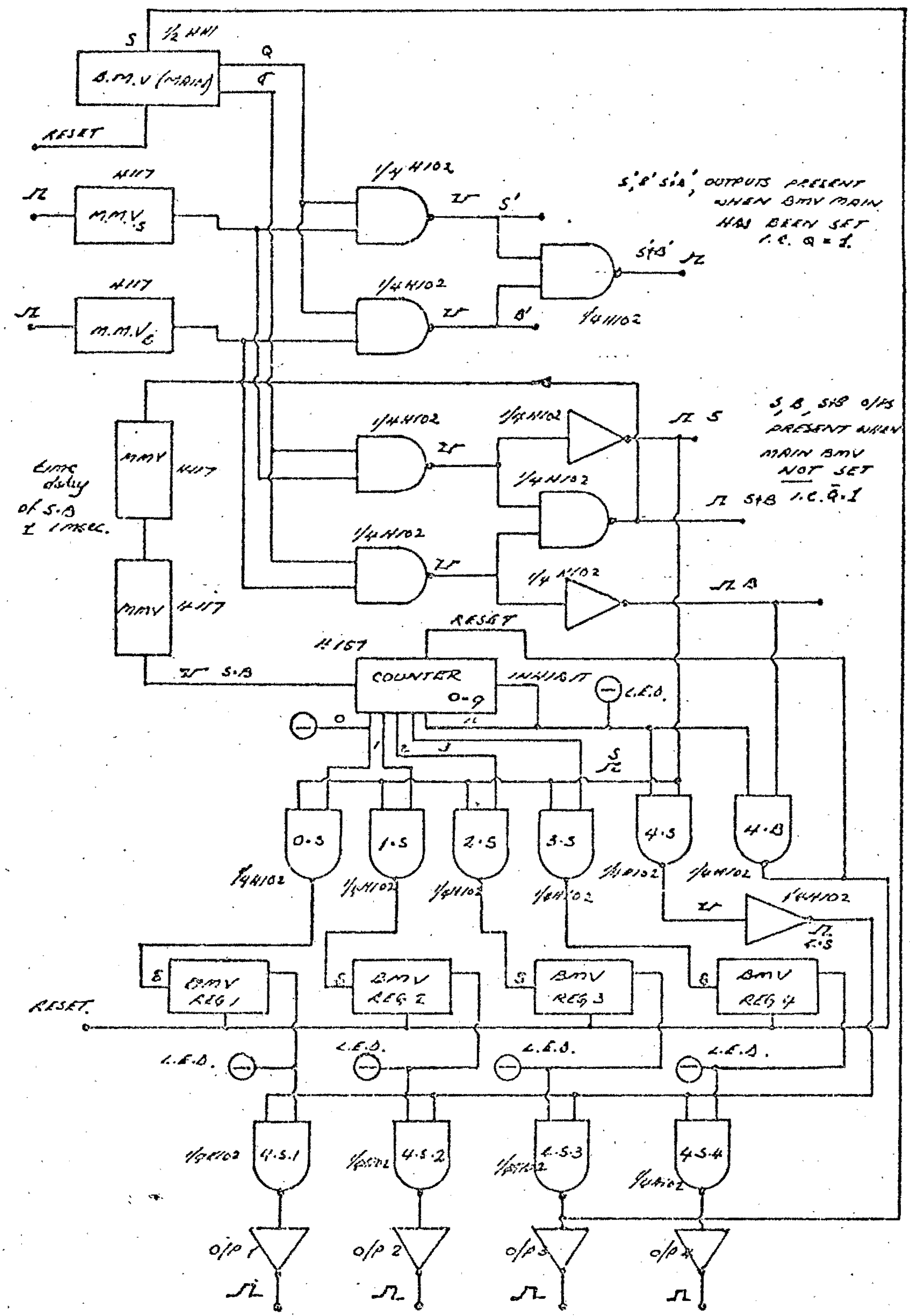


Fig. 7.7. Main Select Unit.

to accept a new sequence of select pulses. If a SUCK pulse is generated, the outputs of the four REGISTERS are combined with the S.4 (SUCK AND FOUR) pulse and outputs equivalent to 4.S . (contents of Reg. 1), 4.S . (contents of Reg. 2) 4.S . (contents of Reg. 3), and 4.S . (contents of Reg. 4), are made available to the subsequent circuitry. Only on S.4 are any signals passed on for further processing by the SBSS electronics. Light emitting dioded are used to provide an indication of the contents of the 4 REGISTER circuits as well as to provide a visual indication to the controller as to when the select sequence is readied to accepts a new coded input (COUNT '0') and when four bits of select information have been entered (COUNT '4') into the REGISTERS.

Since there are four registers, up to 16 different combinations of register settings may be entered by the controller; nine of these combinations are used to provide outputs for the main SBSS programmes.

The codes associated with control of the multifunction selection possibilities presented by the RADIO, TAPE RECORDER, TELEPHONE AND INTERCOM systems, i.e. complex functions, are so chosen that REGISTER 3 must be set to the high state if any of these functions are required to be selected. If such a code is generated and if the code is confirmed by the controller generating a 'SUCK' pulse on count '4' of the COUNTER, the MAIN FLIP-FLOP (BMV main, Figure 7.7) is triggered - (by nand gate 4.S. Reg. 3) - so that the output Q goes high. ALL SUCK, BLOW, and SUCK + BLOW signals are then diverted to provide outputs S', B' and S' + B' signals for control of selection of the individual functions associated with the particular complex function selected.

7.4.5. Main Decoder Unit

The REGISTERS.4.S outputs from the MAIN SELECT UNIT are decoded by the 4 to 10 line decoder circuit and individual functions of the main programmes are selected by the logic of the MAIN DECODER UNIT (cf. Figure 7.8).

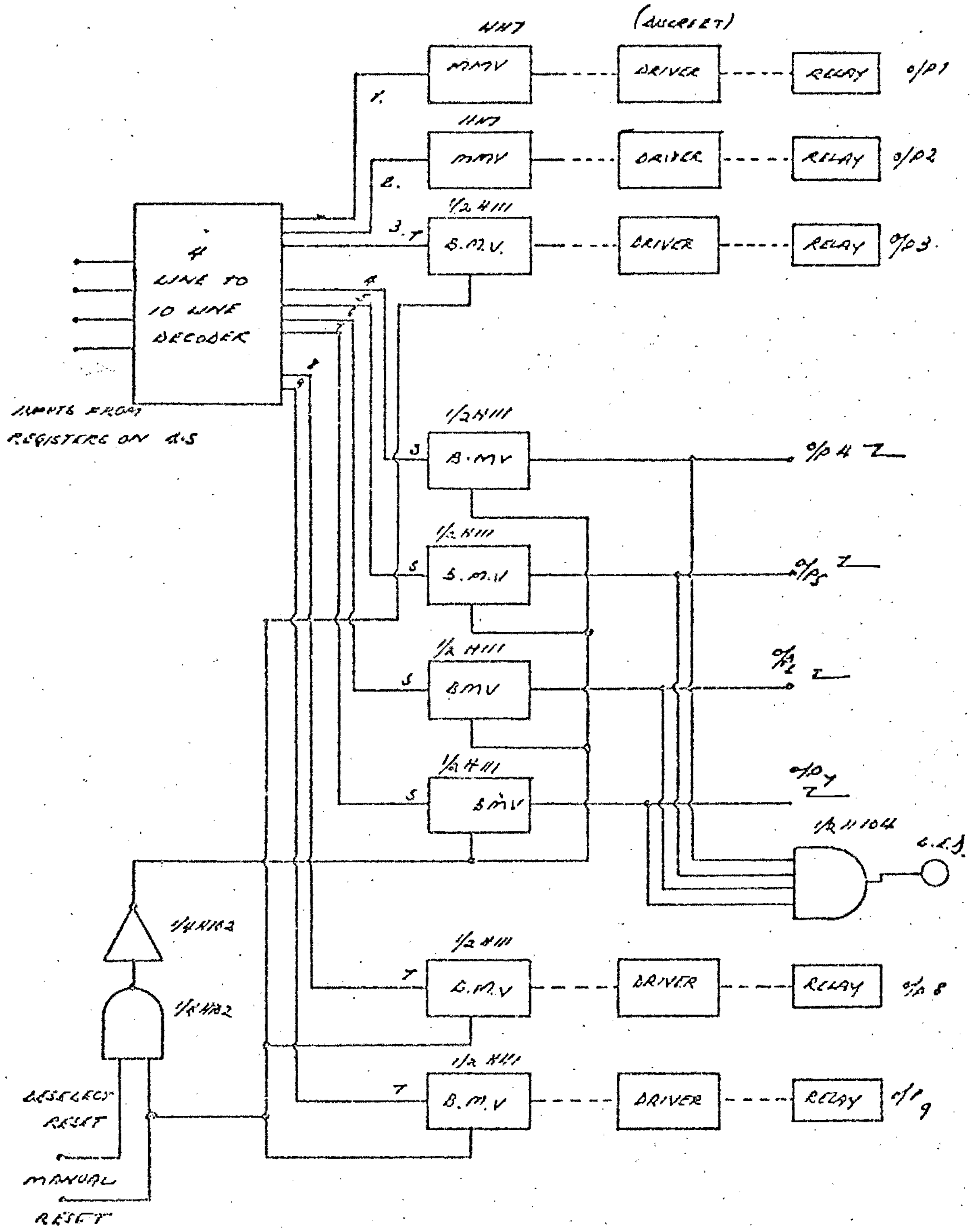


Fig. 7.8. Main Decoder Unit.

The 4 line to 10 line decoder - driver provides 'select' pulses on one of nine lines once the appropriate codes have been entered. Outputs '1' and '2' of the decoder-driver are fed to two monostable multivibrators which result in two relays being energised for periods of time determined by the MMV R-C time constants. (The CALL and PAGE TURNER functions are connected to these relays).

Output '3', '8' and '9' are coupled to respective toggle BMV circuits and are used to drive relays associated with ON-OFF type selected functions. All three of these relays control mains supply to 3 x 15 amp sockets mounted on the side of the selector mechanism cabinet.

Outputs '4', '5', '6' and '7' are fed to RS type BMV's, the input connections being made on the S line. These BMV outputs, which correspond to the selection of SUB-PROGRAMME ENABLE commands are routed to the appropriate individual circuit boards associated with programmes for providing control of suitably modified RADIO, TELEPHONE, TAPE RECORDER AND INTERCOM systems. Programme disenable or deselect signals are available either by entering the appropriate code or by depressing the manual reset button. All T flip-flops are reset to zero output when the manual reset is activated.

To advise the controller that the SBSS is operating in a sub-programme, a visual LED display indicates when any of the 4 BMV's associated with multi-function programme selection, have been triggered.

7.4.6. Sub-Select Unit

The S', B', and S' + B' signals generated once a complex function has been selected, are processed by the SUB-ELECT unit (Figure 7.9) and pulses corresponding to the coded input signals generated by the controller are made available on the unit's output lines. These are combined with the 'PROGRAMME ENABLE' signals originating at the MAIN SELECT UNIT to provide the trigger pulses for individual function selection in multifunction programmes. The functioning of the SUB-SELECT unit is analogous to that of the MAIN SELECT UNIT so far as the setting of the desired codes in

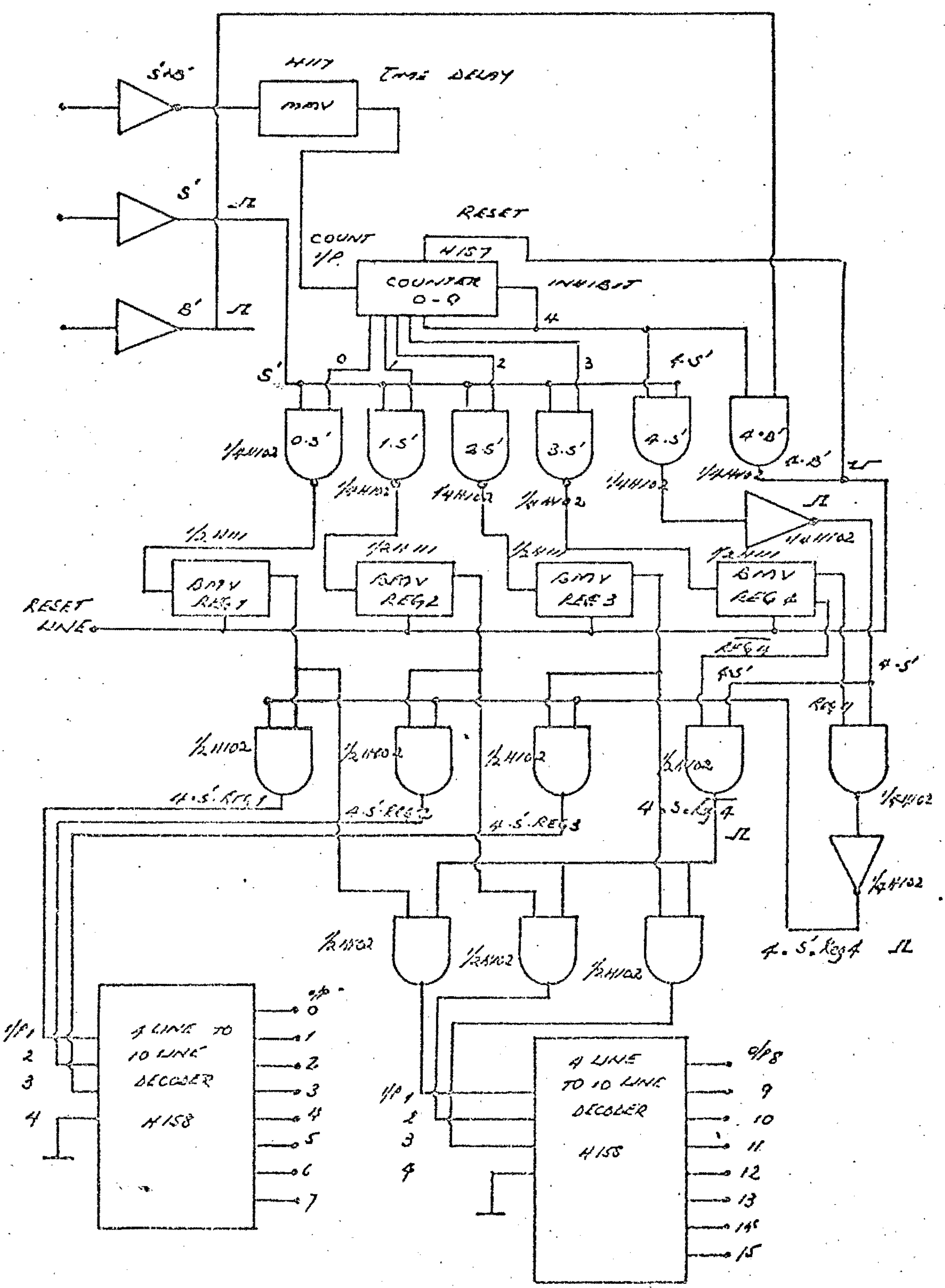


Fig. 7.9. Sub Select Unit.

REGISTERS 1-4 is concerned (cf. Figure 7.7.) As is the case in the MAIN SELECT UNIT, on count 4 of the COUNTER cycle further input impulses to the COUNT node of the COUNTER are inhibited, 4.B' resets all REGISTERS and the COUNTER to zero and 4.S' results in the contents of the REGISTERS being passed on to the decoder-driver circuits for further processing. Sixteen discrete outputs are made available by using two decoders in parallel. The output of REGISTER 4 is used to decide which of the decoders will process the entered code. If REGISTER 4 output is high, 8 output pulses are gaited via one H158 decoder; if REGISTER 4 output is low, 8 output pulses are gated via the remaining H158 decoder. Output 15, represented by code SSSS is used throughout all sub-programmes for resetting the BMV MAIN control in the MAIN SELECT circuit board, i.e. if output 15 is entered into the SUB-SELECT registers and the controller then generates a SUCK pulse, the MAIN FLIP-FLOP in the MAIN SELECT circuit is reset to enable the controller to effect selection of other functions in the MAIN PROGRAMME.

7.4.7. Complex Function Circuitry Description - Radio Control

The functions that need to be provided to facilitate total control over a commercial radio receiver system are:-

i) Radio on and off
ii) Change or select different stations
iii) Volume level control
iv) Tone level control.

A radio that was found to interface extremely well with the Suck Blow Selector System design is the Blaupunkt Wiesbaden car radio. This particular set has a station seeking facility and is easily modified for use in completely automatic mode. (The Wiesbaden does not have band selection facilities being able to receive only in the F.M. band, however, should a controller require to be able to select different wave bands, other models of radios which do have this facility are available).

The composite schematic diagram of the control circuitry employed is shown in Figure 7.10. The RADIO ENABLE signal from the MAIN DECODER UNIT is passed through an inverter before being combined with the four by 2 input nand gates.

If RADIO has been enabled i.e. if it has been selected, and if the appropriate input code has thereafter been entered, a pulse is passed to the BMV - (T flip-flop) - which results in a change of state of its output. The output change is interpreted by the driver circuitry as a signal to cause the relay controlling the ON/OFF condition of the radio to be energised. Subsequent input pulses to this BMV result in the relay being alternately de-energised and re-energised i.e. result in the radio being switched on and off.

Should the controller wish to tune into a different station, the appropriate code is entered and after having been nanded with the RADIO ENABLE signal, the pulse so generated triggers a monostable multivibrator which energises the relay associated with station change. The relay contacts short-circuit the necessary input controls of the radio for approximately 0.5 secs to initiate the station seeking sequence.

Motor Driven Potentiometers

Motor driven potentiometers are used to provide control of the volume and tone facilities of the radio. Graupner type TO 5 motors and matching gear-boxes -(gear ration 485:1) - are situated conveniently near the volume and tone potentiometers. Rubber driving belts connect the respective shafts and pulleys together (Figure 7.11).

The control circuitry operation for the motor driven potentiometers is common for both the volume and tone controls (cf Figure 7.10) and applies equally to the motor driven potentiometers associated with the volume, tone, balance and record levels of the Tape Recorder. The SUB-PROGRAMME ENABLE signal is combined with the pulses generated by entering an appropriate suck-blow sequence and fed to a 2 input nand gate. This signal is passed

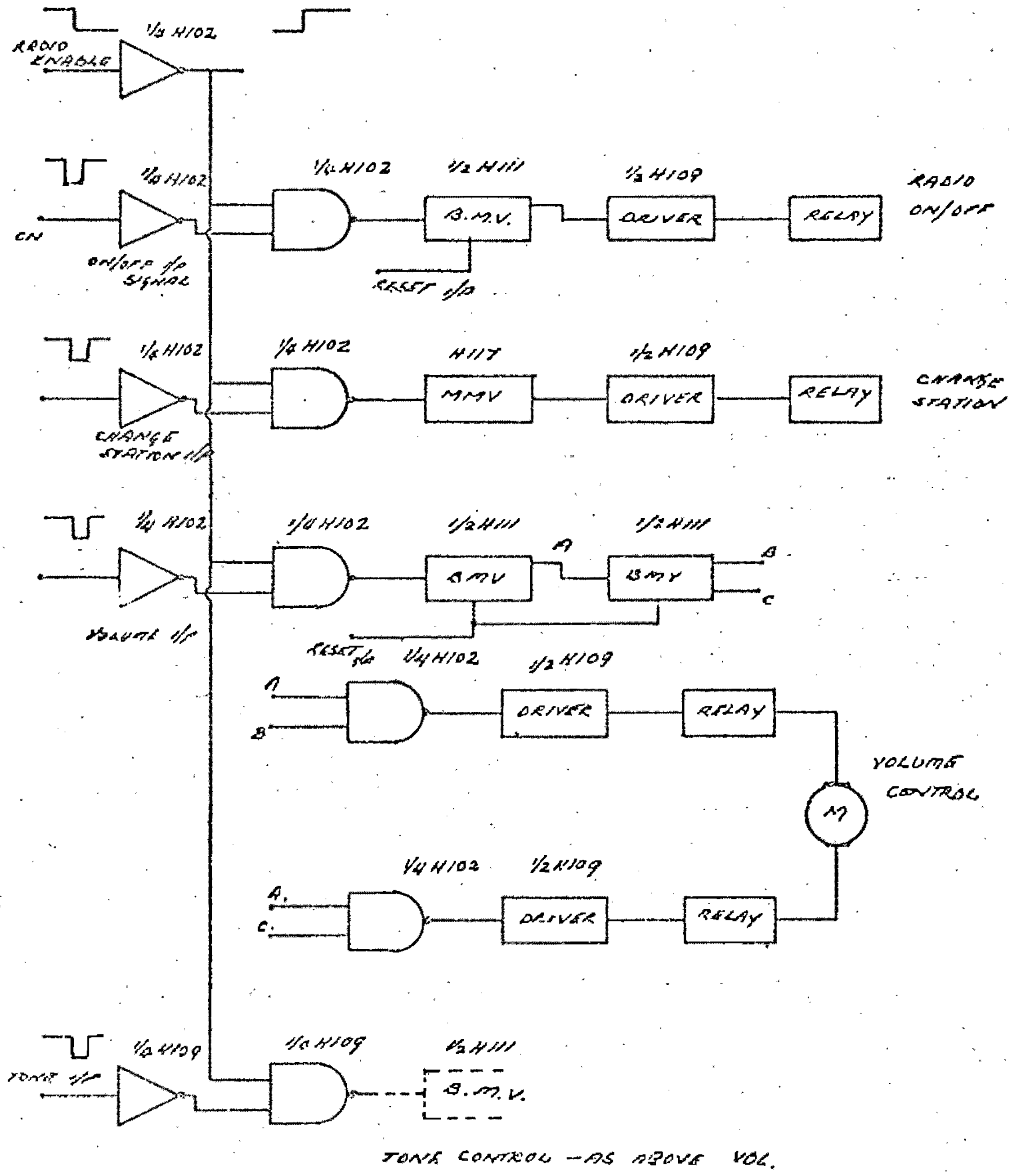


Fig. 7.10 Radio Enable

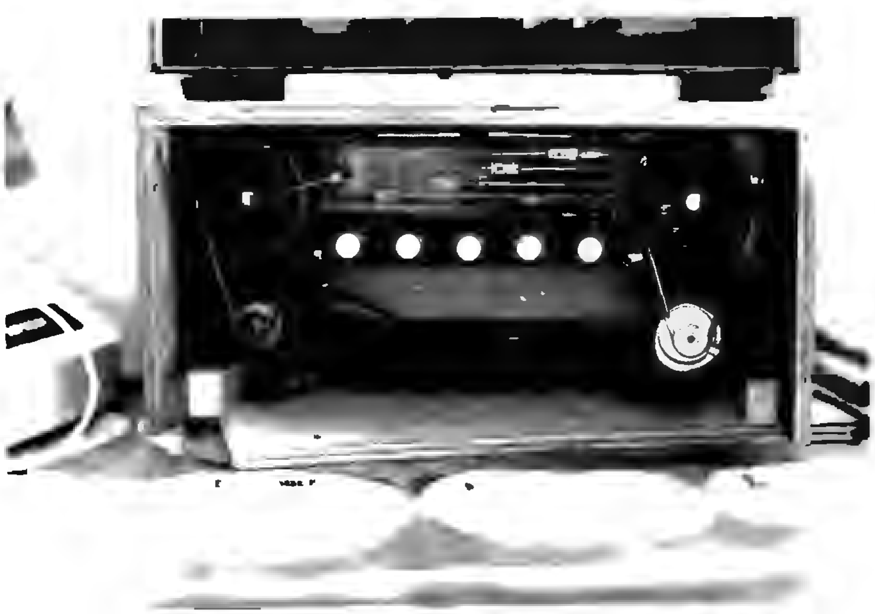


Fig. 7.11 Motor Driven Potentiometers on Radio.

to a BMV - (T flip-flop) and its output is in turn passed to a second T flip-flop. Together these two BMV circuits make up a divide by 4 cyclical counter which logs input pulses as they are generated by the controller. Two x 2 input nand gates are used to decode the counter flip-flops' output and to provide signals to respective relay driven circuits on counts 1 and 3 of the counter cycle. On arrival of the first trigger pulse, that is on count 1 of the counter cycle, a signal to the relay driver energises RELAY ONE thereby connecting the motor for clockwise rotation. At the second pulse, the relay is de-energised and the motor is consequently switched off. Count 3 results in connection of the motor for counter-clockwise rotation via RELAY TWO and count '4' once again switches the motor action off. The next select pulse starts the cycle over again.
Belt drives are adjusted so that the belts are permitted to slip once the potentiometers reach the limit of their travel so preventing stalling and overloading of the driver motors.

7.4.8. Telephone Control

The TELEPHONE Sub-Programme, once selected, results in a two c/o relay being energised. The relay is so connected to the electrics of a G.P.O. approved telephone apparatus mounted in the Selector System Cabinet, that when energised it has the effect of lifting the telephone handset off from its cradle. Incoming calls are therefore answered and outgoing calls are initiated by merely ensuring that the Telephone Sub-Programme i.e. TELEPHONE ENABLE, has been selected.

Dialling is accomplished by entering the appropriate codes specifying digits 1-10. Respective pulses so generated are combined with the TELEPHONE ENABLE line as explained below with the aid of diagrams in Figures 7.12, 7.13 and 7.14.

The SELECT DIGITS pulses arriving from the SUB-SELECT UNIT are nanded (Figure 7.12) with the TELEPHONE ENABLE line. A 10 input OR gate, made up of 3 x 4 input nand gates and 3 invertor circuits, provides a signal that indicates when the TELEPHONE ENABLE and any of the 1-10 digit signals are present - (output P Figure 7.12). Simultaneously the digit select input signals are encoded by means of a diode array to provide an appropriate 4 bit binary coded signals (Figure 7.14)

The encoded signals are entered via lines 1-4 into a 4 bit register comprised of 4 R-S flip-flops. As illustrated in Figure 7.13, the 4 R-S flip-flops are interconnected to form a 16 bit counter; the outputs from these flip-flops are connected to a 4 input nand gate.

Once a digit select signal has been entered into the Register-Counter, the nand gate output goes high and this provides a signal to energise a 2 c/o contact relay. This relay, when energised effectively short circuits the transmitter and receiver terminal of the telephone handset - (as is the case when dialling is effected with normal telephone usage). Further, the 4 input nand gate output is fed to a 3 input nand gate having as its other two inputs, input P (of Figure 7.12) and an input derived from a free running astable multivibrator (Figure 7.13).

Input P to the 3 input nand gate, returns to its high state once the dialling select signal has passed, and, should the 4 input nand gate output be high - (as would be the case if a digit had just been entered into the 4 bit register), all 3 inputs to the nand gate would be high for periods of time determined by the astable multivibrator time constants. Consequently, for as long as P is high and provided the outputs of the 4 registers are not all high, the AMV signal is passed on by the 3 input gate. This output signal triggers a monostable multivibrator which feeds the COUNT node of the Register-Counter configuration and also causes the driver to energise its corresponding relay to pulse the G.P.O. line thus effecting dialling. This continues until the Register-Counter has all its outputs in the high state. At this time one of the inputs to the 3 input gate feeding the monostable multivibrator will go high thereby preventing further AMV Count pulses and Dialling pulses from being generated.

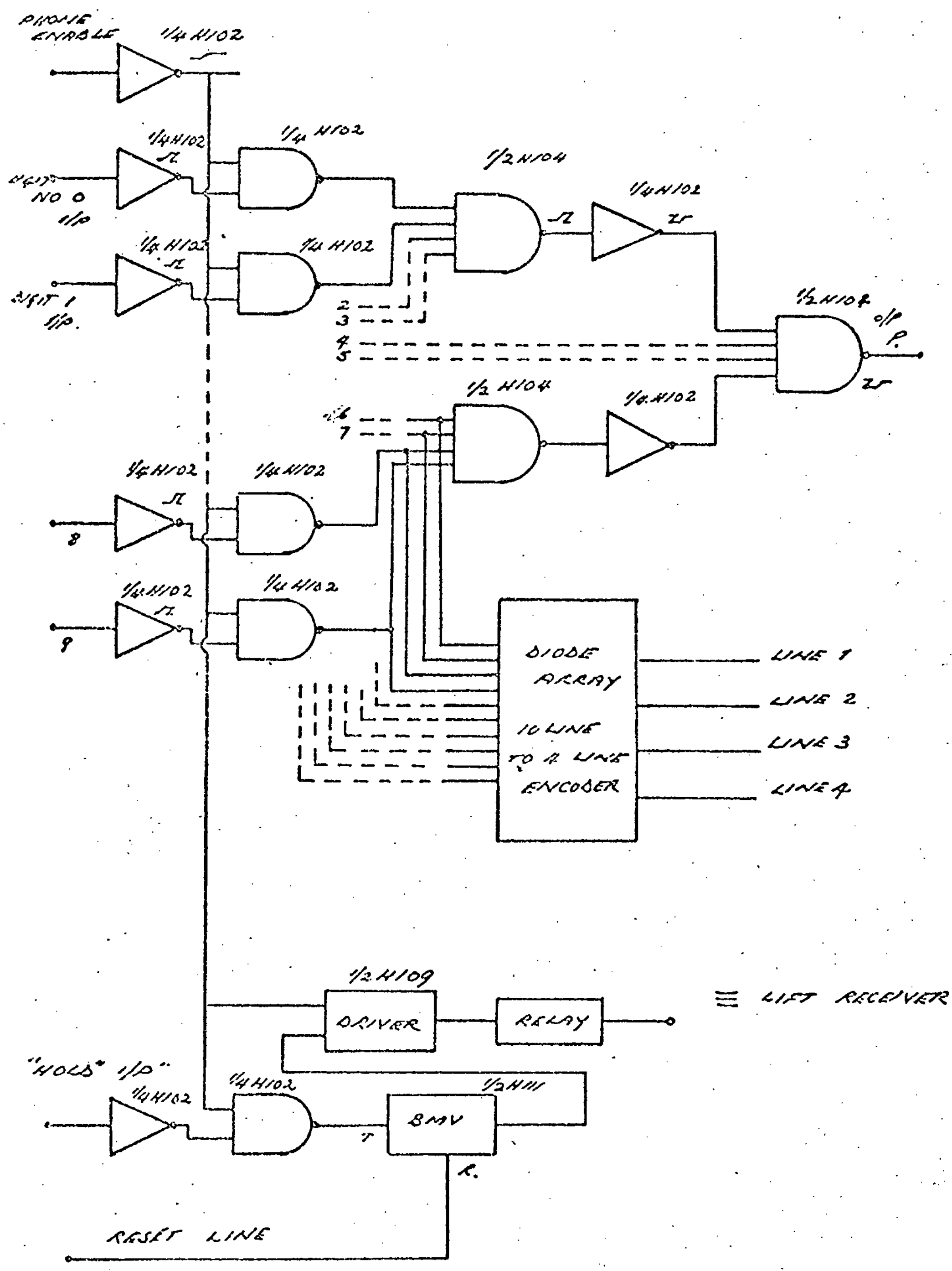


Fig. 7.12 Telephone Control No.1.

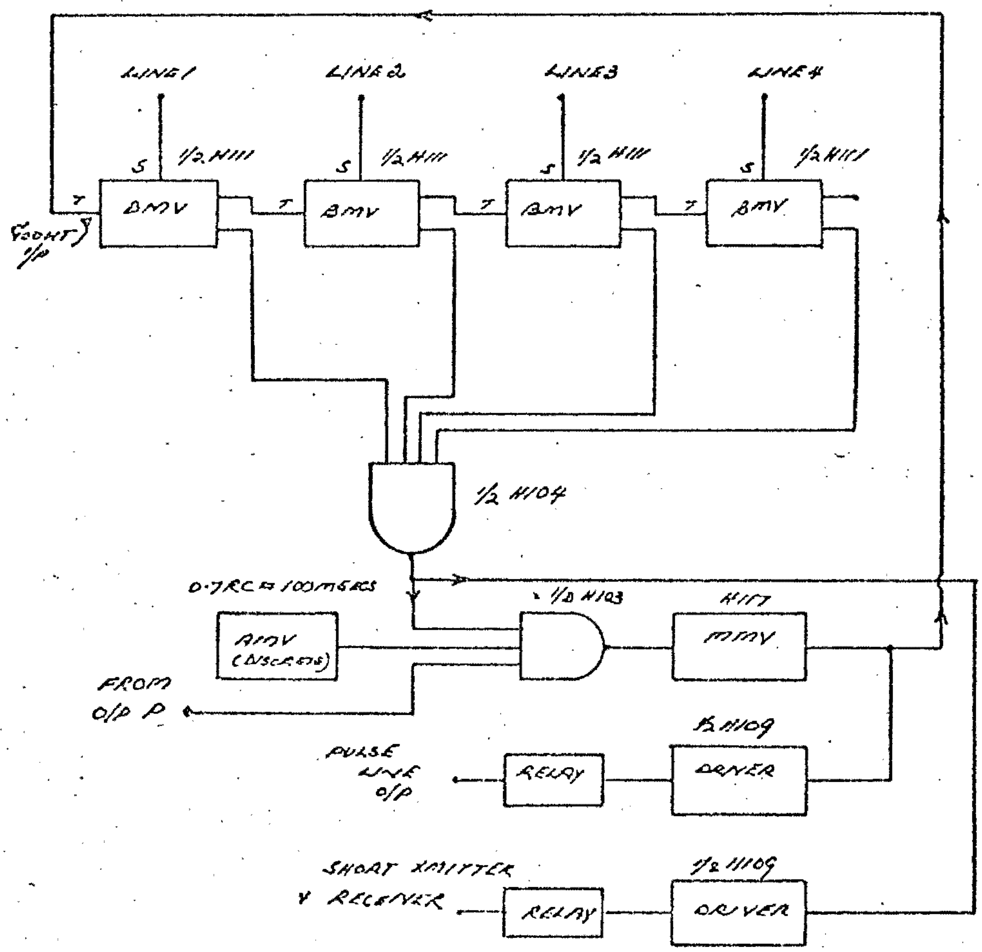
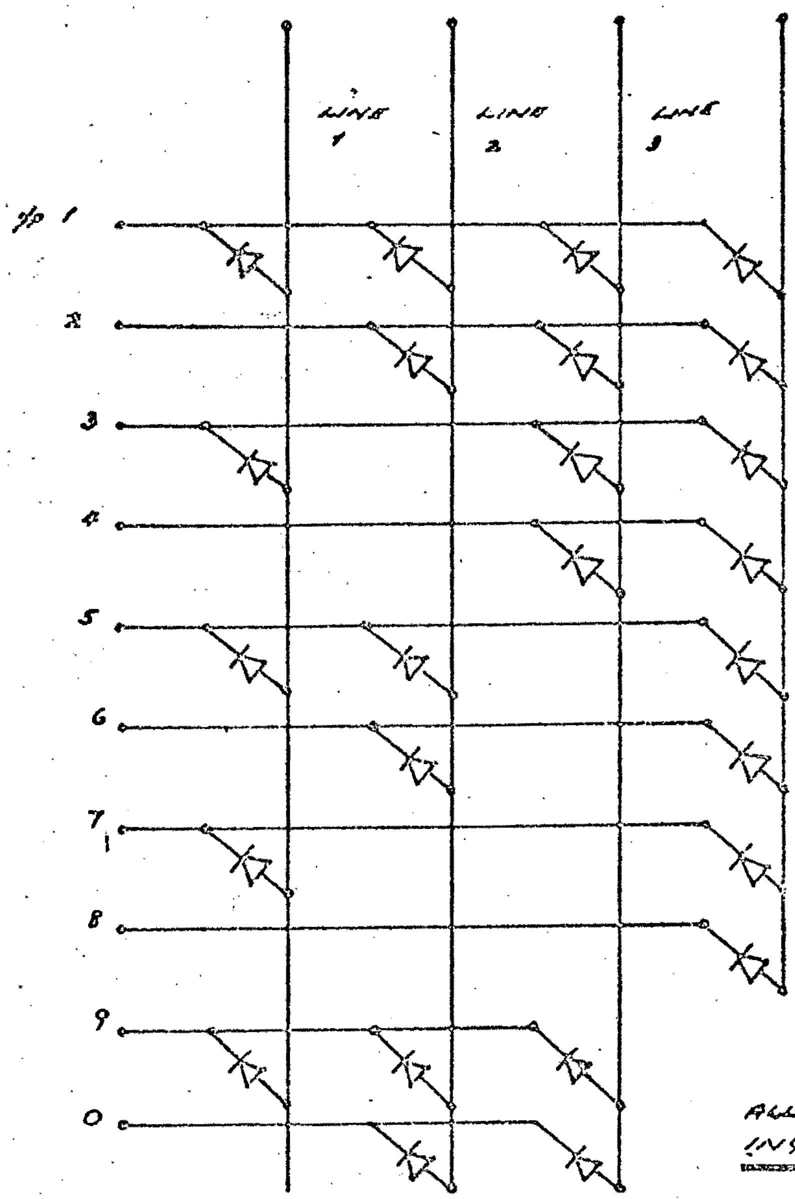


Fig. 7.13 Telephone Control No.2.



DIGIT	LINE 1	LINE 2	LINE 3	LINE 4
1	0	0	0	0
2	1	0	0	0
3	0	1	0	0
4	1	1	0	0
5	0	0	1	0
6	1	0	1	0
7	0	1	1	0
8	1	1	1	0
9	0	0	0	1
0	1	0	0	1

ALL DIODES IN914 OR EQUIV.

Fig. 7.14 Telephone Input Encoding.

Encoding

Referring to Figure 7.14 it is seen that to select digit 1 - (i.e. to dial digit 1) - all 4 Registers' outputs are set to zero; i.e. counter outputs are 0000. The arrival of an encoded '1' pulse sets all Registers to the '1' state. Encoding Registers so that their outputs are 1000 results in two pulses being permitted to pass through to the counter before their outputs become 1111 thereby inhibiting subsequent AMV pulses from triggering the counter input. Setting Registers such that the counter output is 1100 results in '3' being dialled, and so on.

Hands Free Telephone Operation

For Selector System operators who are unable to lift the telephone handset to their heads, a loudspeaking telephone set - (AIWA GA88 or sim.) may be used to facilitate conversation in a 'hands-free' mode. The obvious lack of privacy when making telephone calls using this type of device can only be overcome in such circumstances by the operator using a telephonists' handset.

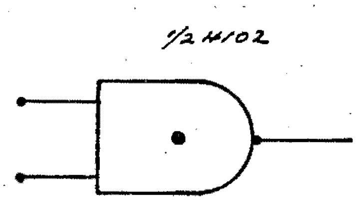
Hold Facility

As indicated above, once the TELEPHONE ENABLE circuit has been selected, a relay is energised which has the equivalent effect of lifting the handset off the cradle. Conversely, once TELEPHONE has been de-selected the effect is to replace the handset on the cradle and thereby terminate the telephonic link. Should the controller wish to enter some other main programme after having accepted or initiated a call - (for example he might wish to turn the radio volume down or wish to switch on the tape recorder) - he would risk losing the call as soon as he entered the other selected sub-programme. To eliminate this undesirable feature, a 'HOLD' facility is built into the telephone circuitry. Selecting 'HOLD' sets a T flip-flop (Figure 7.12) thus providing an alternate OR signal to the 'lift handset' relay. Having selected 'HOLD' the controller is free to move to any of the remaining programmes to effect selection of a function of his choice. 'HOLD' should be de-selected once TELEPHONE has been selected so that the alternate OR input signal is no longer present when the controller wished to terminate the telephone call.

7.4.9. The Impulse Triggered Monostable Maintained Switch (ITMMS)

By connecting two x 2 input nand gates as shown in Figure 7.15 it is possible to synthesise a switch which finds application in a number of circuits of the Selector Systems.

It is at times required to channel a sustained signal such as that put out by a monostable or by a PROGRAMME ENABLE signal to one of a number of possible circuits. Applying this signal to all the circuits and a trigger pulse to the particular circuit will result in that circuit changing its output state from high to low; it will maintain itself in the low position for as long as the monostable pulse or PROGRAMME ENABLE input signal is present. For identification purposes the writer has designated the circuit as follows:-



7.4.10. Tape Recorder Control

The tape recorder deck, Philips type 2401, was chosen for use in the Select Systems for the following two main reasons:-

i) the push button controls facilitate interfacing with linear motors, and

ii) an inbuilt casette eject and re-cycle system permits a choice of any of 12 sides of taped music, dictating space, etc. without external intervention.

Aside from volume, tone, balance and record level controls, provision for start-eject, stop, pause, record, tape forward and rewind controls must be

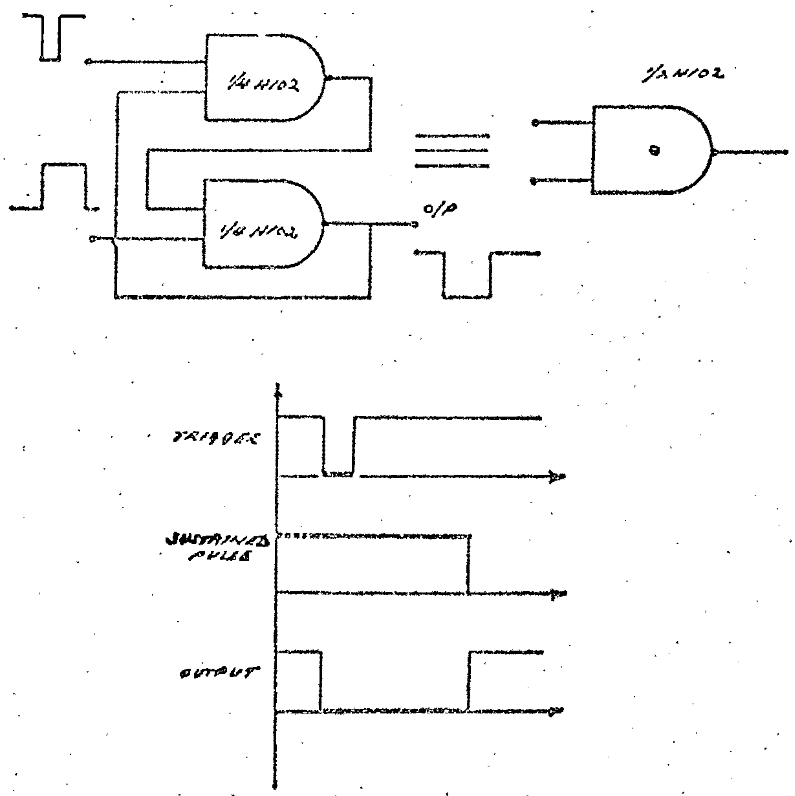


Figure 7.15

Fig. 7.15 Impulse Triggered Monostable maintained Switch.

made. Four motor driven potentiometer control circuits permit volume, tone, balance and record level adjustments. For these four circuits the TAPE ENABLE signal is combined with 4 decoded SUB-PROGRAMME inputs to generate pulses to the appropriate four bit cyclical counters (Figure 7.16 and page 175).

Substantial efforts directed at using solenoid operated rams for pushing down lever operated tape recorders decks yielded disappointing results. Continual adjustments to the lever and spring return mechanisms (Figure 7.17) were necessary and the powerful solenoids actions that were required generated excessive noise. Further the workshop time taken to construct the solenoid operated unit was inconsistent with the quality of the overall results obtained.

After due consideration it was decided to investigate the possibility of using pneumatic piston and cylinder rams for providing the motor power necessary to operate lever or push button tape recorder controls. The simplicity of operation of the system and the ease with which the prototype was constructed left no doubt as to which system, the electro-mechanical or, electro-pneumatic, was to be preferred. The advantages of the pneumatic system i.e. ease of operation and maintenance free operation far outweigh the inconvenience of having to change the 40 cubic ft. compressed air supply cylinders approximately once every 10 weeks.

Two way and three way solenoid operated pneumatic valves with 220 volt AC coils are provided to control the gas flow (Figure 7.18) to the rams.

Solenoid Operation

The three way valve is the Master Control for the gas supply to the ram array. When the solenoid of the valve is not energised, a flow path between ports C & B (cf Figure 7.18) is available. When the solenoid is energised gas is permitted to flow from the supply cylinder via the regulator, through path AB of the system to the individual 2 way valves supplying particular rams. The operation of the valve timing sequence is illustrated with the aid of Figures 7.19 and 7.20.

After the RECORDER ENABLE signal has been inverted it is fed to nand gates which provide an output when a desired function is selected. The - (negative going) - impulses so generated when 'START-EJECT', 'STOP', 'PAUSE', or 'RECORD' TAPE RECORDER functions are required, are passed through a NOR gate comprised by the triple 3 input nand gate - (H103) - and MMV_3 as well as MMV_2 are triggered. The MMV_3 output is coupled to the solenoid of the three way valve, and gas flow is permitted to flow through path AB for a time T_3. Simultaneously, MMV_2 and the trigger pulse associated with the selected function, are passed to the appropriate impulse triggered-monostable maintained switch - (for detailed operation of this ITMMS switch of page) - and the corresponding 2 way valve is opened for time T_2. Since time T_2 is greater than T_3, the gas is exhausted from the selected ram - (via path BC) - after time T_2 - T_3 has passed. Ram impulses are thereby available for the functions 'START-EJECT', 'STOP', 'PAUSE' and 'RECORD'.

Since it is necessary - (from the tape deck operation viewpoint) - for the 'PAUSE' ram to be depressed prior to the 'RECORD' ram being operated, the 'PAUSE' ram is always triggered whenever RECORD is selected. An R-C circuit delays the input to the RECORD ram solenoid however, by approximately 0.2 secs, thereby ensuring that the PAUSE button has already been depressed before the RECORD ram is operated.

For TAPE FORWARD and REWIND it is necessary to maintain the push button controls on the Tape Recorder in the depressed state for as long as these functions are required. A third monostable MMV_1, together with MMV_3 provide the timing pulses necessary to accomplish this. Referring to Figure 7.20 it is seen that the FORWARD or REWIND pulses are passed through to respective T flip-flops which provide a change in output signal of the nand gate - (output forward - rewind ÷ 2) - for every <u>second</u> 'FORWARD' or 'REWIND' impulse generated. This signal is passed through to the OR

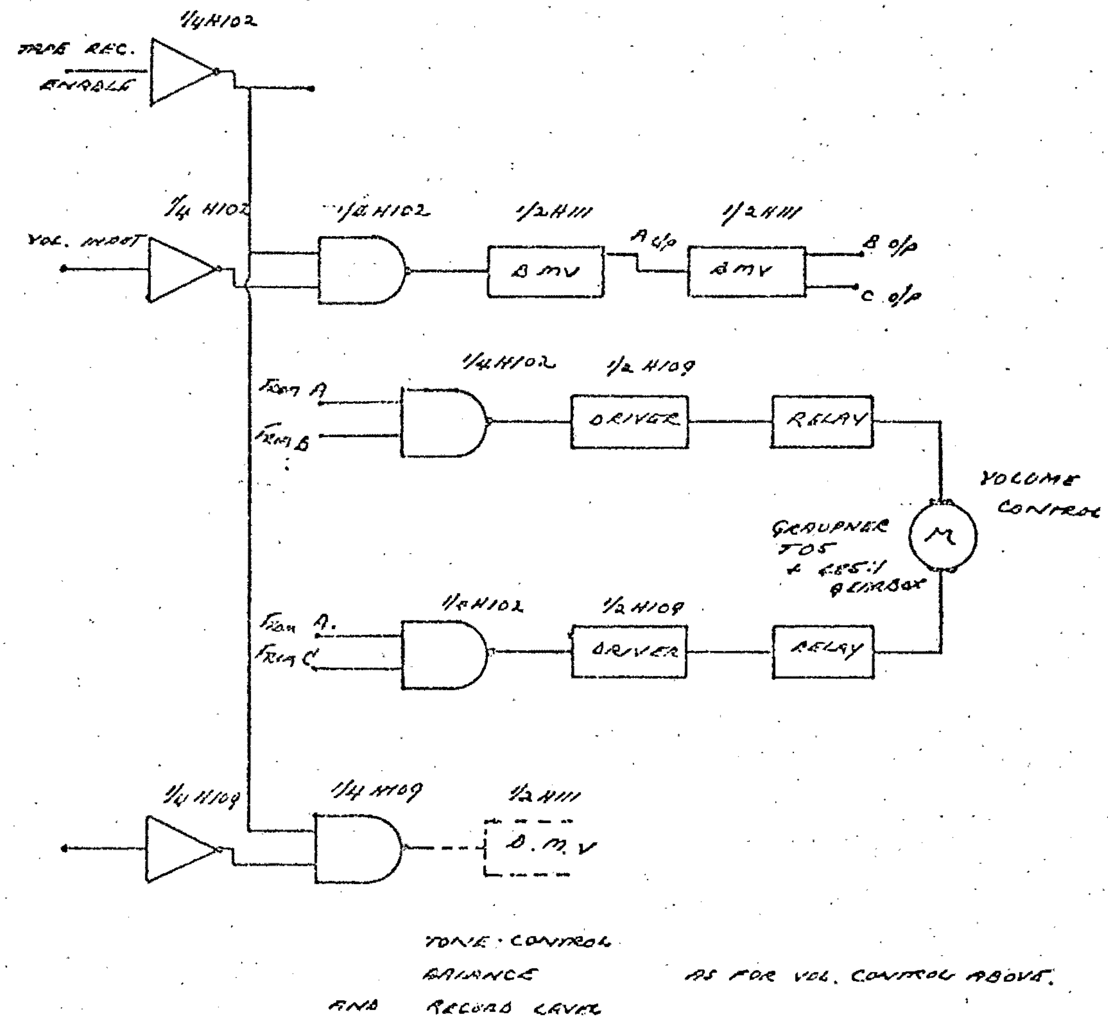


Fig. 7.16. Motor Driven Potentiometers for Tape Recorder Controls.

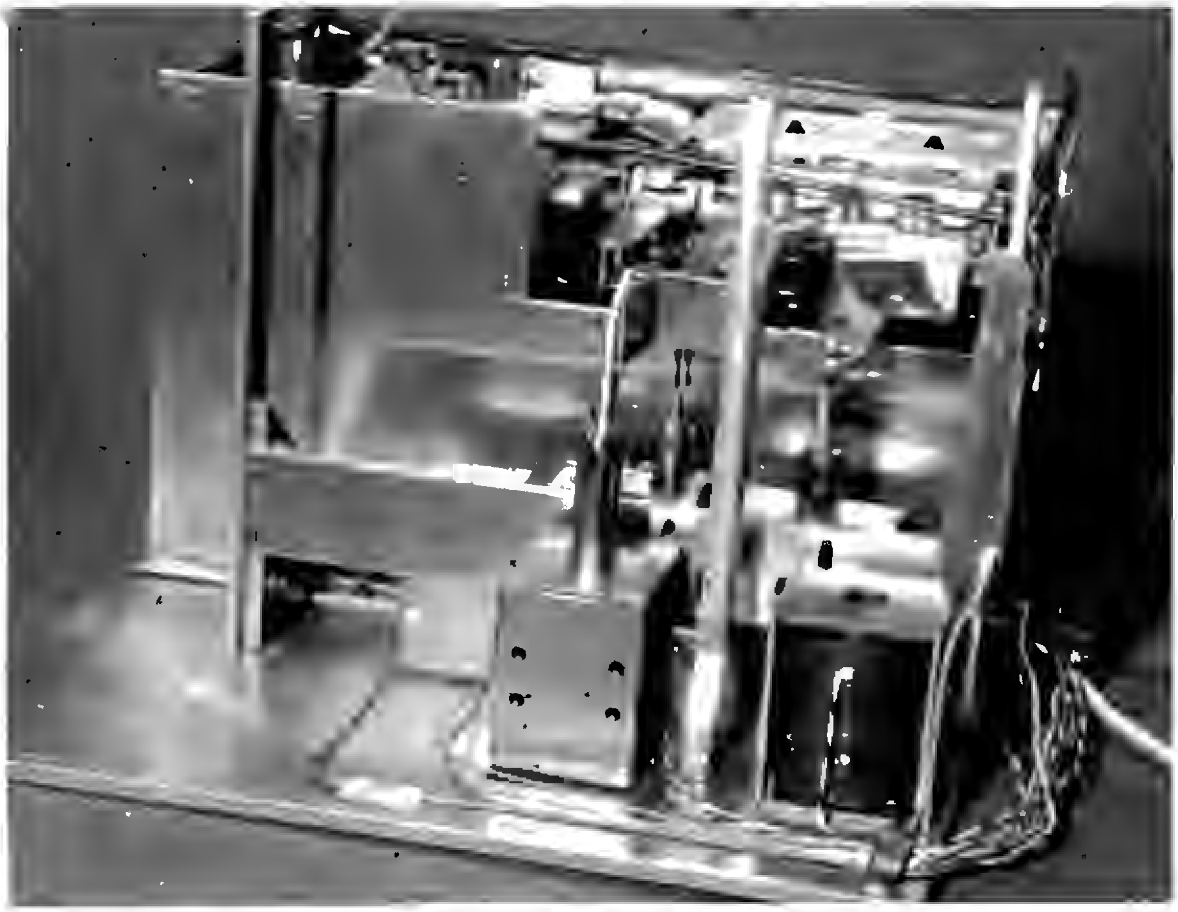


Fig. 7.17. Electro-Magnetic Solonoid Operated Tape Recorder Control.

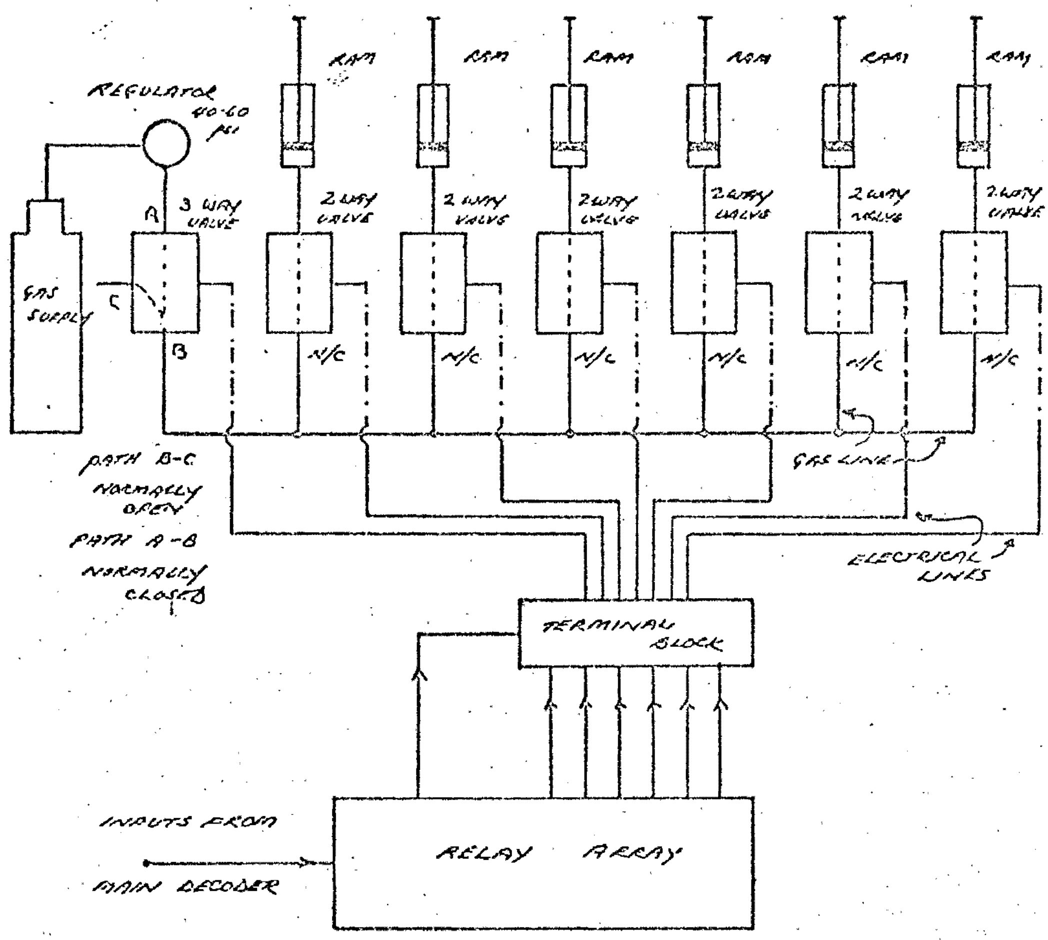


Fig. 7.18 Tape Recorder Operation.

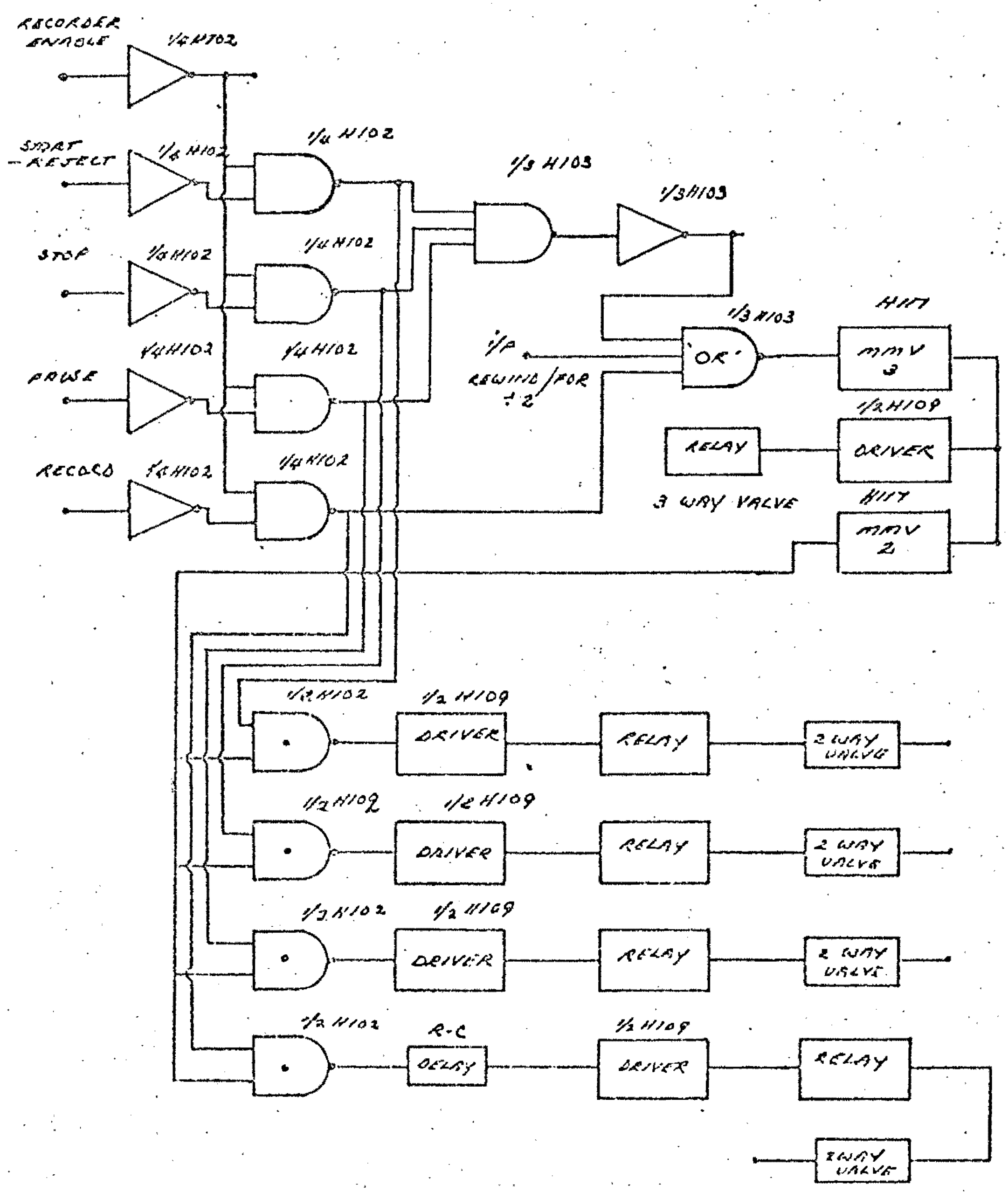


Fig. 7.19 Tape Recorder Control No. 1.

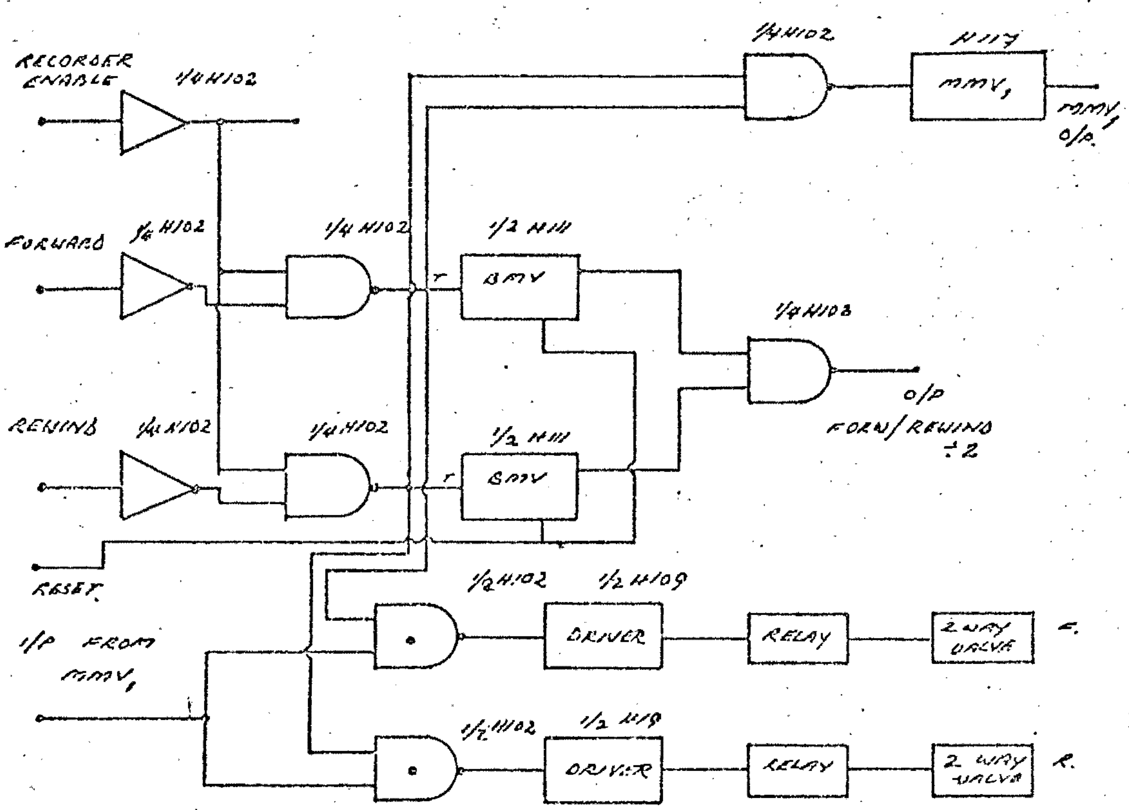


Fig. 7.20 Tape Recorder Control No. 2.

gate of Figure 7.19 and causes MMV_3 to open the 3 way valve. Simultaneously (Figure 7.20) MMV_1 is also triggered and this signal together with the appropriate trigger pulse sets either the FORWARD or REVERSE ITMMS opening the corresponding 2 way valve for time T_1.

The interval T_1 is however shorter than T_3; the gas present in the ram therefore is trapped since the two way valve closes before the three way valve has permitted the gas to be exhausted from the system. The ram piston is consequently held in the extended position, thereby maintaining the push button associated with the selected function in the depressed position. When the function is reselected the 'reverse - forward $\div$ 2' signal goes high again and since MMV_3 can only be triggered by negative going pulses on the NOR input gate, MMV_3 and hence the 3 way solenoid valve remains untriggered. MMV_1 however <u>is</u> triggered and the appropriate two way valve is opened. The gas entrapped in the ram is now able to escape through path BC of the unenergised 3 way valve and the ram piston is retracted thereby cancelling the FORWARD or REWIND selection. It should be noted that once a FORWARD or REWIND signal has been entered, no other operating instructions can be accepted - (other than instructions to the motor driven potentiometers) - since the NOR gate of Figure 7.19 is permanently triggered. The 3 way valve can not be further triggered until the FORWARD or REWIND instruction is cancelled. The safety feature is necessary for the protection of the tape deck mechanism.

Mechanical Details

Compressed air stored at 2200 lbs/sq. inch in a 40 cubic ft. cylinder is directed to the solenoid-ram assembly via flexible rubber hose. A gas regulator is used to reduce the pressure to a working pressure of 40 lbs/sq. inch. Single acting miniature piston and cylinder assemblies of 1" stroke - (types TF 1006 (8mm bore) and TF 1016 (12mm bore) made by CPOAC Pneumatics-Hydraulics of France), are mounted on a steel framework overhanging the tape recorder push button array. The framework is bolted down to the cover of a wooden cabinet in which the solenoid valves and their associated relays are housed. Miniature 2 way and 3 way valves with 220 volt coils supplied via a double wound isolating transformer are used to control gas flow to the piston and cylinder assembly. Flexible plastic tubing of ¼" diameter connect respective rams and valves together.

To facilitate servicing the cabinet cover is hinged, thus providing access to the control system. A second metal framwork is provided for the mounting of the motor and gearbox assemblies. As in the RADIO control, the potentiometers are connected to their respective gearbox outputs by suitable pulleys and driving belts. Adjustments may be made to the tension of the driving belts by altering the motor positions along milled slots in the metal framework assembly. The tape recorder may be removed from the ram and motor assembly quite easily by merely detaching the driving belts associated with the motor power supply to the tape recorder.

7.4.11 Intercom Unit

The INTERCOM ENABLE signal generated by selecting the appropriate sub-programme is combined with signals derived from the SUB-SELECT UNIT to provide inter-communication on a Master-Slave basis between the controller - (master) - and three remote stations - (slaves) - (Figure 7.21).

Once the controller has entered the necessary signal to connect to the required slave station, an ITMMS provides a signal to energise the relay associated with the particular slave. Any or all of the stations may be selected and switched in at the same time.

The Speak-Listen relay of the intercom is activated by combining the appropriately encoded signal with the INTERCOM ENABLE so that repetitive triggering of this function results in pulses being made available to a T flip-flop. The T flip-flop alternately causes the Speak-Listen relay to be energised or de-energised. A visual indication of when a station has been selected is incorporated in the Slave speaker units. The occupants

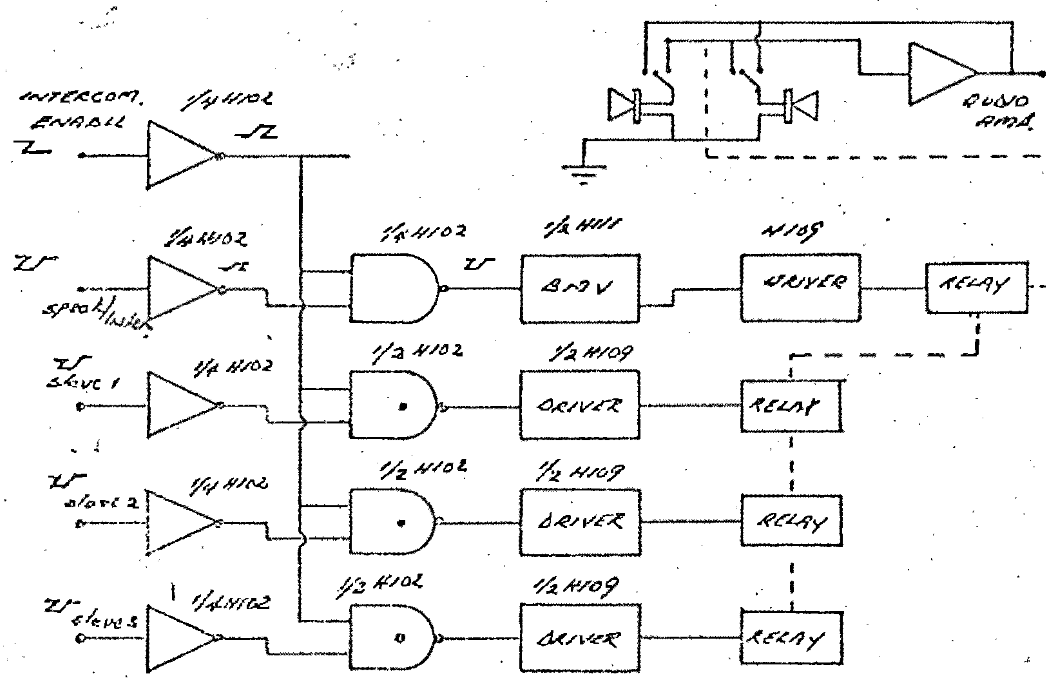


Fig. 7.21. Intercom Control.

of the room or area in which the speaker is situated, are thus able to tell that the SELECTOR SYSTEM controller is in contact with them.

The amplifier used in the prototype selector system intercom is constructed using an integrated circuit module. The design of this circuit is not at all critical and any convenient amplifier may be used provided that the input and output speakers have common negative connections going to earth. The power supply for driving the amplifier may be taken from the existing VCC_2 12 volt supply of the MAIN SUPPLY unit (cf page 190).

7.4.12 Indicator Display Cabinet

So that the controller is aware of the state of the major nodes in the SBSS electronics and to facilitate controller proficiency and efficiency, a numerical display is provided. The display indicates the contents of the two sets of REGISTERS i.e. the contents of MAIN SELECT and SUB-SELECT REGISTERS and in what states the respective COUNTERS are. The display unit is housed in a small cabinet separate from the Main Processor Unit (cf photograph) and is connected to the Main Processor Unit via a multi-way plug and socket. This enables the display unit to be situated in an optically convenient position for the controller.

Output signals taken directly from the REGISTERS are fed to 'high level logic to low level logic' convertor circuits - (H113 of Figure 7.22) - and after inversion are coupled directly into 4 line to 10 line decoder driver circuits plus associated Nixie indicator tubes. For the REGISTERS associated with the SUB-SELECT decoder unit, visual display of the tens as well as units digit is required - (to display digits 0-15). The tens digit is consequently derived by suitably gating the input to a driver transistor of the appropriate Nixie tube filament. Light emitting diodes indicating the states of the multi-function programmes and their respective appliances are mounted on the front panel of the indicator unit. The operation of these LED's is determined by the INDICATOR DRIVER circuit board.

Display Cabinet

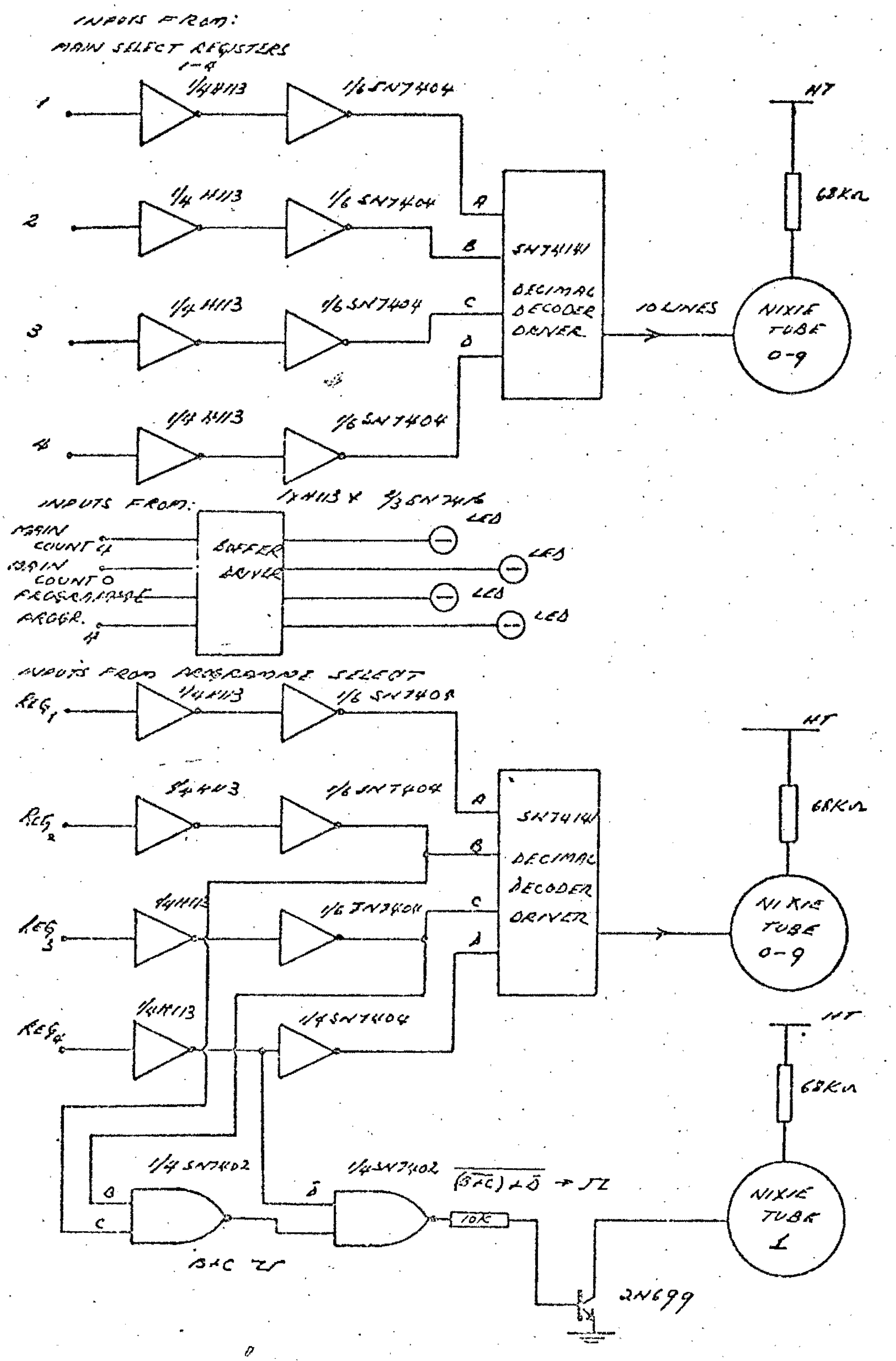


Fig. 7.22 Indicator Display Circuitry.

7.4.13 Indicator Driver Circuit

Signals for the control of the INDICATOR DRIVER circuitry (Figure 7.23) are derived from the MAIN SELECT UNIT outputs and from individual Sub-Programme circuit boards. When functions '8', '9' and sub-programme INTERCOM are selected and switched on i.e. if Mains power is present at plugs '8' or '9' and/or if the INTERCOM is in use, a corresponding LED is switched on. When these functions are de-selected the LED is switched off.

The display circuitry associated with the remaining multifunction controls is more complex. For example, four states are indicated by the LED associated with the RADIO circuit. These are:-

1) LED off	- Radio off, and radio programme not selected
2) LED on and flashing quickly	- Radio programme selected but power to radio itself is switched off
3) LED on and flashing slowly	- Radio programme selected and power to radio present
4) LED continuously on	- Radio programme de-selected and radio power present.

Two free running astable multivibrators constructed from 2 by $\frac{1}{2}$ SN 7413, Schmidt Trigger circuits provide the timer pulses for the different flashes signal rates - (fast and slow).

Signals representing the state of the programme i.e. whether the programme has been selected or not, and whether the radio etc. has power supplied to it or not, are fed to 3 by 3 input nand gates and depending on their input conditions, there is a discrete output from each of these gates.

The outputs from the 3 nand gates are fed to a further 3 input nand gate and its output indicates what the combined state of the sub-programme selection and its associated appliance is. After being inverted by a 1/6 SN 7404, the signal is current amplified - (by 1/6 SN 7416) - and used to drive the appropriate LED indicator lamp.

The Tape recorder display circuitry is the same as that employed for the Radio display.

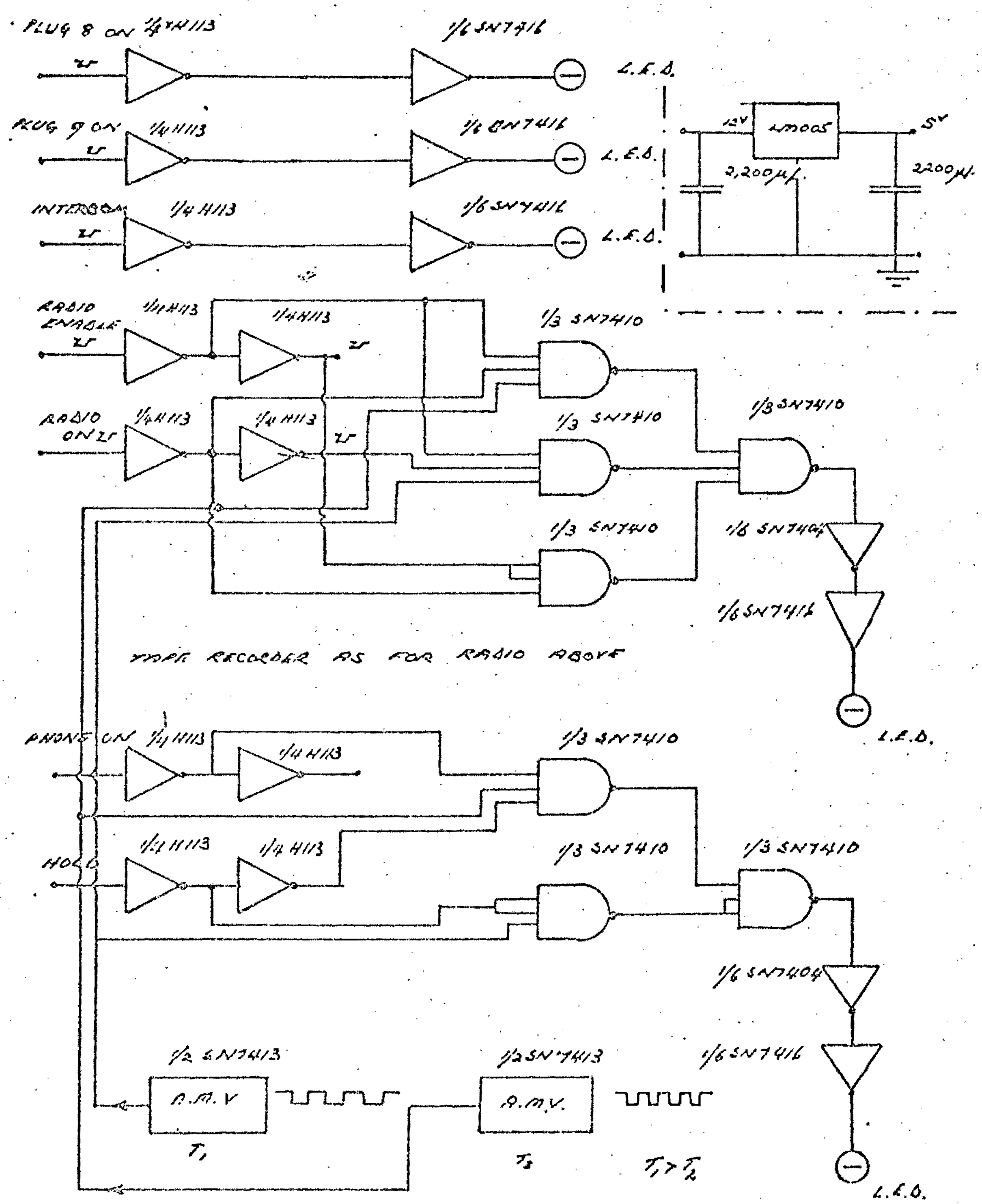


Fig. 7.23. Indicator Driver Circuit.

The Telephone circuit is slightly different in that it indicates only when the telephone has been selected - slow flashing, and when the HOLD circuitry is operational - fast flashing. The TELEPHONE ENABLE, the HOLD off, and Long Time Constants amv signals are combined to form one input to the LED driver circuitry, while the 'HOLD' on and Short Time Constant amv provide the second input to the LED driver circuitry. Since the display circuitry consists only of passive type circuits, i.e. it does not contain any bistable or monostable decision making elements, there is no danger that noise generated by spurious interference could cause erroneous signal outputs. It is therefore not necessary to use high level logic circuits in this unit. Except on the input side where high level to low level logic converter circuits are used - (H113) - TTL circuitry is used for the remaining parts of the circuit. Provision for a low voltage power supply for the TTL circuits, is made by incorporating on card, a SGS type LM 005 5 volt regulator.

7.4.14 Relay Driver Circuitry

Where practicable card relays - (Siemens Type V 23012) - are incorporated directly on the plug-in printed circuit boards to switch output contacts associated with function selection. However, for mains operated circuits and other functions requiring substantial power for their operation, relays with heavier switching contacts are employed - (Omron Type 5 amp c/o contacts). The command signals for operating these relays are directed to the DRIVER x 10 circuit board which is mounted directly onto one wall of the SBSS cabinet. This board consists essentially of ten current amplifiers as shown in Figure 7.24, which are able to supply sufficient current to operate the power relays.

7.4.15 Power Relay Mounting Board

Provision is made for mounting up to fourteen power relays on the Power Relay Mounting board (cf Appendix F). Printed circuit board mounting plug-in sockets are used for each relay to facilitate replacement of the

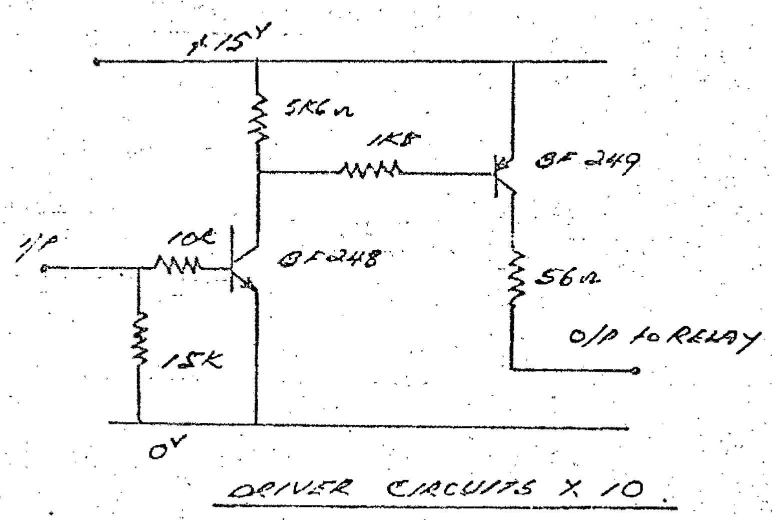


Fig. 7.24 Relay Driver Circuitry.

relays should this become necessary. Appropriate capacitor and resistor protection is provided for the c/o contacts to prevent arcing, thereby minimising electrical interference and extending contact life. The Relay Driver circuitry is also protected by connecting a reverse biased diode and suitable condensor across the relay coil terminals.

An OR gate driver circuit - (IC H109) - is also incorporated on the Power Relay Mounting board. Signals from the TELEPHONE ENABLE and Telephone HOLD circuitry are directed to the inputs of this OR gate. When energised, the relay associated with the OR driver circuit has the effect of lifting the telephone from its cradle.

The Power Relay Mounting board is located on the base of the Control System Cabinet and is held in place by four locating screws.

7.4.16 Main Power Supply

Separate supplies (Figure 7.25) are provided for:-

i) logic circuitry, and

ii) the relay drivers, indicator and other components requiring 12 volt regulated supply.

Integrated circuit regulators which are internally short circuit protected provide the basic regulation for the supply. The units used, SGS type LM 036, can provide up to 500 m.amps without external components. However, to extend the current handling capabilities of the device an external power transistor type 2N3055, mounted on a suitable heat sink is provided. Each supply is fed from a 4 amp 30^V centre tapped transformer via two BFX 39 diodes - (rated at 6 amps), and a 2,500 mf smoothing condensor. When switching the system on, to ensure that all the logic circuitry output relays, etc., are in the 'off' or 'reset' state, the system RESET line is held at zero volts - (the required reset voltage), for approximately 0.25 secs. This is accomplished by means of the relay in Figure 7.25, supply L. Since it takes a finite time for capacitor C_1, to charge via R_1 to the voltage necessary to switch transistor T on,

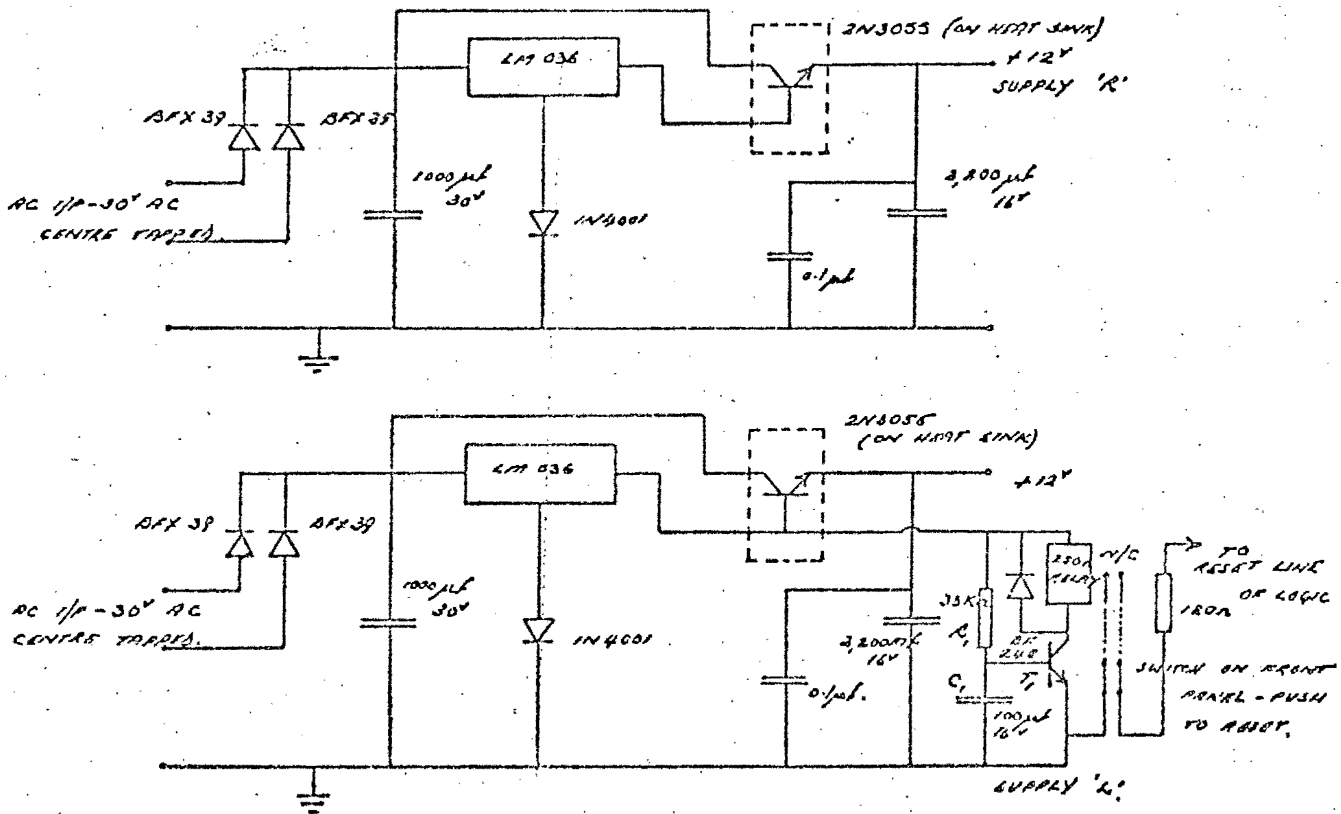


Figure 7.25

Main Power Supply.

thereby energising the relay, the normally closed contacts of the relay maintain the reset line at zero volts - (via a 120 ohm resistor) - until such time as the relay is energised. A manual reset push button is also provided on the Power Supply modules front panel (Figure 7.25). The connections to the switch are paralleled with the normally closed contacts of the relay.

Smoothing condensors (2500 mf) are situated on the power supply outputs and these are augmented by other capacitors situated on some of the other circuit boards in the system.

7. 4.17. Wiring Diagrams and Circuit Interconnections

All printed circuit wiring diagrams giving details of component layout as well as diagrams showing circuit board interconnections are to be found in the Appendix F.

7.5. THE TOUCH BUTTON SELECTOR SYSTEM

7.5.1. General Operation

The Touch Button Selector System (TBSS) is designed for controllers having more residual functional ability than that available to a C_4 lesion quadriplegic. Biceps on one side with at least Oxford Standard Grading of 3 must be present if a controller is to be able to operate the TBSS.

An array of 18 Touch Buttons is used to provide the input signals to the TBSS Electronic Control Unit. Six buttons control the selection of MAIN PROGRAMMES, while the remaining 12 buttons control individual function operations in these PROGRAMMES.

The six MAIN PROGRAMMES available to the controller are:-

1) GENERAL - (TOUCH BUTTON 13)
2) RADIO - (" " 14)
3) TELEPHONE - (" " 15)
4) TAPE RECORDER - (" " 16)
5) INTERPHONE - (" " 17)
6) SPARE - (" " 18)

The GENERAL programme provides control over 6 bistable mains operated on-off circuits (15 amp output sockets mounted on the side of the cabinet housing of the TBSS) and two monostable on-off circuits. As well as control over a suitably modified radio receiver, the RADIO programme control operates 3 low power bistable on-off circuits and two monostable circuits. The SPARE circuit may be used for additional facilities such as television - (when the service is introduced), or as the controller desires.

7.5.2. Function Selection

Table 2 illustrates what functions are available to the controller and which touch button must be operated to select a particular function. After having decided on a selection, the MAIN PROGRAMME into which the desired function is categorised is selected by the controller touching the appropriate button. The 12 remaining touch buttons not associated with MAIN PROGRAMME selection are now linked to the selected MAIN PROGRAMME so that when touched - (triggered) - their outputs will only be related to functions - (sub-programmes) - of the selected MAIN PROGRAMME. The controller then touches the button associated with the particular function required thereby causing it to be selected.

For further clarification of the select procedure consider the following example:-

The patient wishes to switch on his reading lamp - (connected to Plug 3 on the side of the TBSS cabinet),, then switch on his tape recorder to listen to some music pre-recorded on a cassette stacked in the cassette hopper; while listening to the music the controller wishes to read a book that has been set up in the Page Turner.

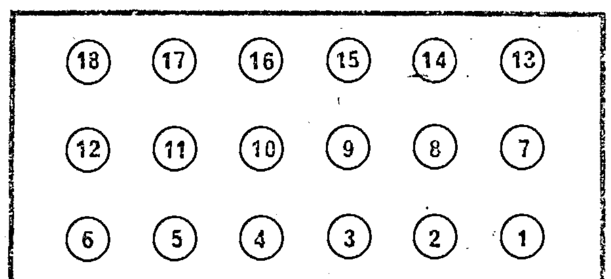
Referring to Table 2 the controller first selects the MAIN PROGRAMME in which the light circuit is situated, i.e. touch button GENERAL is triggered. Thereafter the particular function in the GENERAL programme is selected by touching button number 4. The power is then supplied on Plug No. 3 and the lamp is switched on. Repeated selection of a function which operates

Table 7.2

TOUCH BUTTON NUMBERS

MAIN PROGRAMME

	1	2	3	4	5	6	7	8	9	10	11
GENERAL	-	CALL ATTENDANT (1)	CALL ATTENDANT (2)	MAINS PLUG 3 ON-OFF	MAINS PLUG 4 ON-OFF	MAINS PLUG 7 ON-OFF	MAINS PLUG 8 ON-OFF	MAINS PLUG 9 ON-OFF	MAINS PLUG 10 ON-OFF	-	-
RADIO	ON-OFF	CHANGE STATION	VOLUME CONTROL	TONE CONTROL	-	-	PAGE TURNER FORWARD	PAGE TURNER REVERSE	LOW TENSION PLUG 1 ON-OFF	LOW TENSION PLUG 2 ON-OFF	LOW TENSION PLUG 3 ON-OFF
TELEPHONE	DIAL DIGIT 0	DIAL DIGIT 1	DIAL DIGIT 2	DIAL DIGIT 3	DIAL DIGIT 4	DIAL DIGIT 5	DIAL DIGIT 6	DIAL DIGIT 7	DIAL DIGIT 8	DIAL DIGIT 9	HOLD CIRCUIT
TAPE RECORDER	VOLUME CONTROL	TONE CONTROL	BALANCE CONTROL	RECORD LEVEL	PAUSE	STOP	RECORD	START-EJECT	ON-OFF	FAST FORWARD	FAST REWIND
INTERPHONE	CONNECT STATION 1	CONNECT STATION 2	CONNECT STATION 3	CONNECT STATION 4	CONNECT STATION 5	CONNECT STATION 6	-	RING SELECTED STATION	-	-	-
SPARE	-	-	-	-	-	-	-	-	-	-	-



in a bistable fashion i.e. which has only on-off states associated with it, results in its being alternately switched on and off. Therefore should the controller wish to switch the lamp off at this stage, he has merely to touch button 4 again.

To switch the Tape Recorder on, the touch button associated with the Main Programme TAPE RECORDER is triggered; touch button No. 8 is then triggered and the Tape Recorder is switched on. (Retriggering the same touch button switches the Tape Recorder off). To select a particular cassette in the storage hopper, button No. 7 - (START EJECT) - is repeatedly triggered until the desired cassette is loaded into the deck.

The Page Turner controls are located in the RADIO programme - buttons 7 and 8. Therefore RADIO must be selected - (enabled) - and thereafter touch buttons 7 or 8 triggered to turn pages in the forward or reverse direction respectively. It should be noted that moving from one MAIN PROGRAMME to a subsequent Programme does not in itself interfere with the state of any already selected function, i.e. having switched the light on in the GENERAL programme and then moving to the TAPE RECORDER programme does not cause the light to be switched off.

To facilitate touch button function identification, a suitably engraved perspex plate is mounted below each touch button. Sufficient information is engraved on the plate to enable the controller to predict system operation for any selected MAIN FUNCTION.

7.5.3. Constructional and Design Details

For the reasons outlined on page147 High Level Logic is used in the TBSS signal processor circuits, and all printed circuit boards are mounted on plug-in frams in a 19" rack. As with the Suck-Blow Selector System all the TBSS electronics are enclosed in a 24" Botley case.

7.5.4. Touch Button Trigger Circuits

A number of methods for entering the trigger impulses necessary for the selection of a desired function were investigated. These included simple contact push button switches, micro-switches mounted in specially constructed housings, skin conduction triggered switches, and capacitive type switches.

Mechanical Switch Assemblies

Since patients who require aids such as the Touch Selector System do not generally have the use of their triceps, they are unable to carry out active elbow extension; they must therefore rely solely on gravity to provide the force whereby push button type switches can be operated. While it is possible to design extremely sensitive micro-switches and push button trigger assemblies, the expense and delays involved in small quantity manufacture of such units and the critical initial adjustments associated with the correct setting of the operating limits, prompted investigations into more suitable trigger means.

Light Beam Switching

Light beam interruption to provide a simple means of accomplishing selection signals without the patient having to exert any downward pushing action was considered. So that the light beam switches would be used in all conditions of ambient lighting, each light sensor would have to have its own chopped light source, frequency selective receiver, and associated lens and focussing system. Since 18 such switching points would be necessary to accomplish function selection it was decided that light beam interruption was not a practical solution.

Skin Conduction Switches

Skin conduction switches made on fibre glass printed circuit board were designed as illustrated in Figure 7.27. Alternate copper strips were connected together to form two multiple contact point electrodes. The electrodes were coupled to a high input impedence FET amplifier and when any conducting medium such as the electrical path offered by normal skin conduction was shunted across the electrodes, a trigger pulse was generated by the amplifier and its associated circuitry. This arrangement worked

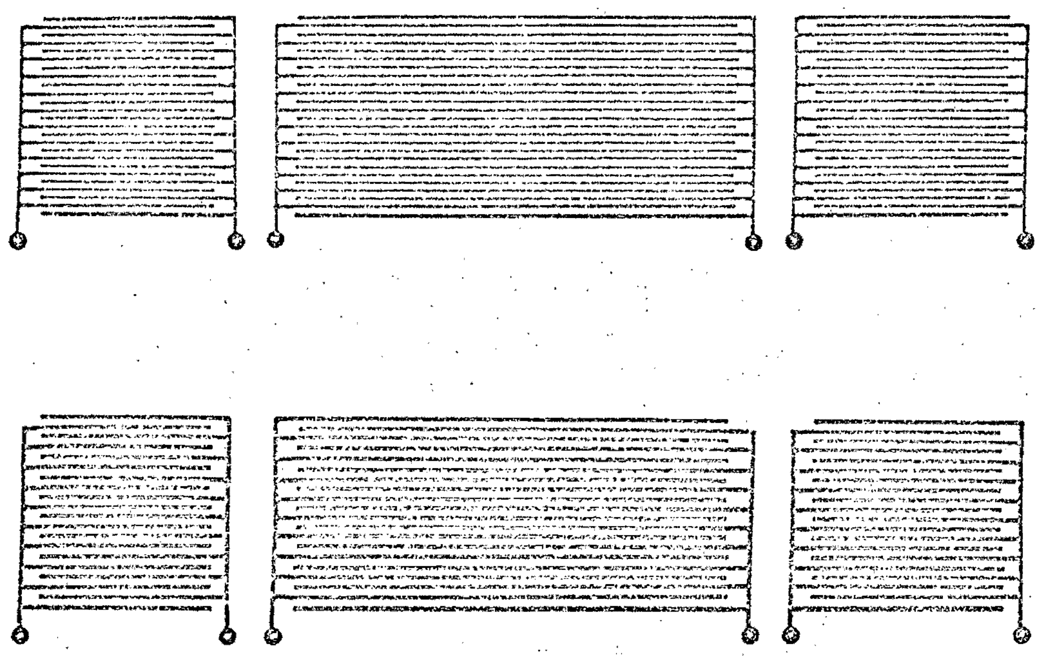


Figure 7.27

Skin Conduction Switch.

adequately when tested on people who were not quadriplegics, however because there is no sensation or at best limited sensation over the major areas of the quadriplegic's hands, normal skin excretions such as sweating, which impart conducting properties to the skin, do not take place. This type of switch therefore was totally inadequate for use by quadriplegics.

Capacitive Switches

Using the same mechanical lay-out as described above (Figure 7.27), and by coating the copper strips with a light covering of plastic, a capacitive type switch was constructed. Placing the hand or finger on the switch increased the inter-electrode capacitance of the arrangement from - (typically) - 25 pf to 120 pf. A change in capacitance of such magnitude is quite sufficient to modulate a high frequency signal source. Before constructing an array of 18 sources and their associated demodulators, a task which promised to be both complex and expensive, other capacitative type switching devices were investigated.

Gas Discharge Tube Capacitance Switches

Relatively few components were used in the capacitative switch ultimately selected for trigger purposes. A gas discharge tube type Cerberus GS11 is the main element in the switch. Touching the button electrode on the outer housing of the discharge tube results in an increase in electrode to earth capacitance which causes the tube to fire; the rose coloured glow of the ionised gas in the tube indicates that the tube has fired and is conducting. The operation of the touch switch is explained with the aid of the circuit diagram in Figure 7.28. Once the glow tube has been triggered i.e. touched, a voltage of approximately 20 volts is established across the 680 ohms resistor in the anode circuit of the tube. Capacitor C_1 charges toward this voltage via R_3. The Schmidt Trigger - (TR_1 and TR_2) - switches once this capacitor has charged sufficiently and causes the 2 c/o relay to pull in. The cathode of the trigger tube is connected to the supply via the normally closed contacts of the relay. Once triggered the

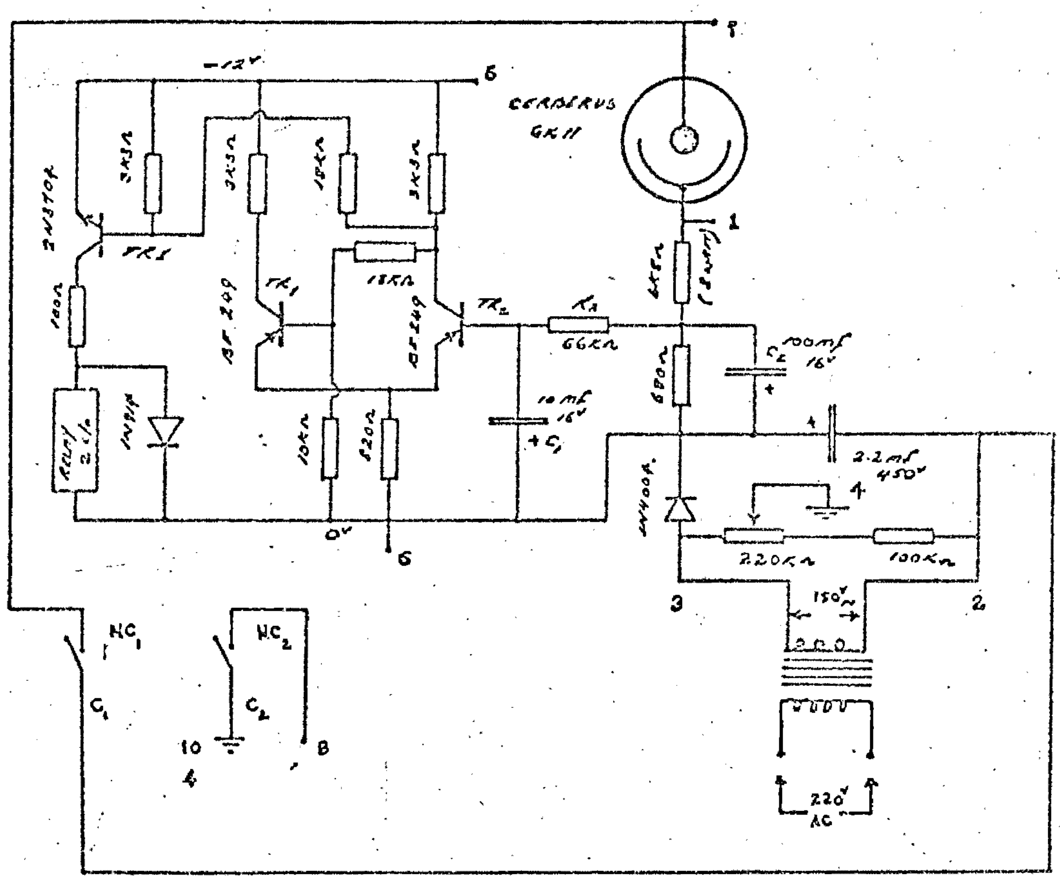


Figure 7.28

Gas Discharge Tube Capacitance Switch.

Schmidt trigger therefore breaks the current flow in the discharge tube and extinguishes it. The second pair of relays contacts are used to provide the trigger pulse to the Select System, one of the contacts being connected to earth, the other directly to the MAIN SELECT unit in the Central Processing Unit via a multiway plug and socket. Once capacitors C_1 and C_2 have discharged the Schmidt trigger circuit causes the relay to be de-energised. After this delay the touch button trigger circuit is automatically reset to receive the next incoming signal. The 220 K ohm trimmer potentiometer connected in series with the 100 K ohm resistor between points 2 and 3 in Figure 7.28 controls the overall sensitivity of the touch trigger circuit. All switches are mounted on individual printed circuit boards which are in turn mounted on a rack inside the touch button cabinet. A single isolating transformer is used to supply power to all touch switches - (points 2 and 3) - in the select unit.

Further Switch Requirements

Because the patient has only biceps remaining in his arm and has to rely on gravity as antagonist for this muscle, it is to be expected that a somewhat unco-ordinated and jittery action is at best available from the patient when he is situating his forearm and hand in front of him. To compensate for this, the delay circuitry as described above is incorporated in the Touch Switch unit. This effectively desensitises the touch switch for $\pm \frac{1}{2}$ sec immediately after it has been triggered and eliminates the possibility of erroneous multiple triggering of selector switches. Also, the switches are situated at approximately 4" distance from each other to ensure that the patient selects only the required switch and its associated function. Eighteen switches are provided for the Touch Select System. These are arranged in a 3 x 6 matrix on a console which is positioned conveniently for the patient. The front panel on which the select buttons are mounted is sloped to facilitate patient access (Figure 7.29).

Fig. 7.29 Touch Button Array on Sloping Cabinet.

7.5.5. Touch Button Main Select Unit

The six main programmes associated with the Touch Selector System are selected by means of the TOUCH BUTTON MAIN SELECT circuitry (cf Figure 7.30). The outputs from switches 13-18 are fed directly to this unit where they are passed through two series invertor and shaper circuits to provide outputs B_1 - B_6 and A_1 - A_6.

A four input nand gate suitably modified to accept the six A_1 - A_6 invertor outputs detects the arrival of an input from the touch button select switches. After having been inverted, the modified 4 input nand gate triggers a monostable multivibrator circuit with a time constant of approximately 15 m.sec. This monostable, whose function is essentially that of introducing a delay into the system, triggers a second monostable multivibrator circuit (Figure 7.30., iii) of a similar time constant - (15 m secs), as it returns to its stable state. The outputs A_1 to A_6 and B_1 to B_6 are then combined with the output from the second monostable multivibrator and depending which touch button has been triggered, the appropriate R - S bistable multivibrator is set; simultaneously all the remaining bistable multivibrators are reset to zero.

It is thus necessary to select only the MAIN PROGRAMME required - the action cancelling all previously selected MAIN PROGRAMME functions automatically. Operating the manual RESET line causes all BMV's to be set to zero.

7.5.6. Selection of Functions in Programmes

Once a particular MAIN PROGRAMME has been selected, the output of the BMV associated with the programme changes its output from a high to a low state (Figure 7.30, iv). The outputs from the 'minor' or 'sub-programme' switches - (tough buttons 1 - 12) - are now combined with the output from the MAIN PROGRAMME BMV's to provide the trigger pulses for the circuitry employed in individual function selection.

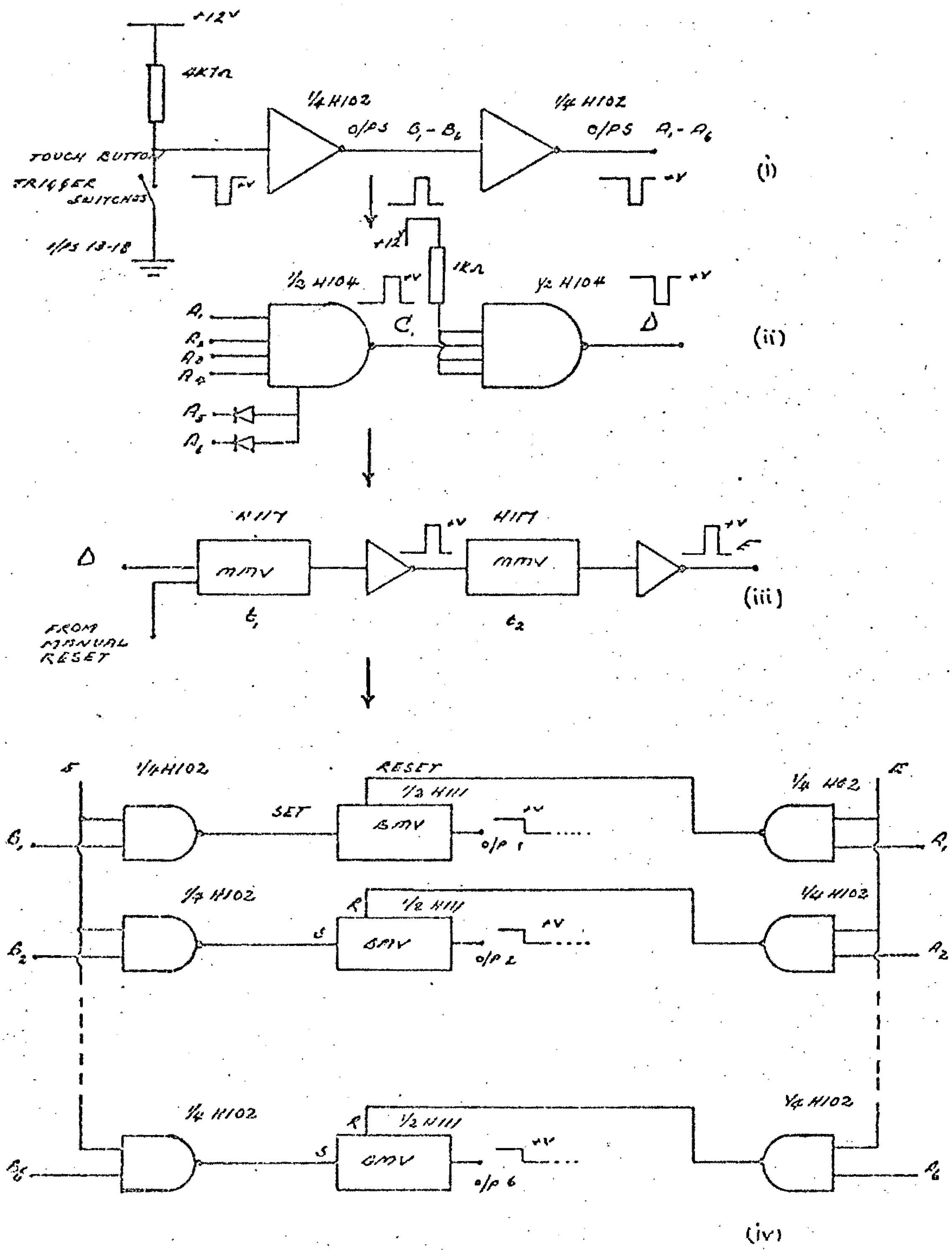


Fig. 7.30 Main Programme Select Operation.

7.5.7. General Select

The GENERAL programme permits selection of six bistable on-off circuits and of two circuits whose on time is determined by monostable multivibrators. Control of mains operated appliances that require only to be switched on or off is effected by the first six switches. Reading lamp, main lights, heater, fan, electric typewriter etc. are some of the apparatus that may be controlled. The two monostable controlled circuits may be used to operate bell calls, alarm circuits or to provide trigger pulses for page turning devices.

After having been inverted the GENERAL ENABLE signal - (i.e. the signal generated by selecting the GENERAL programme) - is combined (Figure 7.31) with the incoming signals derived from the touch button minor programme array. If there is an input on any of lines 1 - 6, the appropriated nand gate output triggers the T flip-flop - (BMV) - associated with it, and a signal is passed to the driver circuit to energise the relay and thereby switch the selected circuit on. Subsequent selection of the same function results in it being alternately switched on and off. The manual reset line when appropriately triggered - (by momentarily shorting it to earth). resets all output relay contacts to the normally open state.

Each of the two monostable controlled circuits are selected in the same way as the bistable elements above. (Once triggered the monostable multivibrators cannot be retriggered until they have returned to their off state).

In the Touch Button Selector System two GENERAL circuits are included in the composite unit. Since the Radio required but 4 of the 11 possible selections available in the programme for its operation, the remaining 7 possible selections are utilised for the second GENERAL circuit. These circuits make available 5 low tension switches and 2 low tension monostable switches for use by the controller.

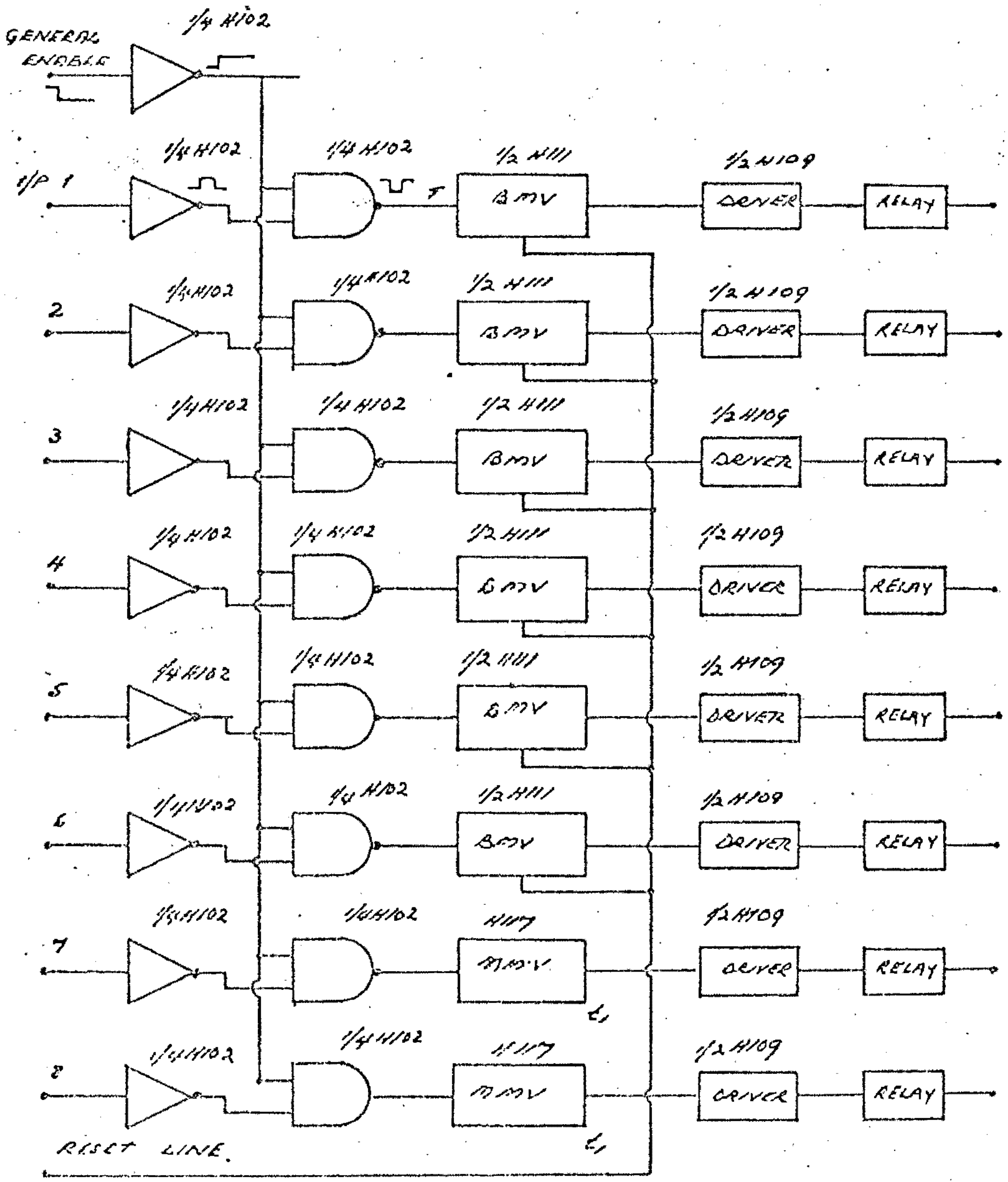


Fig. 7.31 General Programme Select Operation.

7.5.8. Radio, Telephone and Tape Recorder Controls

The circuitry associated with the operation of the Radio, Telephone and Tape Recorder controls of the Touch Button Selector System is identical to that of the Suck Blow Selector System. It is thus unnecessary to explain the operation of these circuits here and the reader is referred to pages 163-182 for circuitry description, substituting Touch Button trigger signals originating at the Touch Button MAIN SELECT for Suck Blow coded trigger signals originating in the SUB-SELECT circuit, where necessary. The circuit boards were designed to be interchangeable between different Selector Systems in an attempt to standardise modules wherever possible and thereby simplify service procedures and construction.

7.5.9. Interphone

The INTERPHONE circuitry is designed to facilitate controller interface with a particular telephone type intercommunication system (Aiphone 12H) installed in the controller's home. Up to six remote stations may be selected by the patient; a 'RING' control is also provided.

Once the INTERPHONE ENABLE has been selected (Figure 7.32) a relay is energised which has the equivalent effect of lifting the telephone receiver from its cradle. To select a desired station, the appropriate touch button is triggered and the corresponding ITMMS - (page 173) - is triggered. The station is now connected to the controller's handset and will remain so connected until the INTERPHONE programme is de-selected. Should the controller wish to operate the call buzzer in the telephone at a particular station, the desired station is first selected and then the RING button - (ref. table 2) - is triggered. The monostable multivibrator associated with this circuit then causes the required pulse to be put onto the line to effect ringing.

All six stations may be called up to the interphone during any one conversation. This feature is inherent in the basic intercom system.

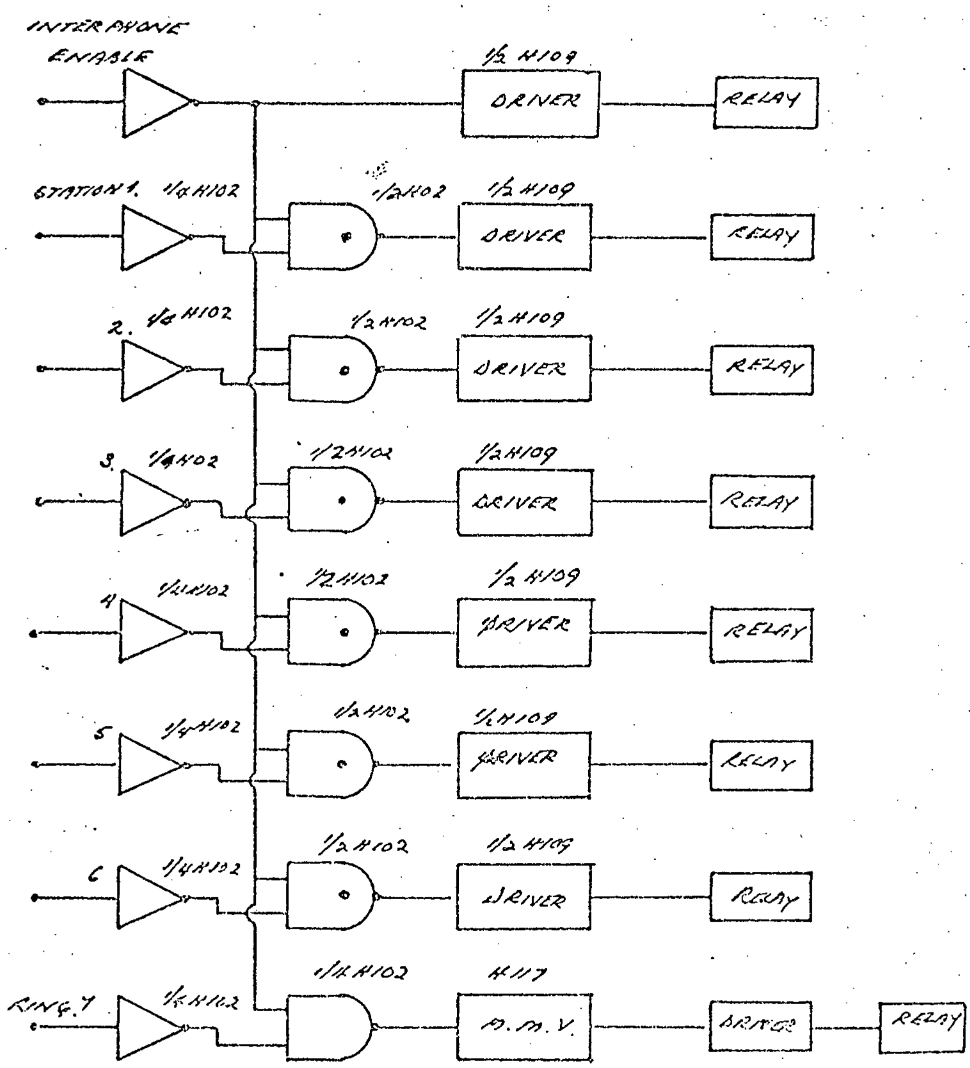


Fig. 7.32. Interphone Control.

7.5.10. Display Circuitry

To enable the controller to know in which MAIN PROGRAMME he is operating, and to advise him of the electrical state of certain of the terminal appliances, a display system is incorporated in the TBSS. The display outputs comprised of 6 light emitting diodes, are situated on the touch button console cabinet. Each of the MAIN PROGRAMME touch buttons has one LED associated with it, the LED being mounted above the corresponding touch button as shown in the photograph of Figure 7.29. Signals for the control of the display unit are derived from the MAIN SELECT UNIT and from the individual PROGRAMME circuits.

The circuitry used in the TBSS Display unit is the same as that used in the SBSS i.e. as with the RADIO, TELEPHONE and TAPE RECORDER programme circuits; the reader is referred to page186 for a detailed description of circuit operation. The output signals generated when programmes GENERAL, INTERPHONE and SPARE are selected however, replace the input signals associated with switching plugs 8 and 9 on, and intercom selection control as indicated in Figure 7.33.

The power supply for the LED's is housed in the touch button array cabinet and consists simply of a transformer, single diode and smoothing capacitor.

7.5.11. Power Supply

The power supply modules used for supplying both SBSS and TBSS are identical and the reader is referred to page 190 and Figure 7.25 for a detailed description of the circuitry.

7.5.12 Wiring Diagram and Circuit Interconnections.

All printed circuit wiring diagrams giving details of component lay-out as well as diagrams showing circuit board interconnection are to be found in Appendix F .

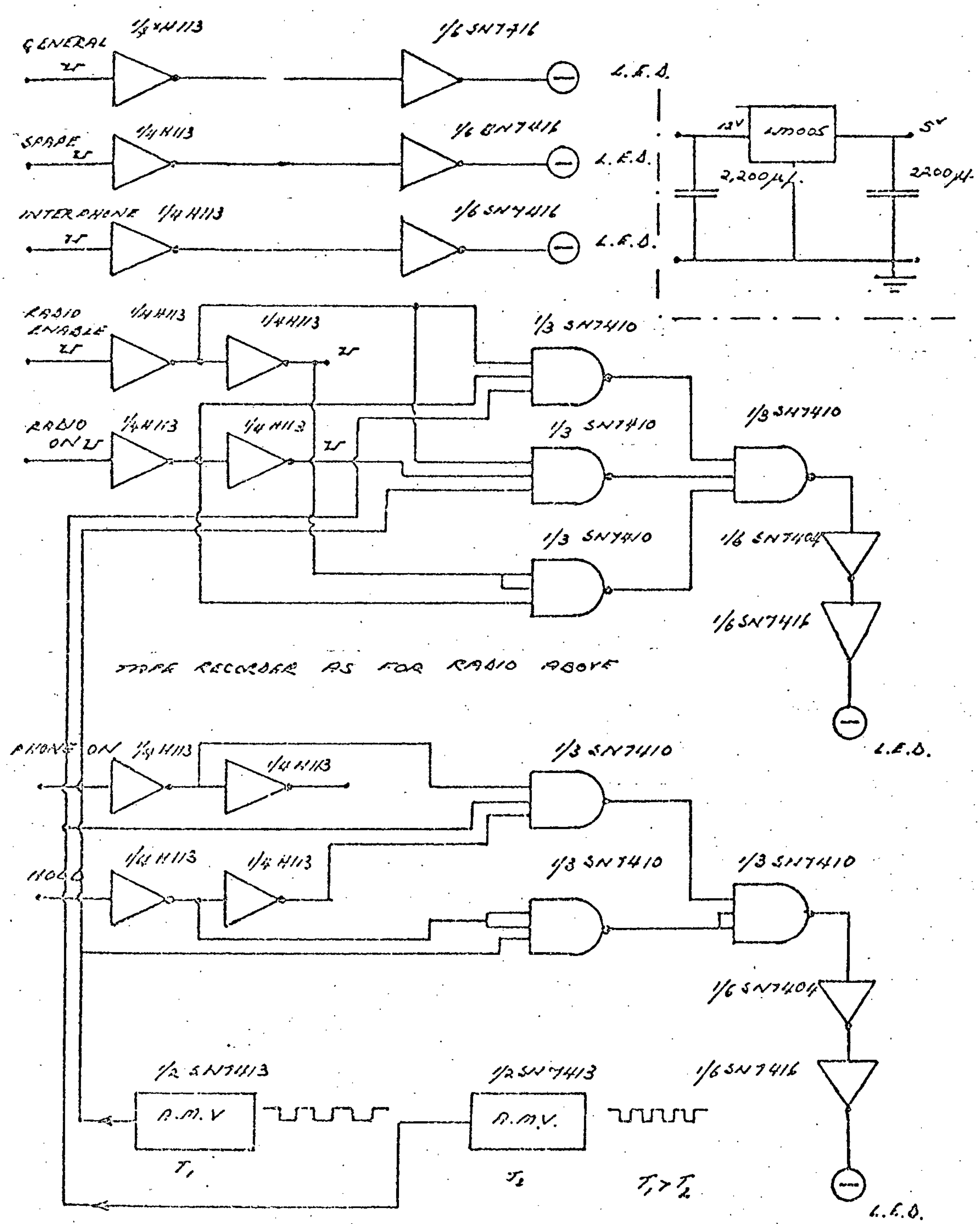


Fig. 7.33. Indicator Driver Circuit.

7.6. INSTALLATION OF THE SELECTOR SYSTEMS AND LAYOUT OF A TYPICAL ENVIRONMENT

In designing the layout of the environment in which the controller is to operate and in which the SBSS or TBSS system is to be installed, the following must be considered:

i) the patient must have easy access to the input device i.e. to the Suck-Blow transducer or to the Touch Button console,

ii) sufficient working space for the controller to situate his typewriter, page turner, desk lamp, etc. as well as sufficient storage for books and other daily requirements must be provided for,

iii) to facilitate servicing the control electronics and associated appliances must be conveniently located and easily accessible,

iv) aesthetic appearance of the Selector System installation and decor of the room in which the patient is to spend most of his active life must be carefully planned to provide a colourful, warm and stimulating environment.

The artificial environment described below was created in the home of a young female school going $C_{4,5}$ incomplete quadriplegic. The patient has bilateral use of strong biceps and Oxford Grading 2+ of extensor carpii readialis on the right hand side. With the aid of a spring assisted flexor hinge hand splint, the patient was able to handle a variety of objects and with practice was able to write legibly. The patient was also able to push a wheelchair with some difficulty.

Diagram 7.34 details a plan and view of the TBSS installation.

The distance between the desk top and the floor is sufficient to permit the wheelchair arm rests to pass underneath the desk thereby allowing the controller to rest her arms on the work surface in front of her. For the controller's convenience a semi-circular area is cut out from the desk top thereby extending the area over which the controller can operate and

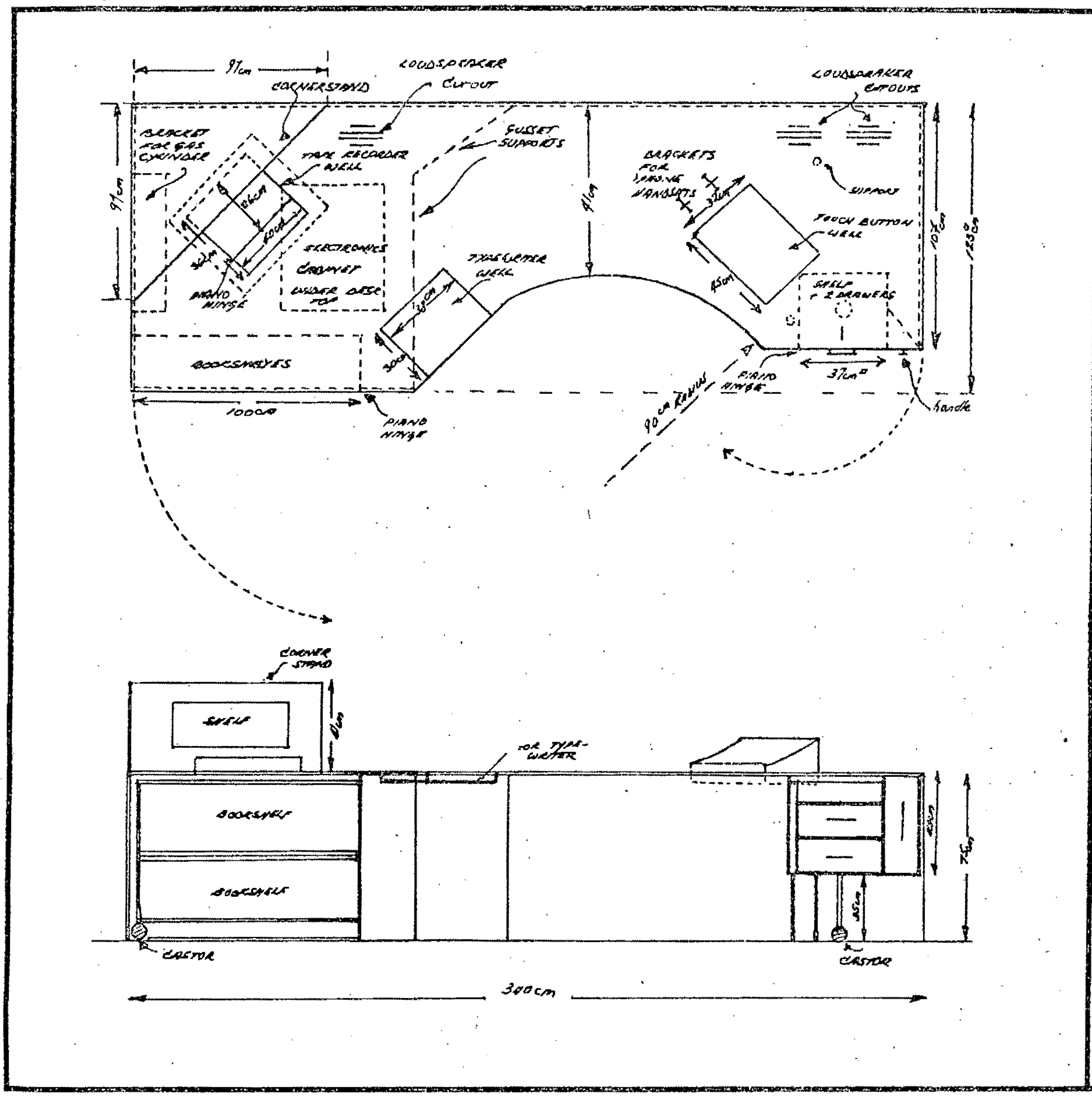


Fig. 7.34 Plan and View of A Touch Button Selector System Installation.

providing additional support for the controller's trunk. Sufficient space is allowed in front of the controller's wheelchair so that the footrests clear the wall against which the desk is built by about 5".

A nest of two drawers and an open shelf is provided on the right-hand side of the desk. The shelf is intended for storage of writing paper, while the drawers are used for the controller's pens, copy books and other items which are used most often during the day. The nest is so hinged that the controller may swivel the entire unit by pulling on a conveniently situated handle. This feature facilitates easy access to the drawers and shelf of the nest. The handles are chosen so that they may be grasped easily (Figures 7.35 and 7.36).

The Touch Button array is mounted to the right and slightly forward of the controller and angled in a cut-out in the desk to provide the most convenient access to the input unit. Two telephone handset stands, one for the G.P.O. telephone and the other for the Interphone system, are situated to the left of the Touch Button Console. An angle poise reading lamp illuminates the work area of the controller. (Figures 7.37 and 7.38).

The cabinet containing the tape recorder, solenoid, and relay assembly is mounted below the surface in the left-hand corner of the desk unit. The top of the cabinet is screwed to the desk top and a cut-out in the desk permits the top of the tape deck, and the framework on which the rams and motor drives for the respective push button and potentiometer controls are mounted, to protrude above the surface of the desk. Access to the speaker input plugs and microphone jack is permitted via a hinged panel on the desk surface. A decorative corner-stand is mounted over the ram array and obscures the tubing used to direct the compressed air to these rams. A mirror is mounted on the corner-stand and its angle is adjusted so that the controller may see the record level indicator dial and the tape footage counter. To provide better illumination of both level indicator and footage counter a 15 watt globe mounted in the corner-stand

Fig. 7.35 and Fig. 7.36   Sliding Nest of Drawers.

Fig. 7.37.

Fig. 7.38.

unit is connected in parallel with the Tape Recorder power supply. (Figures 7.39 and 7.40).

The typewriter which the controller operates occasionally is situated on the left-hand side of the semi-circular cut-out of the desk. The platform on which the typewriter is mounted is 2" lower than the surface of the desk to enable the controller to reach the keyboard easily. The width of the platform is such that the controller may manoeuver the wheelchair so that the wheelchair arm rests straddle the platform. (The controller types using one finger of the splinted right hand).

Two shelves are provided on the left-hand side of the desk unit in which books or ornaments may be stacked. (Figure 7.41). The shelf unit is hinged at one end. It may thus be swung away to one side to provide access to the rear compartment under the desk top. The cabinet in which the control circuitry is housed as well as the radio assembly and gas cylinder are stored in this area. (Figures 7.42 and 7.43).

Three loudspeakers are mounted on the desk top, two in the rear left-hand corner and the remaining one in the right back corner. The speakers in alternate corners of the desk are for the stereo Tape Recorder while the other speaker is used for the Radio.

An earth-leakage relay which controls power supply to the whole system is mounted on the desk wall. This safety feature is incorporated in the system for the maximum protection of the controller against electric shock.

7.7 CONCLUSION

7.7 1. System Cost

At all times during system design, efforts were made to keep costs down to a minimum so that as many patients as possible might find it within their means to benefit from the Selector System.

As is to be expected the cost of the TBSS is greater than the SBSS; the Touch Button console component cost alone exceeds R200. Excluding

Fig. 7.39 Tape Recorder and Ram Array

Fig. 40 Tape Recorder Mounted in Desk Top.

Fig. 7.41 Bookshelf Unit.

Fig. 7.42. Bookshelf Swivelled to provide access to Rear Compartment.

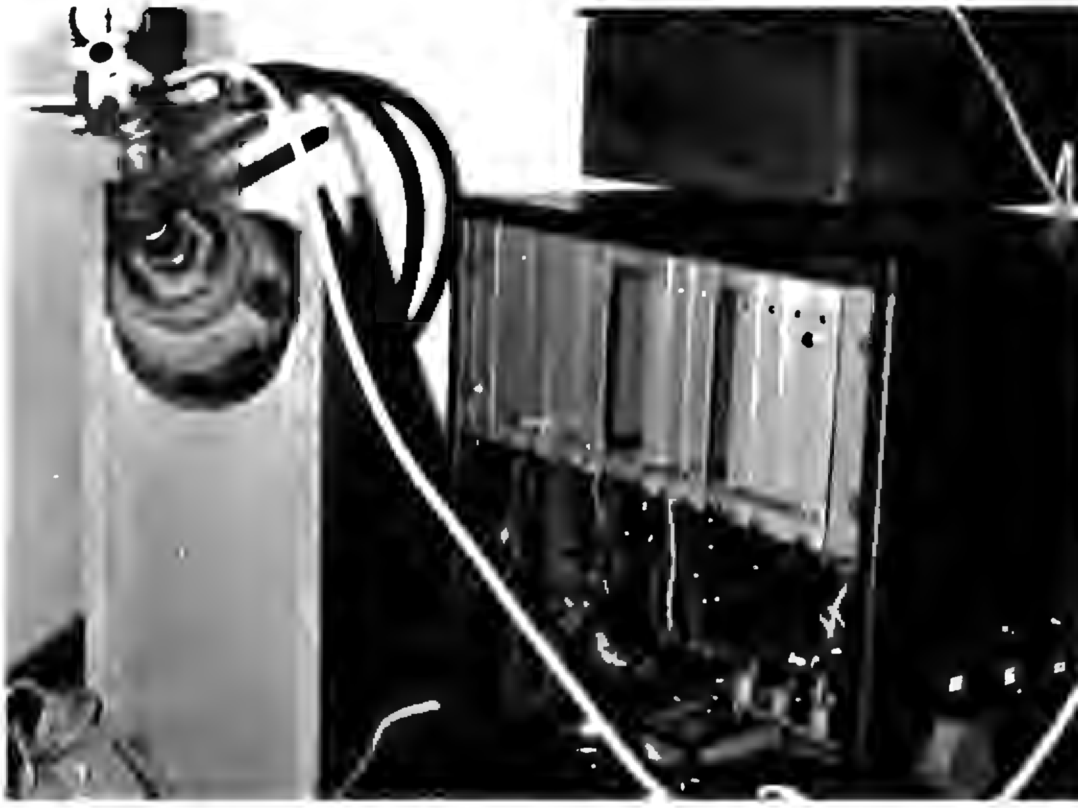


Fig. 7.43. Gas Cylinder and Electronics Cabinet Under Desk Top.

development and labour costs complete SBSS and TBSS may be made for approximately R1,200 and R1,350 respectively. These figures do not include the cost of the custom made desk which will differ from patient to patient as financial circumstances dictate.

The cost of High Level Logic is very much more than TTL Logic - (approximately 6 to 8 times more expensive) - but the improvement in system performance more than adequately compensates for this expense. Further, the cost of mounting the various printed circuit boards on plug-in card modules is expected to minimise the cost of periodic service inspection and repairs that might be necessitated from time to time.

7.7.2. Reliability of Operation

The Selector Systems have undergone extensive testing both in the laboratory and in patients' homes. In both instances system operation has been most reliable and no breakdowns whatever have occurred in the Central Processing Units electronics. Poor connections in multiway plugs and sockets have thus far accounted for most of the difficulties experienced with the system. However, since the systems have been installed in permanent locations in patients' homes problems of this nature are not expected to recur.

7.7.3. Patient Acceptance

Throughout the development and construction of the Selector Systems described above the patients for whom the equipment was being made were constantly consulted for their comments and attitudes with regard to the various aspects of function selection and programme operation. At each stage of system development patients' reactions were considered and where necessary suitable changes were made to satisfy patients' requirements. The systems were therefore designed 'around' the patient in the true sense of the word and as was to be expected, patient acceptance of the equipment is good.

Initial indications are that both systems described above are being used extensively by the patients for whom they were constructed and that they are extremely satisfied with system operation. There can be no doubt that the patients' effective capacity and independence have been immensely increased by using this apparatus and that thereby their disability is made easier to bear.

It is appropriate that the closing paragraphs of this chapter should deal with patient acceptance of his equipment, since in the end it is on success in this direction that the value of the project as a whole should be assessed.

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CHAPTER 8.

> "The goal of rehabilitation is always directed toward promoting ego integrity and feelings of self-worth.... The aim is to assist the person toward reformulating a self that approves of continuity to be, despite important discontinuities with its past identity. Specifically, this means the promotion of a new self predicated on worth, rather than on deficiency and self contempt."
>
> Jerome Siller Ph.D(1)

8.1 GENERAL ASPECTS OF THE REHABILITATION OF THE QUADRIPLEGIC.(')

Rehabilitation of the quadriplegic may be divided up into three distinct and separate stages:

1) Intensive Care - where the patient requires the continuous attention of medical personnel (of Chapter 2)

2) Intermediate Care - during which time the patient is taught some activities of daily living within his capabilities, and is fitted with orthotic appliances and other equipment, (of Chapters 5,6,7)

3) Self Care and Long-term Rehabilitation. - where the patient makes his first contact with society outside the sheltered confines of the hospital, seeks employment and attempts to return to his home.

Stage 3, probably the most protracted period, is the most crucial for the quadriplegic who as a severely disabled individual, must renew contact with society. It is in this time that the various techniques and procedures that have been applied to the patient will be put to the test.

(') the observations on this subject apply particularly to conditions in South Africa.

Unhappily, in South Africa as in many other countries of the Western World,because of the acute shortage of hospital beds and accommodation, and because of an unrealistic approach to rehabilitation, stages 2 and 3 of the rehabilitation programme are combined and compacted, to the ultimate detriment of the rehabilitant. The patient is considered to be 'rehabilitated' as soon as he is deemed able to exist without constant medical attention and when he has become proficient in some of the basic activities of daily living.

Ideally the quadriplegic should remain hospitalised or should reside in a convalescent home in an atmosphere permitting an ordered adjustment to life in a wheelchair; it is really only at this stage when the patient is medically fit, that his rehabilitation can be practically implemented. It is from such a haven that he should be able to venture slowly into society permitting the transitional difficulties that quadriplegics experience as they progress along the road to social independence to be overcome at a leisurely pace.

During stage 3 the quadriplegic should be thoroughly tested to define his physical and mental capacity, his work potential, and he should be adequately trained for employment in a suitable occupation. It might be appropriate to place the quadriplegic in sheltered employment temporarily until his work tolerance and capacity reach an acceptable and competitive level.

The patient should spend a few days at home from time to time to accustom himself to life at home as a quadriplegic- the patient's family would also have an opportunity to accustom themselves gradually to the medical and psychological difficulties of caring for a severely disabled person.

Where long stay 'transitional' accommodation is not available, it is the practice of some spinal injury centres(') to encourage the family member most likely to be concerned with tending to the patient's personal hygiene and care, to spend approximately one week prior to the quadriplegic's discharge with the hospital personnel. During this time the regimes for bladder and bowel control, precautions necessary for the prevention of bed sores, as well as procedures which must be followed to ensure the overall well-being of the patient are explained. The limitations of the quadriplegics functional capacity as well as the use and operation of any equipment with which he might have been supplied are demonstrated. Time should also be spent with the psychologist of the rehabilitation team so that an understanding of the psychological implications of quadriplegia may be gained. Unless the quadriplegic and his family are adequately equipped both physically and psychologically to cope with the stresses that the disabled person will encounter once he has left hospital, much of the effort of rehabilitation will have been wasted.

8.1.1. Optimisation of the Quadriplegic's Functional Capacity.

The ultimate purpose of orthotic appliances and other sophisticated equipment supplied to quadriplegics is to maximise the functional capacity of patients. Consider the example of the Touch Button Selector System environmental controller installed for use by a patient who could not really be classed as a high lesion quadriplegic (Chapter7). The patient had strong bilateral biceps and was able to use a spring assisted flexor hinge hand splint. It has been suggested by some of the writer's colleagues, that such patients should not be equipped with versatile environmental controllers because they are able to effect some control over their environment using residual body movement.

(') Spinal Injuries Centre at Conradie Hospital, Pinelands, Cape Province.

Also, it is argued that it is good therapy for the quadriplegic to do whatever he can without aid. The writer disagrees with the foregoing and recommends the judicious use of a combination of all the techniques available to simplify the existence of the quadriplegic and to facilitate his interface with society.

This difference of opinion arises from a fundamental disagreement on the essence and purpose of rehabilitation and the ultimate goals which are set for the quadriplegic. While the writer concedes that body movement can be used for environmental control, the time rate at which the patient can effect such control is excessive. For example, the patient could indeed dial a telephone number without the use of the T.B.S.S. but the successful accomplishment of such a task would require much physical effort and concentration. Such efforts are not consistent with the overall measure of achievement attached to the task, since the motions of dialling were never ever intended to be time consuming and frustrating.

Further, the writer does not view the accomplishment of activities such as telephone dialling as being meaningful, worthwhile or even useful in the patient's rehabilitation programme.

Efforts directed toward attempting to interface quadriplegics directly with machines designed to be operated by healthy subjects are without logical foundation. While the patient must certainly be encouraged to accomplish activities which are within his capabilities, the practice of expecting the patient to master activities which require excessive effort with little reward should not be pursued.

Ortheses and environmental controllers are designed to facilitate freeing of the quadriplegic patient from the frustration of petty incumberances which confine both his physical and mental activities within the limitations of his physical disability.

8.1.2. Employment for Quadriplegics.

The growing need for brainpower rather than physical effort, coupled with the fact that very seldom do employment opportunities require the use of all human faculties, suggests that employment for even the severely disabled quadriplegic might be found. Mechanical and electronic aids make it increasingly possible for individuals who are able only to operate a switch or two to contribute substantially in a suitably structured work situation.

That so much difficulty is experienced in finding employment for quadriplegics and other severely disabled individuals may be attributed chiefly to two factors. These are:-

i) employers' prejudice against the handicapped and

ii) the technical inability of the social and welfare authorities who seek employment for the disabled to create the necessary environmental conditions or prescribe modifications to prospective work situations.

Employer's prejudice against the physically disabled and indeed that of the public at large is rooted in ignorance. Thus, it should be one of the objectives of those responsible for the rehabilitation of the physically disabled to educate the public to appreciate the needs of the handicapped. Particularly it should be demonstrated to potential employers that once adequately equipped and trained even the severely handicapped are capable of substantial achievement.

The problem of environment modification deserves consideration. No facilities exist in South Africa for consultations with technically qualified personnel to effect modifications to a disabled persons work environment. Whereas an employer might be persuaded to employ a disabled person, it is unrealistic to expect him to meet the costs of environment modification even if such modifications are comparatively minor. A state subsidy should therefore be provided in instances where expenses cannot be borne by the disabled person or his family. This expenditure could be viewed by the authorities as a capital investment transforming a non-productive person who is a burden on the State, to that of being a productive member of society. Until such time as this becomes standard practice, the prospect of large scale employment of the disabled and particularly of the quadriplegic remains remote.

8.1.3. Patient After-Care

Patient after-care from the medical, psychological and technical aspects must be ensured if the patient is to realise and maintain his maximum physical and mental capacity. Medical after-care for quadriplegics is usually effected through regular house visits by a district nurse. Bed sores, bladder and bowel complaints of a relatively minor nature may be treated at home. Where complications do arise the quadriplegic is hospitalised for treatment.

There are no psychiatric personnel attached to the district nursing service, nor are there district technical personnel to attend to maintenance, repair, or replacement of patient's equipment.

Thus, quadriplegics who are not financially independent must wait for readmission to hospital on medical grounds before they can have access to technical facilities. The benefit of recent orthotic and other technical advances are therefore denied to those who do not need to be hospitalised. Whilst free State hospitalisation is available to indigents in South Africa, there exists no mechanism whereby funds may be made available for post hospitalisation non-medical necessities. An incongruous and paradoxical situation exists where the patient receives the best possible medical care in hospital and in some instances is provided with free orthotic appliances, wheelchair and environmental controllers but on discharge, irrespective of his financial ability, the patient must fend for himself as regards the installation and maintenance of his equipment at home. To illustrate the above, consider the case of a particular $C_{4,5}$ quadriplegic who, considered medically fit, was discharged from hospital with a motorised wheelchair; no other equipment was supplied. This man returned to live at home with his wife and children in a semi-detached cottage. A small State disability grant does not allow for hired help. Thus, the sole responsibility of caring for the quadriplegic rests on the wife who must rely on the kindness of neighbours for help in lifting her husband out of bed, into the wheelchair or into the bath. Very often days go by when this unfortunate individual has to spend all his time in bed because there is no assistance for his wife. Further, this quadriplegic experienced great difficulty in manoeuvering his motorised wheelchair within the small confines of his house, and was unable to negotiate steps in and about the house. Since a motorised wheelchair cannot be manually operated with ease, an independent welfare organisation was persuaded to donate a standard wheelchair. Unfortunately the sides of this wheelchair are not removable and as such it is not entirely suitable for quadriplegics. Relatively minor structural changes to the house such as widening doorways and replacing the steps with ramps and the provision of a simple mechanical hoist to facilitate single handed lifting of the quadriplegic into a wheelchair with removable sides would greatly alleviate the distress of this family.

The extent of a quadriplegic patient's disability is such that the rehabilitation programme cannot be considered complete, nor society's obligation fulfilled, with the patient's discharge from hospital. It is apparent that present hospital and medical facilities are not yet orientated towards perceiving the practical essentials for promoting rehabilitation of the quadriplegic. Rehabilitation becomes meaningful once the patient is able to compete with normal subjects and is restored to a condition where he can become independent and productive. It is unfortunate that so many quadriplegics are saved from death only to be consigned to the scrapheap of humanity soon after discharge from hospital.

8.2 SUGGESTIONS FOR IMPROVEMENTS TO EXISTING SPLINTS FOR QUADRIPLEGICS.

8.2.1. The $C_{5,6}$ and $C_{6,7}$ Quadriplegic.

The techniques using Engen type Ortheses (Chapter 5), provide a good measure of functional restoration to the $C_{5,6}$ and $C_{6,7}$ quadriplegic. The orthesis construction however, precludes the patient from holding objects in any manner other than by a three point pincer grip. Since this is not always convenient it would be advantageous if some means could be provided whereby this three point grip could be changed to a grasp utilising full finger flexion in a fist-type grip. The functional capacity of the quadriplegic would be markedly improved if the desired grip could be selected as simply as changing the orthesis lever length controlling the degree of wrist extension necessary to oppose fingers and thumb.

8.2.2. The $C_{4,5}$ Quadriplegic.

By appropriate linkage connections between wrist and elbow joints of a total arm prosthesis, Simpson (4) ensured that during elbow extension and flexion, the attitude of the terminal device (i.e. of the prosthetic hand or hook), remained at a constant angle to the horizontal. Thus,if the user was engaged in bringing a spoonful of food up to his mouth, the spoon would remain at a constant angle to the horizontal and its contents would not spill out. In normal hand-arm co-ordination the process of maintaining the wrist at a constant angle to the horizontal is a most useful compensatory action. It is therefore suggested that the principle embodied in the pantograph type elbow-wrist linkage system devised by Simpson (for use in prostheses for limb deficient thalidomide children) could be put to beneficial use in externally powered prehension ortheses for $C_{4,5}$ quadriplegics.

As detailed in Chapter 6, the wrist joint of the splinted fore-arm of the $C_{4,5}$ quadriplegic is maintained in a preselected position of wrist extension or flexion by a friction or lock joint. Any radial movement of the wrist is thus precluded and should the patient attempt to lift a spoon of food or lift a glass of water in the normal manner using elbow flexion only, the results would be disastrous. To lift a glass of water to his mouth therefore, the quadriplegic must compensate for the lack of radial movement at the wrist by abducting the shoulder until the splint-held glass is at mouth height. He must then flex the elbow to bring the glass toward his face. Because of insufficient innervation of the shoulder girdle muscle, this movement is difficult to accomplish.

The following arrangement might be a means whereby automatic compensatory wrist movement to maintain a hand-held utensil or object at a constant angle relative to the horizontal could be provided. The splint to be constructed should have two degrees of powered movement; that of prehension, and radial wrist extension and flexion.

A suitable constructed goniometer which would provide an electrical output signal proportional to the degree of extension and flexion of the elbow should be incorporated in the splint. The output from the gonio-meter would be fed to a servomechanism controlling the degree of radial extension and flexion of the wrist. The transfer characteristic of the servomechanism should be such that the degree of radial extension or flexion of the wrist would be related directly to the degree of elbow extension and flexion. Using this, or a similar system the patient would be able to lift a glass of water to his mouth without spilling using bi-ceps action only.

8.2.3. High Lesion Quadriplegics.

The potential use of a miniature computers to reduce the information input requirements of complex multi-degree of freedom of movement orthesis con-trol and the consequent diminution of the load on the decision making capacity of the human controller, has been discussed in Chapter 4 and 6. The application of such techniques would certainly extend to a marked degree the funtional range of the severely disabled quadriplegic. It is hoped that encouragement of research in this direction will soon place more versatile complex ortheses at the disposal of the rehabilitation team. The development of optimal orthotic control systems however cannot be contemplated until much basic research in the life sciences has been successfully completed. There is a need for better understanding of how the central nervous system functions and how volitional motor control over the limbs and other body segments is affected. Whilst the mechanism of impulse conduction through nerve pathways is relatively well understood (5), researchers have still to devise means whereby motor control inform-ation carried in impulse form in a bundle of nerve fibres to a particular body point may be monitored, decoded and correlated to permit specific impulse patterns to be identified with corresponding movement patterns.

To achieve optimal orthesis control for quadriplegics it will be necessary to monitor impulses in the upper motor neuron centres of the body, i.e. inside the spinal cord or even in the cerebral cortex itself, for relay to the orthesis control system. To complete the control loop, feedback signals from the anaesthetic body segments must be channelled to the motor control centre. Outputs from the body receptors on the skin and in the muscle must be directed across the broken link at the site of damage to the spine. Thus, many of the most closely veiled secrets of the human body and of the mind must be unmasked if the above is to become a practical and realistic solution to achieving absolute man-machine integration.
To theorise on whether the ultimate in orthotic systems would consist of suitably motorised hardware or would operate by the ordered stimulation of the quadriplegic's musculature is pure speculation at this point in time.

8.2.4. Improvements to Environmental Controllers.

To operate the environmental controllers described in Chapter 7, the quadriplegic must situate himself at a specific station at his console. A radio link between the patient in his wheelchair and the environmental controller electronics to provide remote environmental control, would no doubt be a useful addition to present systems. Suck-Blow signal transmission could quite easily be accomplished using a single channel transmitter attached to a pipe transducer mounted on the patient's wheelchair (as illustrated in fig.6.9.). Remote Touch Button Selector System control would be complex since this would necessitate the incorporation of a touch button console on the wheelchair; this cumbersome addition to the wheelchair could be obviated by requiring the controller to effect control by generating Suck-Blow signals if remote operation is required.

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APPENDIX A

Glossary of Medical Terms

APPENDIX A.

GLOSSARY OF MEDICAL TERMS.

Afferent - conveying towards a centre (brain)

Cartilage - a specialised connective tissue.

Catheterisation - introduction of a tubular surgical instrument into the bladder for the withdrawal of urine.

Contracture - Condition of fixed high resistance to passive stretch of a muscle from fibrosis of the tissue supporting the muscles or of the joints.

Efferent - conveying away from the centre (brain).

Electromyogram - recording of changes of electrical activity of a muscle.

Fibrous tissue - tissue composed of or containing fibres.

Focus - chief centre of a morbid process.

Granuloma - the formation of wounds of small rounded fleshy masses.

Guillan Barré Syndrome - encephalitis of virus origin.

Hypostatic Pneumonia - congestion of the lungs due to stagnation of the blood in portions of the lung.

Ischemia - Deficiency of blood in a part due to functional constriction or actual obstruction of a blood vessel.

Lesion - any pathological or traumatic discontinuity of tissue.

Ligaments - bands of tissue that connects bones or organs.

Luxation - dislocation.

Motor System - Muscular system.

Myelitis - inflammation of the spinal cord.

Nerve Block - regional anaesthesia secured by making extraneural or paraneural injections in close proximity to the nerve whose conductivity is to be cut off.

Oedema - swelling, presence of large amounts of body fluids in the intracellular tissue spaces of the body.

Osteoporosis - rarefaction of the bone.

Pathologies - diseases causing structural and functional changes in tissue or organs of the body.

Polio Myelitis - viral disease of the central nervous system.

Renal failure - failure of the function of the kidneys.

Spasm - a sudden violent, involuntary contraction of muscle or group of muscles.

Tetanus - continuous tonic spasm of a muscle.

Toxic - of the nature of poison.

Trauma - wound or injury.

Tumor - mass of new tissue which grows independently of its surrounding structures and which has no physiologic use.

Urological - pertaining to the urological tract of both male and female and to the genital organs in the male.

Reference: "Dorlands Illustrated Medical Dictionary"

24th edition - W.B. Saunders & Co., London.

APPENDIX B.

THE MYO-ELECTRIC SIGNAL MONITOR

Instrument Operating Procedure,
Circuit Diagram and Component
Specifications.

THE MYO-ELECTRIC SIGNAL MONITOR (')

OPERATION PROCEDURE

1. Materials required.

    1. Electrode assembly consisting of two Beckman electrodes (similar to Part No. 350040 plus one earth plate 2cm. x 10cm. of copper backed bakelite.)

    2. Two Hypodermic syringes with blunted needles.

    3. Disposable adhesive collars (Beckman Part. No. 350075 or similar).

    4. Electrode gel similar to Beckman Paste.

    5. Scissors.

    6. Steel wool.

    7. Cotton wool.

    8. Acetone.

    9. One roll of adhesive PVC tape.

2. Application of Electrodes.

    1. Clean a patch of skin directly over muscle bulk, of the muscle selected for treatment. The area to be cleaned should be large enough to accommodate the two electrodes and the earth plate. A cotton wool swab dipped in acetone is used for this purpose.

(') The above is an extract from the "Instructions for Use of the Myo-electric Signal Monitor" drawn up by the author in conjunction with the National Construction Committee of Occupational Therapists in Pretoria, South Africa.

2. Clean the earth plate with steel wool to remove any insulating oxide coating which might have formed.
3. Apply the exposed surface of the collar to the electrode so that the small holes in the electrode body are directly beneath the hole in the collar .
4. Partly fill a hypodermic syringe with electrode paste.
5. Completely fill the cavity between the electrode sensing element and the skin baffle with electrode paste, being careful not to leave any air bubbles, by injecting into the middle hole of the electrode until it overflows from the surrounding holes: be certain to fill the cavity to the top of the cardboard backing of the collar.
6. Remove the remaining cardboard backing from the collar, and apply electrode to the cleaned area of skin over the muscle bulk.
7. Apply electrode paste to the copper surface of the earth plate and affix to the skin in the vicinity of the other two electrodes by means of the adhesive PVC tape. To ensure good skin-paste-earth plate contact, rock the plate gently backward and forward over the skin.
8. The electrode assembly is now ready for use.

3. Operating Procedure.

1. Open the flap on the left hand side of the M.S.M. instrument. There are two Din sockets in this compartment. The electrode cord is plugged into the rear socket.
2. Plug the M.S.M. into the power point and switch the instrument on by turning the power knob. This lights up to indicate that power is connected.

3. Turn the three control knobs on the lower half of the front panel completely in a clockwise direction.

4. Turn up the sensitivity knob from 20-15, ensuring that the patient maintains a relaxed muscle. The Zero Cross-over Count meter should remain at zero. If this is not the case, check electrodes, paying special attention to the earth plate. Instruct the patient to contract the muscle under test. Movement of the needle on the meter should now be detected. Continue to turn the sensitivity control toward "0" until a maximal deflection of the meter pointer is obtained. It is not usually necessary to set this knob to less than about 12 and where ever possible the knob reading should be as high as possible to minimise external interference. (This control sets the amplitude sensitivity of the instrument.)

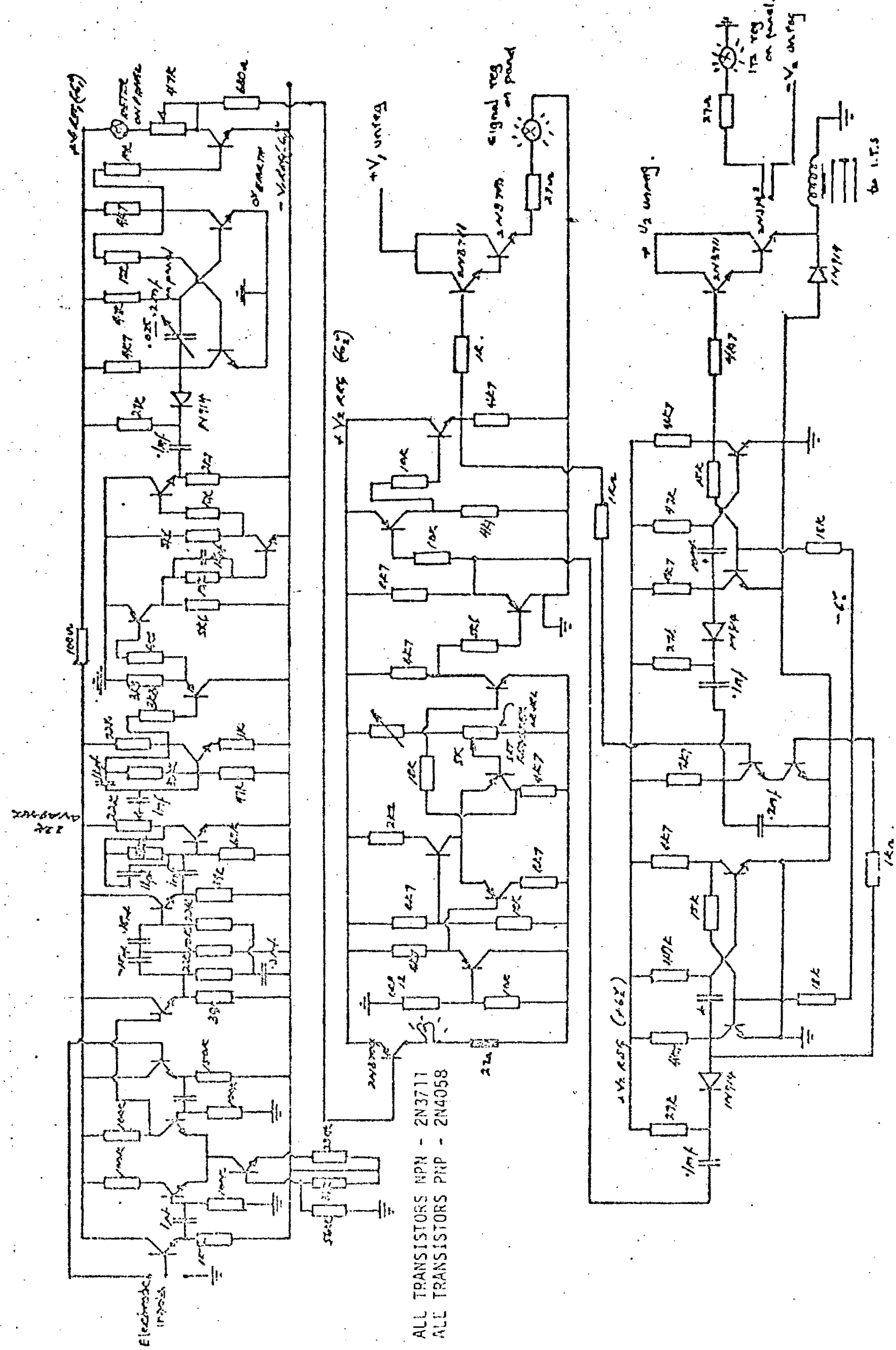
5. Set the frequency range knob such that the reading on the meter should be approximately in the centre of the meter when the patient is contracting his muscle. (For muscles used in gross movements, such as the M. Quadriceps, M. Biceps the frequency range should be set to the 100 or 200 range. For the flexor and extensor group of the muscles in the wrist, which are used for finer movements,the frequency range must be set within the 200 or 400 range setting. For a very weak muscle with limited innervation the 50 range setting would be used.)

6. The Set Register Level knob is used to regulate at what reading of the Zero Cross-over Count meter the signal register light will switch on.

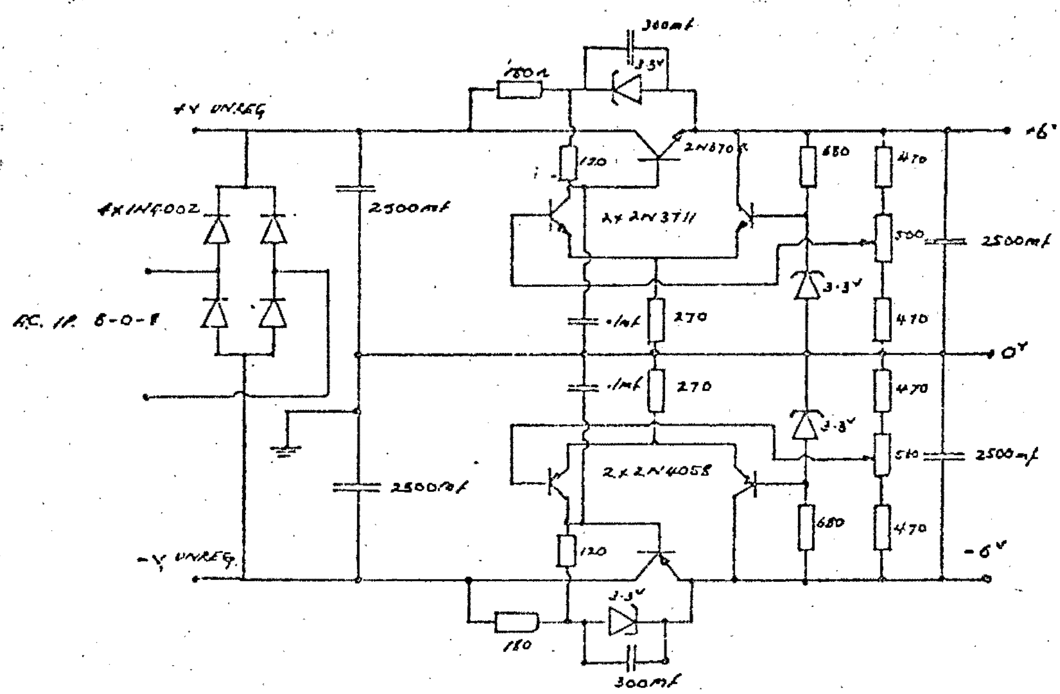
The patient is instructed to contract his muscle to obtain a reading on the meter. Turn the set register level knob anti-clockwise until the signal register light goes on. The patient must maintain a contraction, keeping the signal register light on for at least .5sec. After that time the I.T.S.(') register indicator will light, and a "click" will be heard. The patient must relax his muscle to allow the signal register light to go off before the I.T.S. register can again be triggered.

7. Connect the I.T.S. and the M.S.M. together by means of the cord provided. The socket on the M.S.M. for this cord is situated adjacent to the electrode socket.
8. The maximum reading on the zero-crossing meter should be noted at each treatment and a progress log sheet should be kept for record purposes.
9. When treatment has been completed remove the electrodes by lifting the edge of the collars. Do not attempt to remove by pulling on wire as it may damage the electrode. Remove the collars being careful not to pull the wire. Thoroughly clean the electrodes with water using a syringe. The earth plate should also be washed with water and dried.

(') I.T.S. - Intermediate Time Switch Unit - this is the timing unit referred to in section 3.3.



Myo-Electric Signal Monitor Circuit Diagram.



Power Supply for Myo-Electric Signal Monitor (X2).

APPENDIX C.

Vulcanisation Of Splint Surfaces

VULCANISATION OF SPLINT SURFACES.

1. Materials Required(')

   Bufso Solvent.

   Pangitol and Hartner Primer.

   Pangolit and Catalyst.

   Pangit White Rubber A.

   Pangit White Rubber B.

2. Procedure.

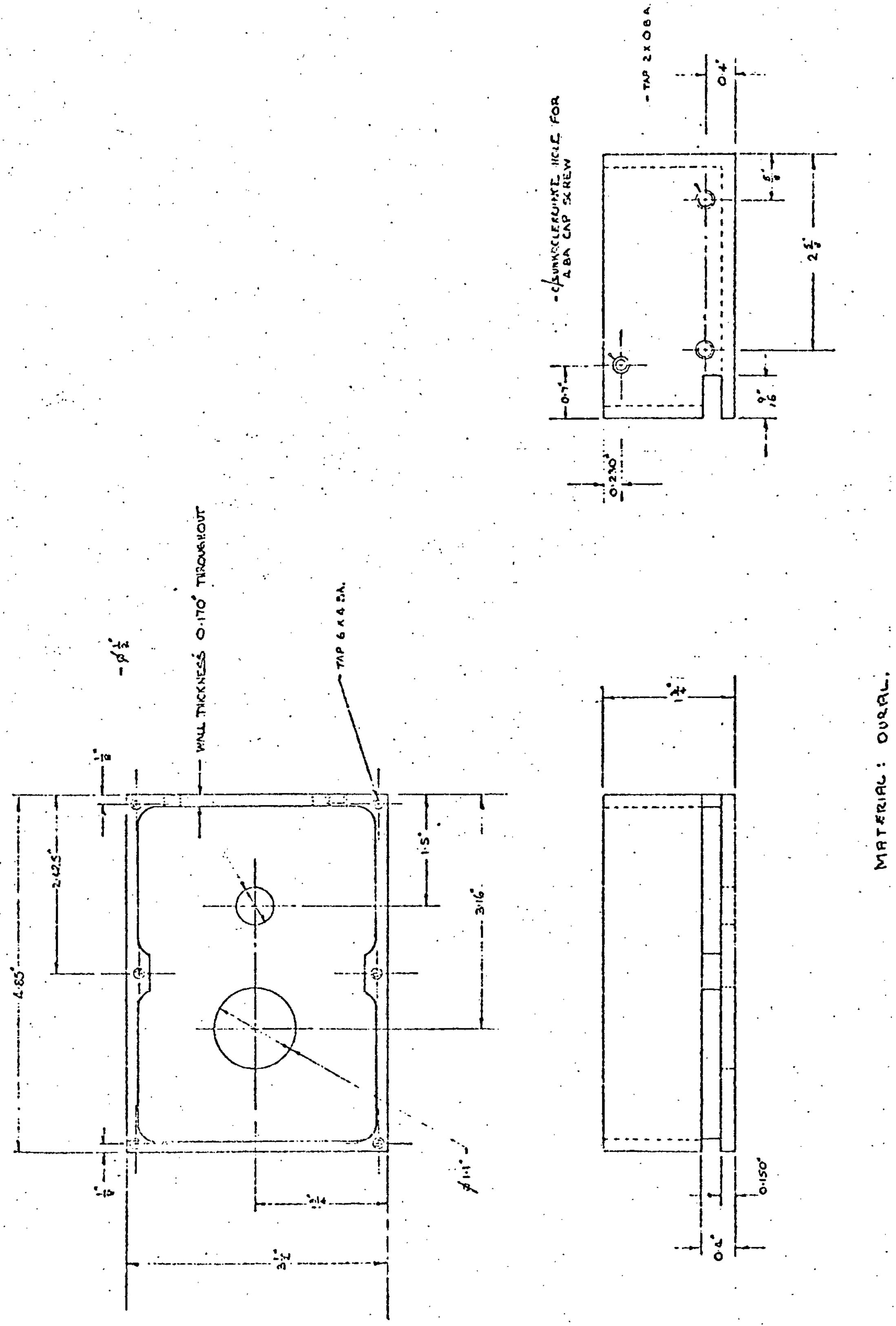
The splint surfaces on which the rubber coating is to be bonded is first prepared by cleaning with 'Bufso solvent'. A coating of primer of a 6:1 mixture of Pangitol and Hartner is then applied to the surface and allowed to dry for 30 minutes. A 25:1 mixture of Pangolit (Pangoprene) and catalyst is then painted over the Pangitol coating and allowed to dry for 15 minutes. Thereafter a second coating of Pangolit and Catalyst is applied.

A quantity of Pangit White A and Pangit White B rubber compounds is mixed and spread over the surface to be rubberised. Allow to harden for 24 hours. The hardened surface may be buffed down as required.

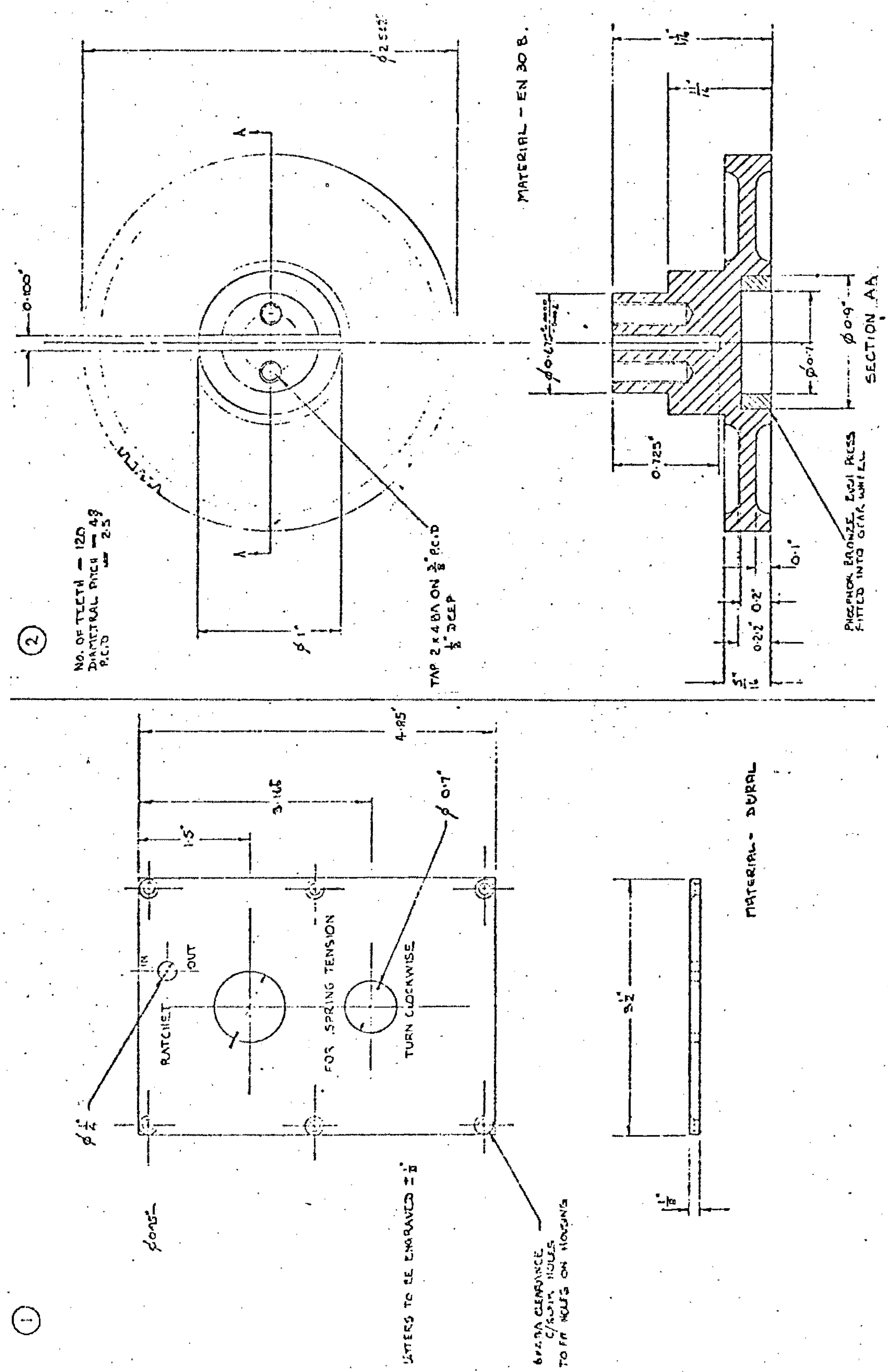
(') Materials available from Automatic Vulcanisers Corporation, 16 Hudson Street, New York. U.S.A. N.Y. 11013

APPENDIX D.

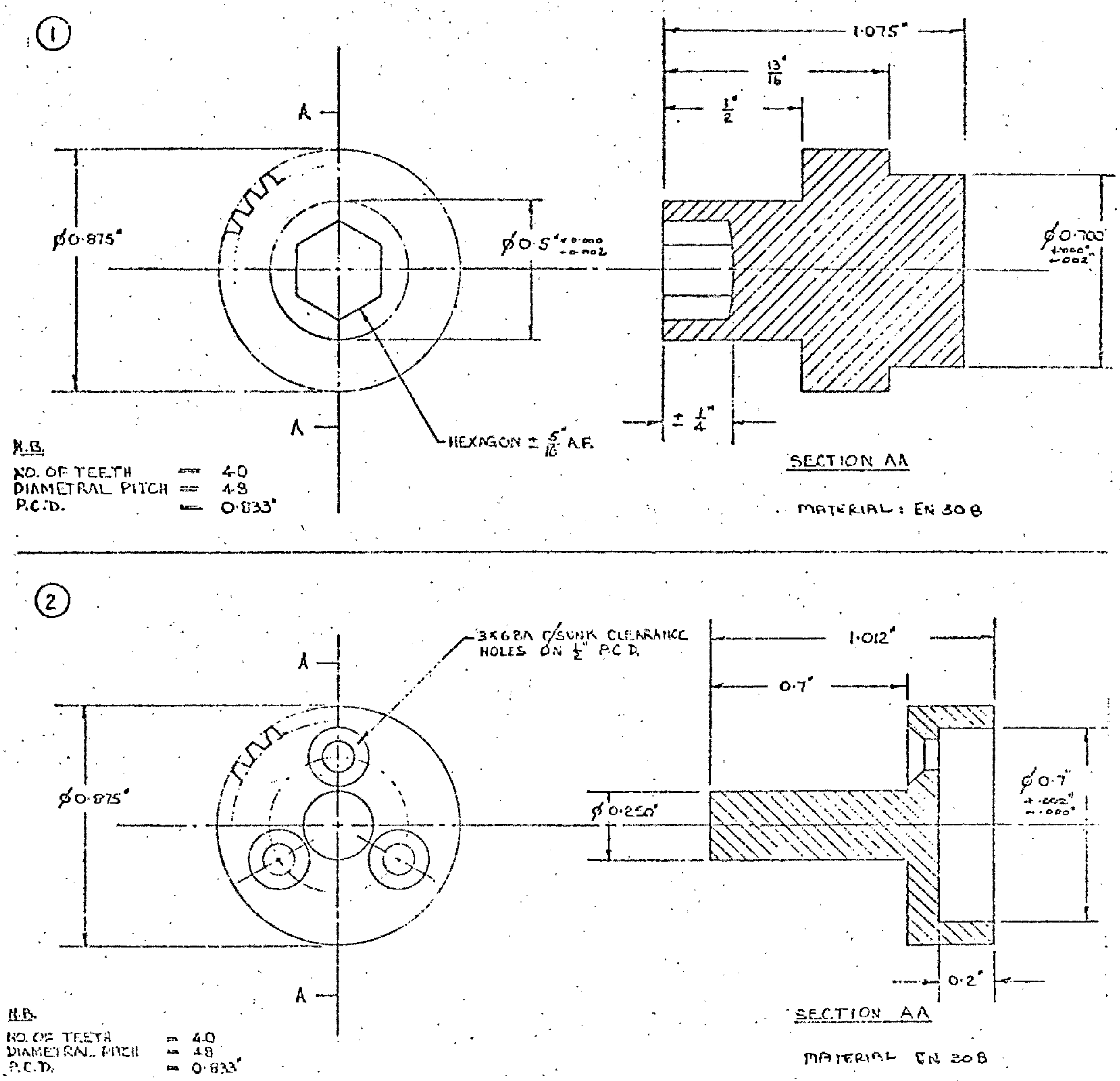
Constructional Details of Spring Loaded Elbow Extension Splint


MATERIAL: DURAL.
WALL THICKNESS 0.170" THROUGHOUT
TAP 6 x 4 B.A.
TAP 2 x 0 B.A.
4.85"
2.425"
3.16"
1.5"
0.150"
0.4"

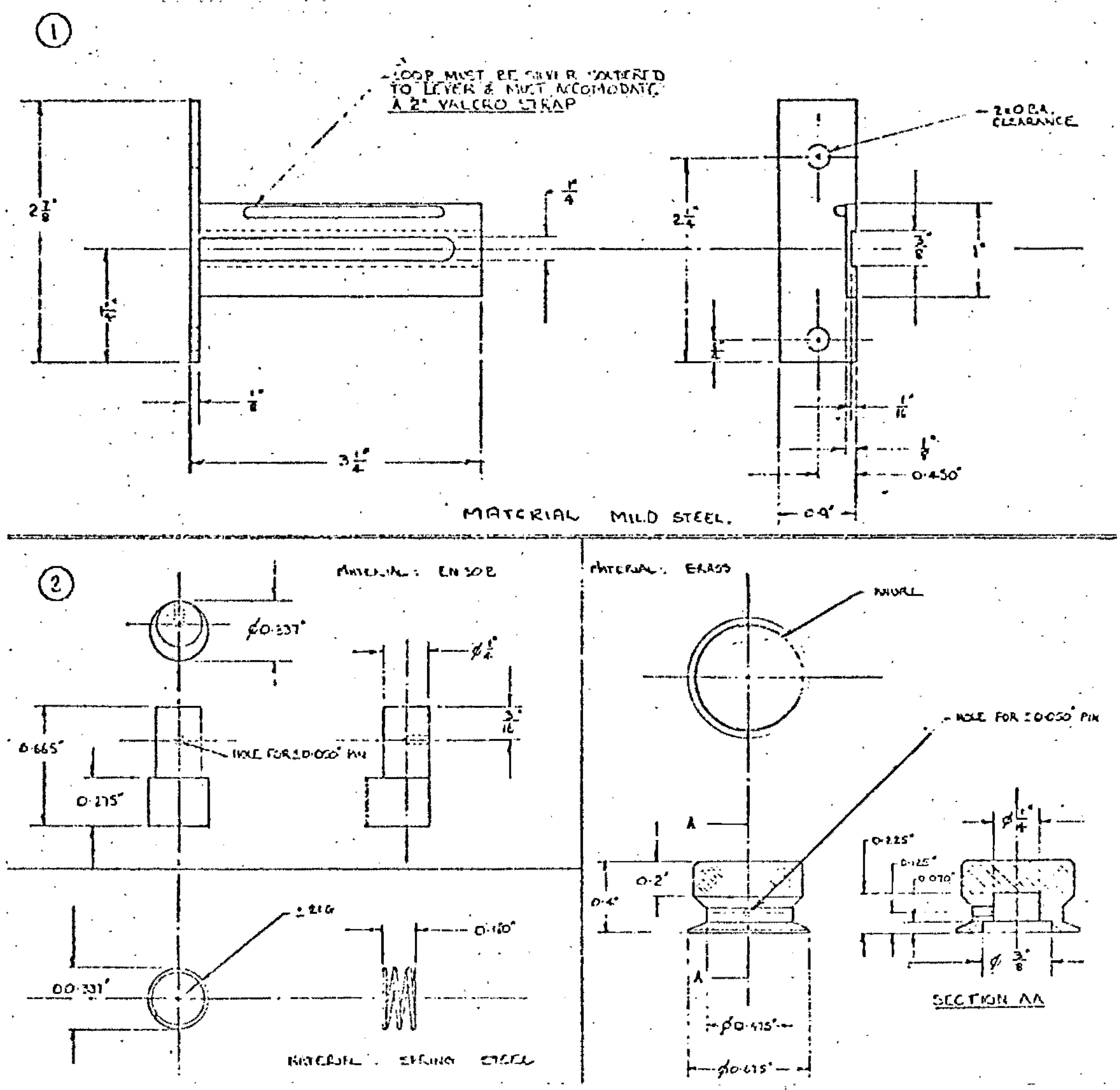
D.1. Gearbox



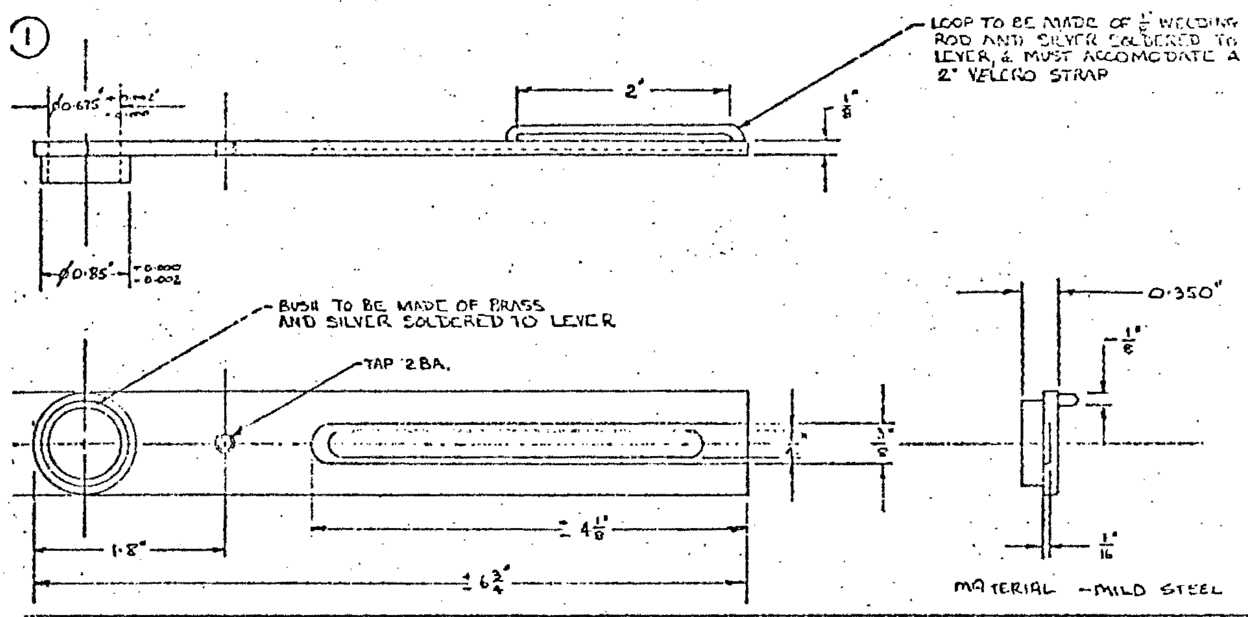
D.2. 1. Cover Plate for Gearbox.
2. Gear.

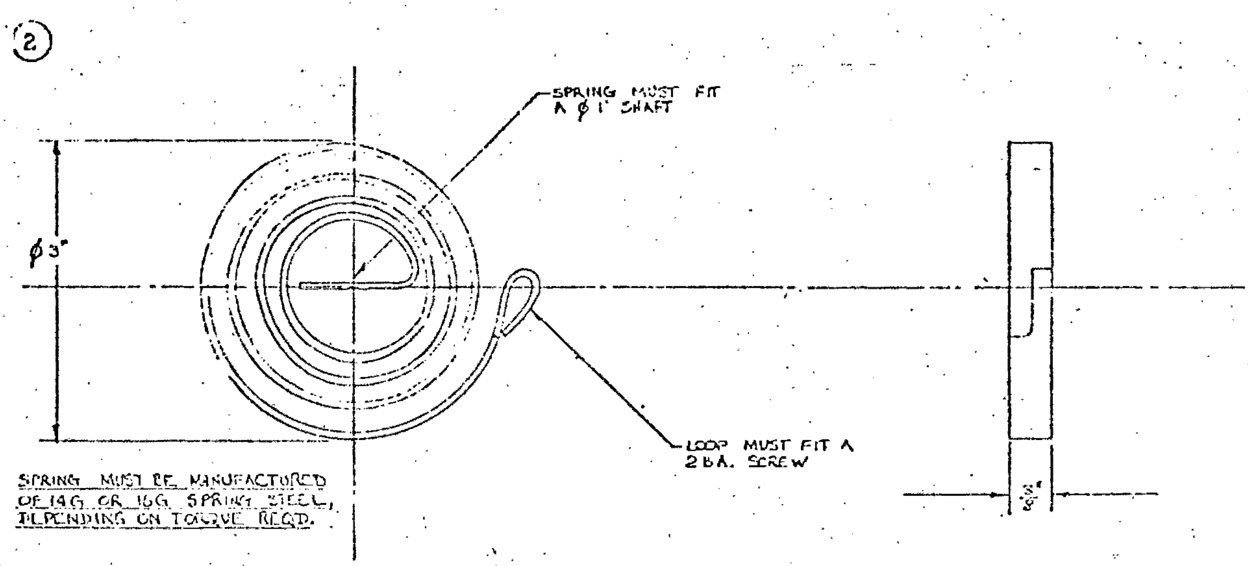


D.3. 1. Gear Wheel.
2. Gear Wheel.

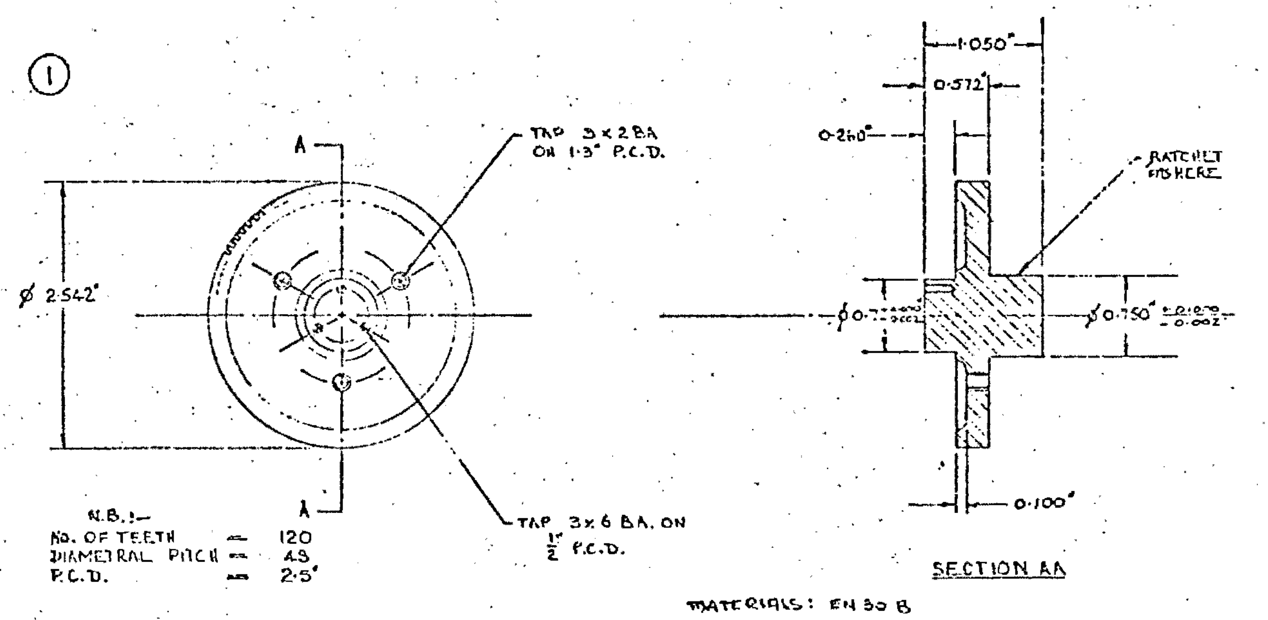


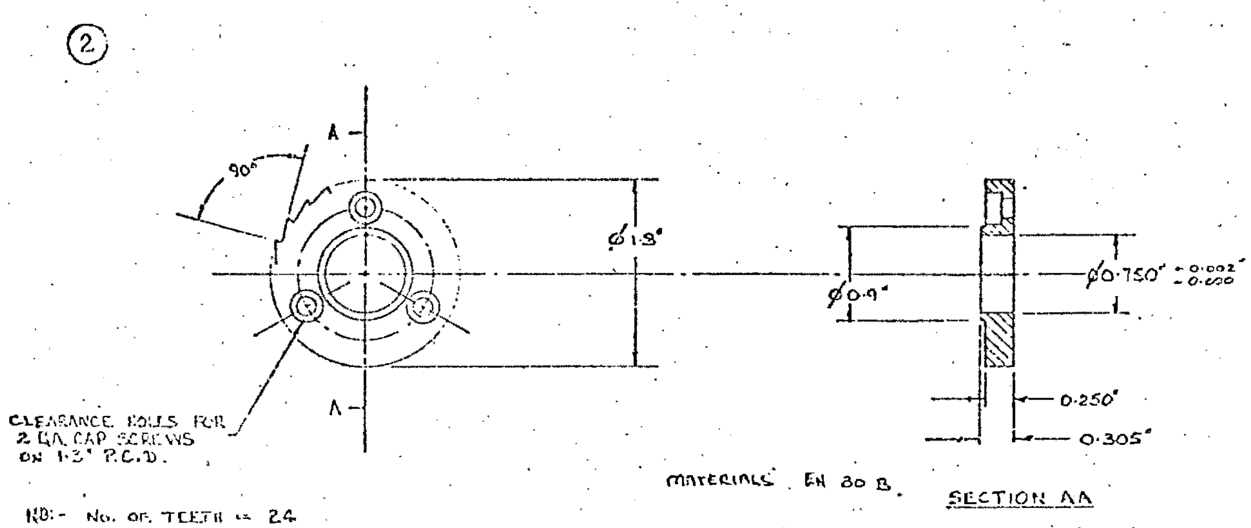
D.4. 1. Lever which Fits into Gearbox.
2. Ratchet Mechanism Complete.



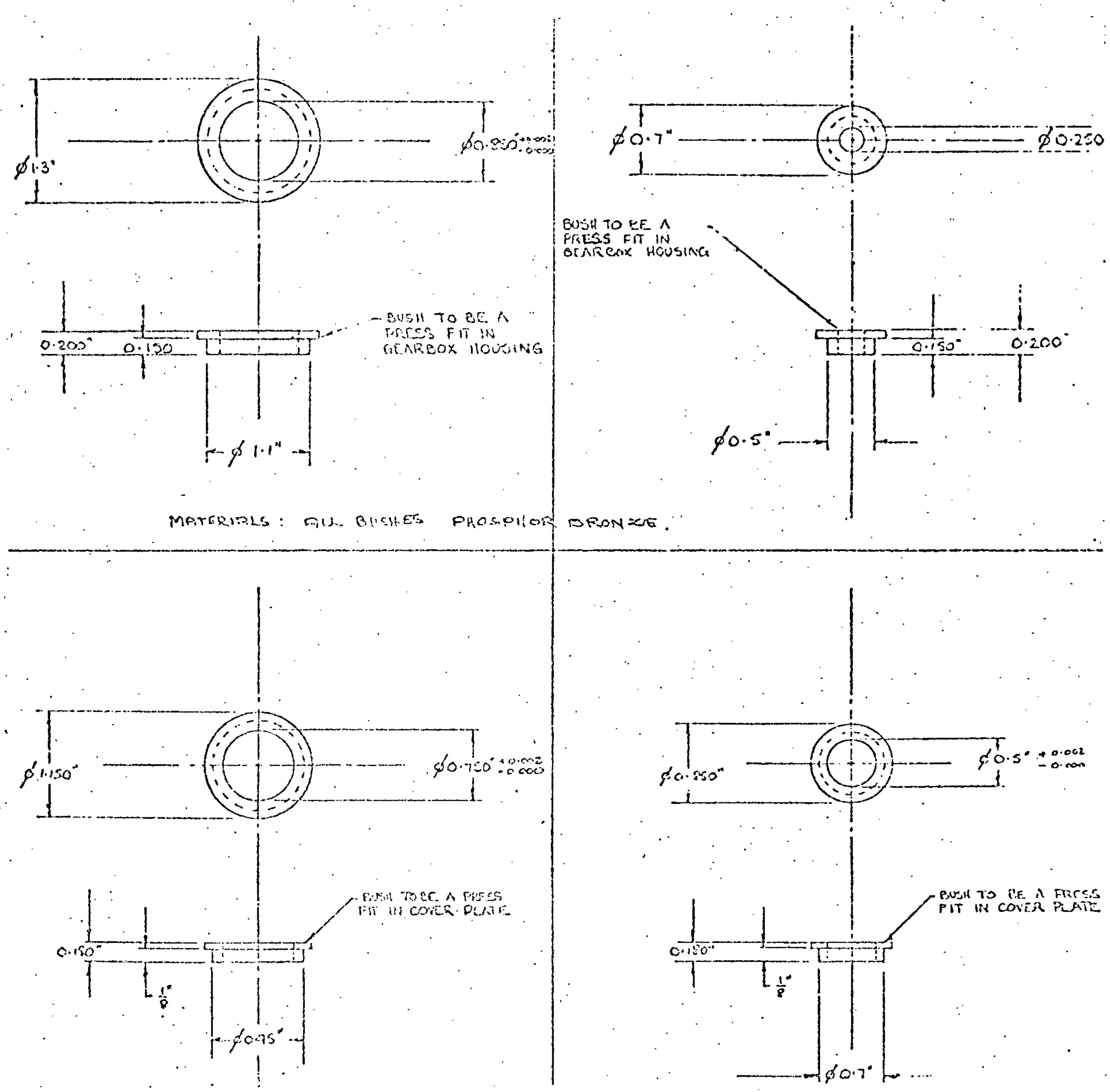


D.5. 1. Lever to which Spring is Attached.
2. Spring.

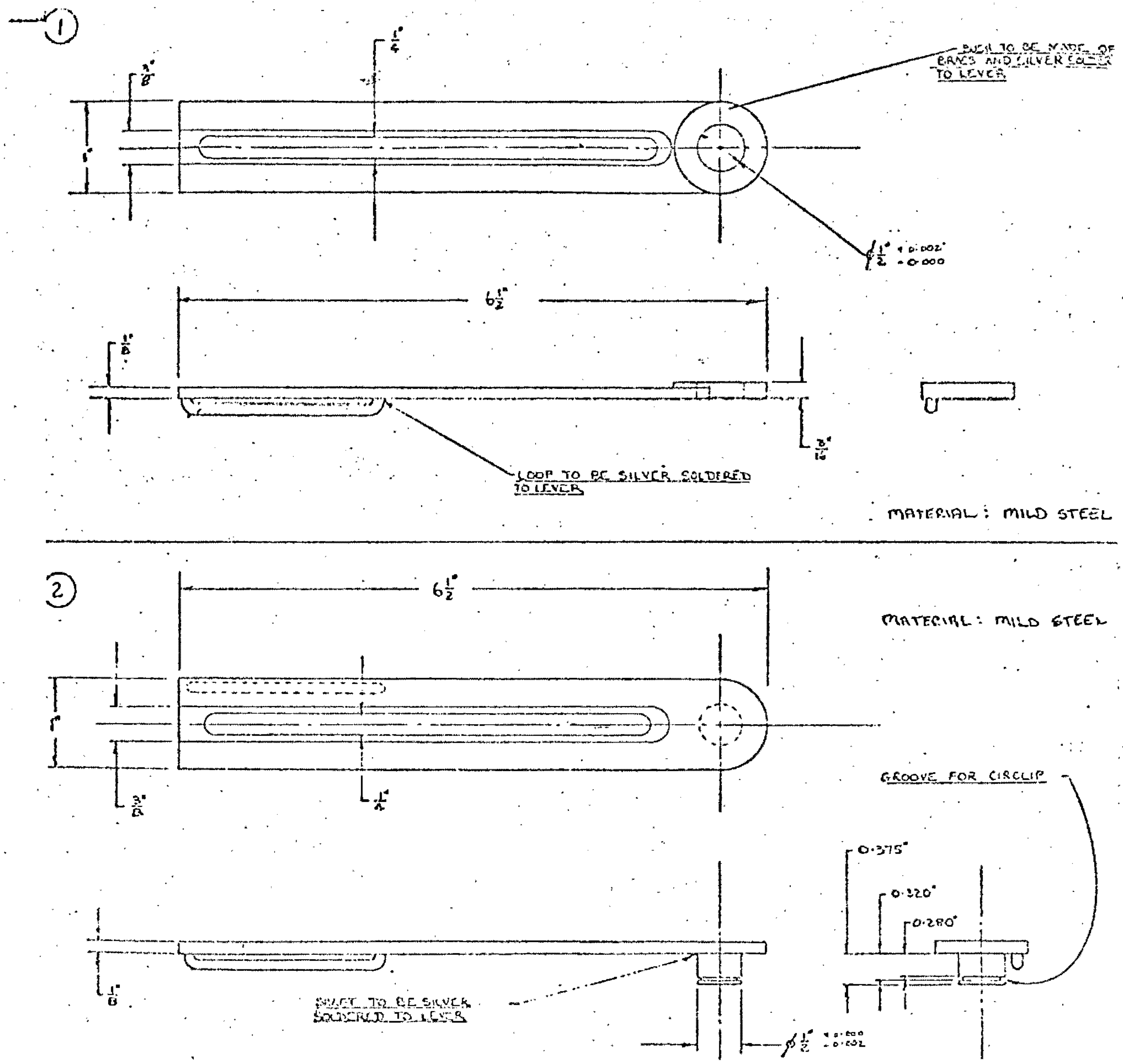




D.6. 1. Gear Wheel.
2. Ratchet Wheel.

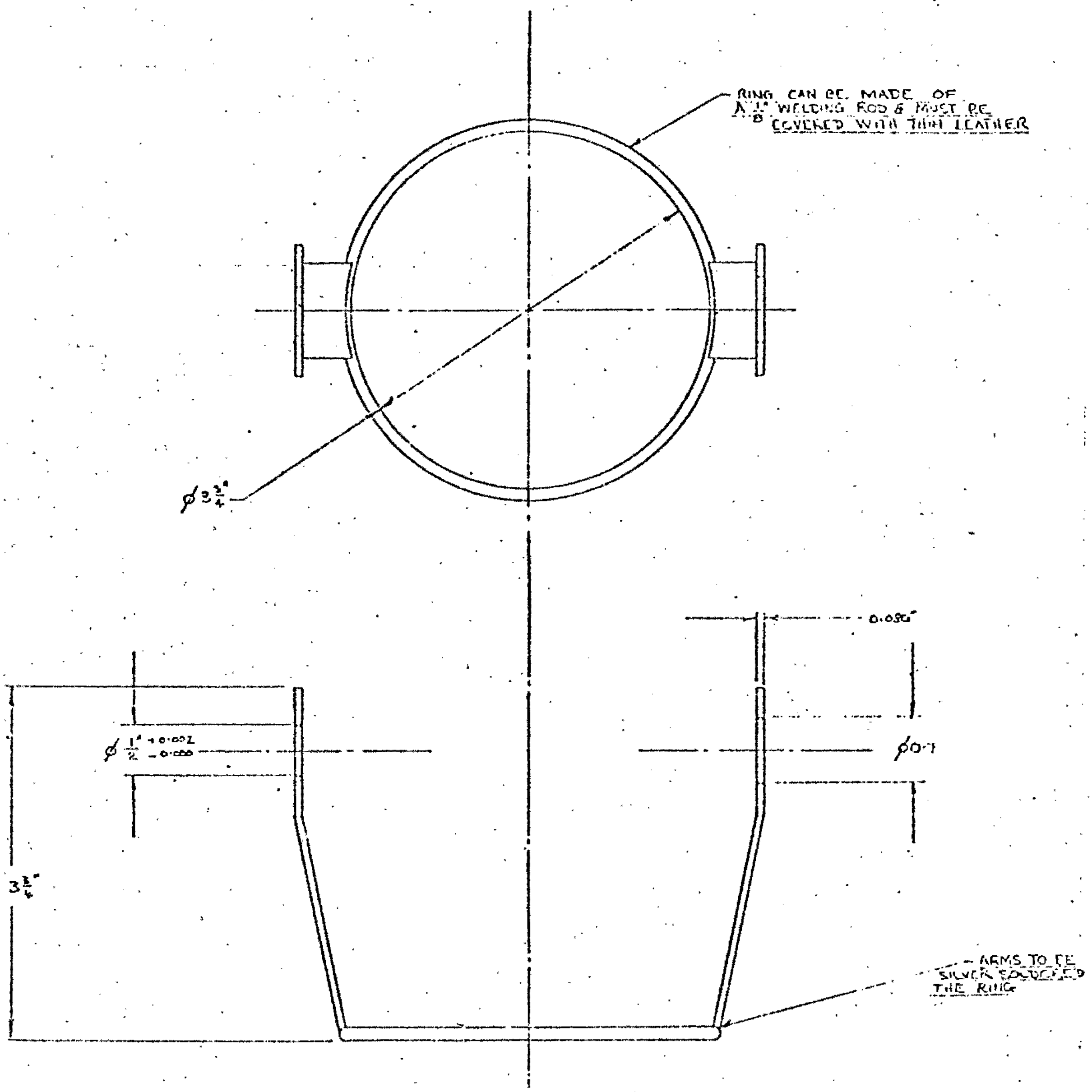

ø1.3"
ø0.850"
0.200"
0.150
BUSH TO BE A PRESS FIT IN GEARBOX HOUSING
ø1.1"
ø0.7"
ø0.250
BUSH TO BE A PRESS FIT IN GEARBOX HOUSING
0.150"
0.200"
ø0.5"
MATERIALS: ALL BUSHES PHOSPHOR BRONZE.
ø1.150"
ø0.750"
BUSH TO BE A PRESS FIT IN COVER PLATE
0.150"
1/8"
ø0.95"
ø0.850"
ø0.5"
BUSH TO BE A PRESS FIT IN COVER PLATE
0.150"
1/8"
ø0.7"

D.7. Bushes.



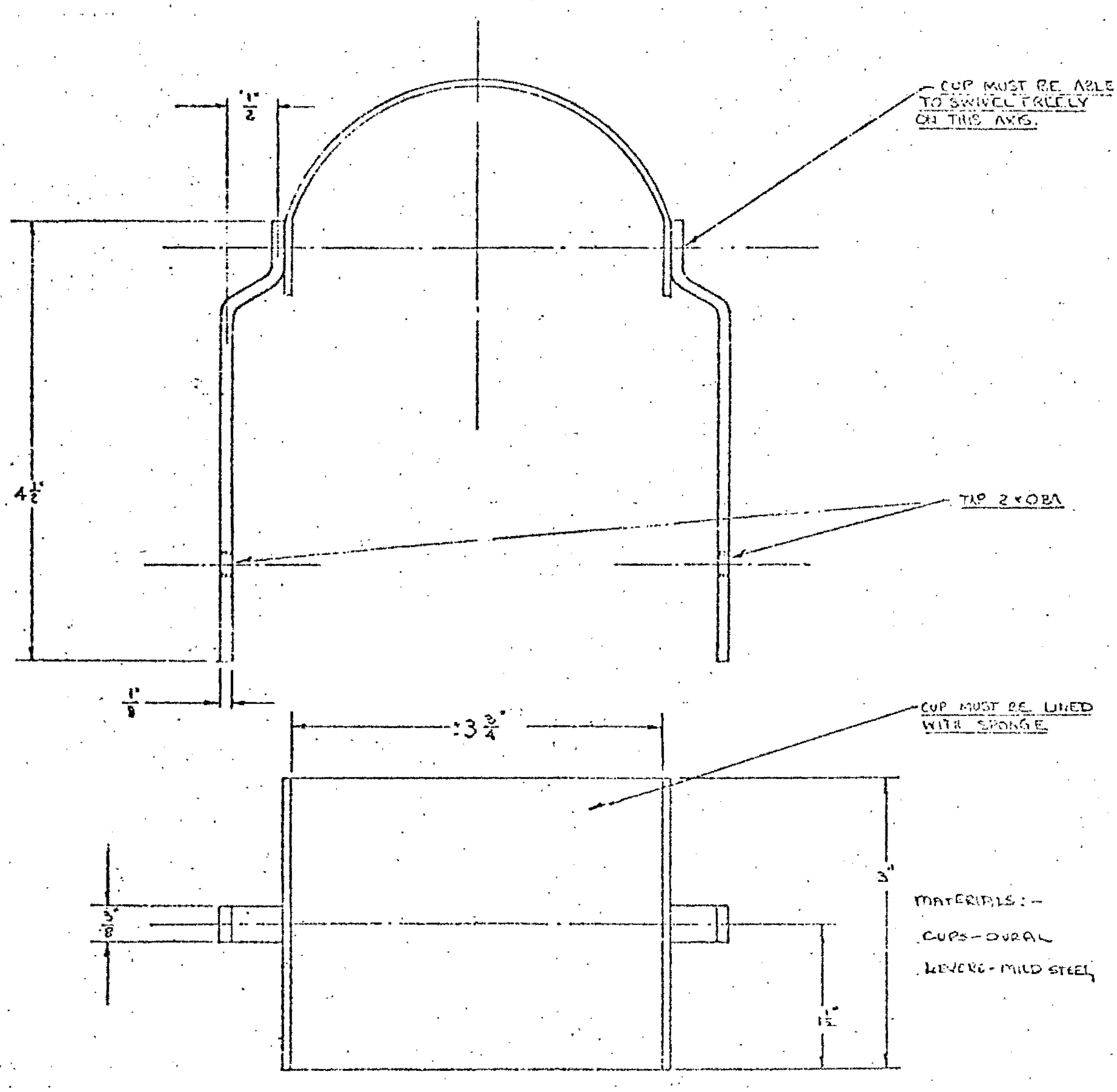
1
LOOP TO BE SILVER SOLDERED TO LEVER
MATERIAL: MILD STEEL
2
MATERIAL: MILD STEEL
GROOVE FOR CIRCLIP
0·375"
0·320"
0·280"
SHAFT TO BE SILVER SOLDERED TO LEVER

D. 8. 1 & 2 Levers.



D.9. Elbow Support.

MATERIAL — MILD STEEL.



D.10. Cups for Arm Support.

APPENDIX E.

Circuit Diagrams of Myo-Electric Control System Utilising Rate of Change of Input Signal to Determine Direction of Orthesis Motor Rotation.

Circuit Description.

The Myo-electric signal amplifier consists of 3 stages (fig. 1) - a differential amplifier input and two common emitter stages. A 50 c.p.s. fitter is used to minimise stray pickup.

After being amplified and full wave rectified (Tr_x and Tr_y), the output is shaped to obtain one rectangular pulse for every rectified signal above zero volts (fig.2). These pulses are then passed to a frequency counter for averaging. To obtain a measure of the rate of change of the signal, the output from the frequency counter is differentiated. Should the differentiator output exceed a set level (determined by R.V. in figure 3), the trigger circuit is initiated and the "maximum rate of change control" is commanded to operate. A latching "AND" gate is then switched on, and as long as a myo-electric signal of about 1/3 of maximum output is present, a relay remains switched in. This relay reverses the power supply to the orthesis motors. (To minimise motor noise interference, separate power supplies are used for the motor and for the electronic unit.)

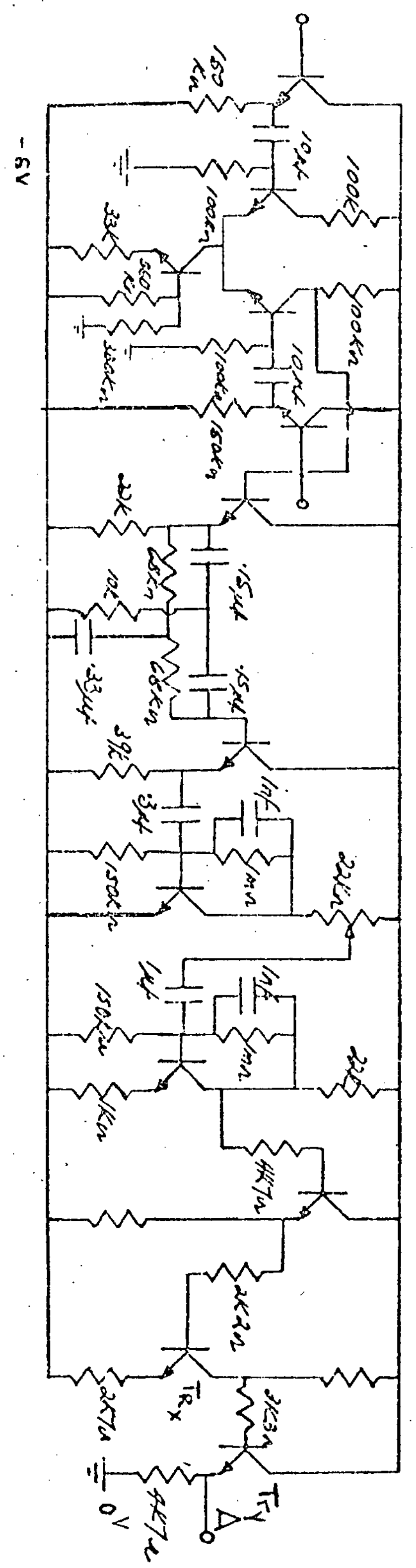


Fig. 1. EMG Amplifier.

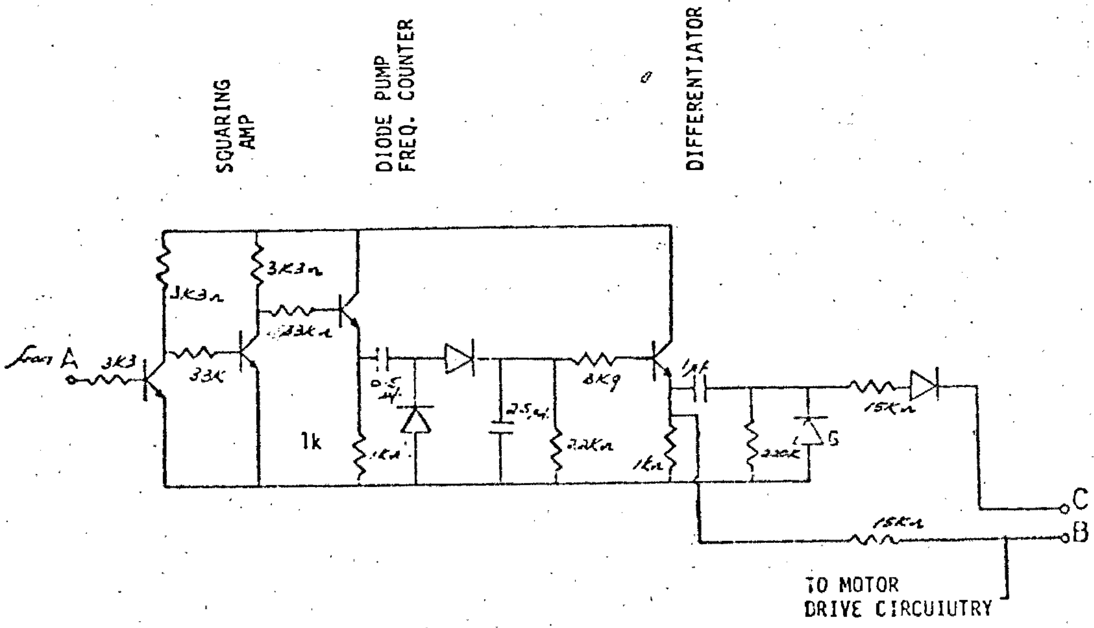

SQUARING AMP
DIODE PUMP FREQ. COUNTER
DIFFERENTIATOR
from A
3K3
3K3Ω
33K
1k
8K2
15KΩ
C
B
TO MOTOR DRIVE CIRCUIUTRY

Fig. 2.

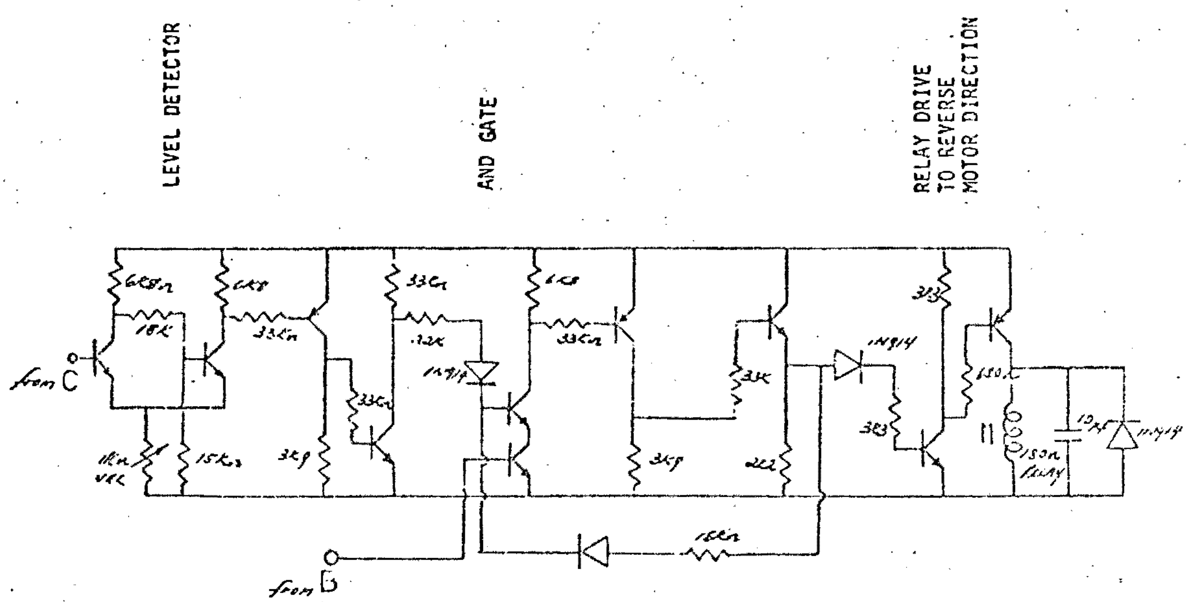
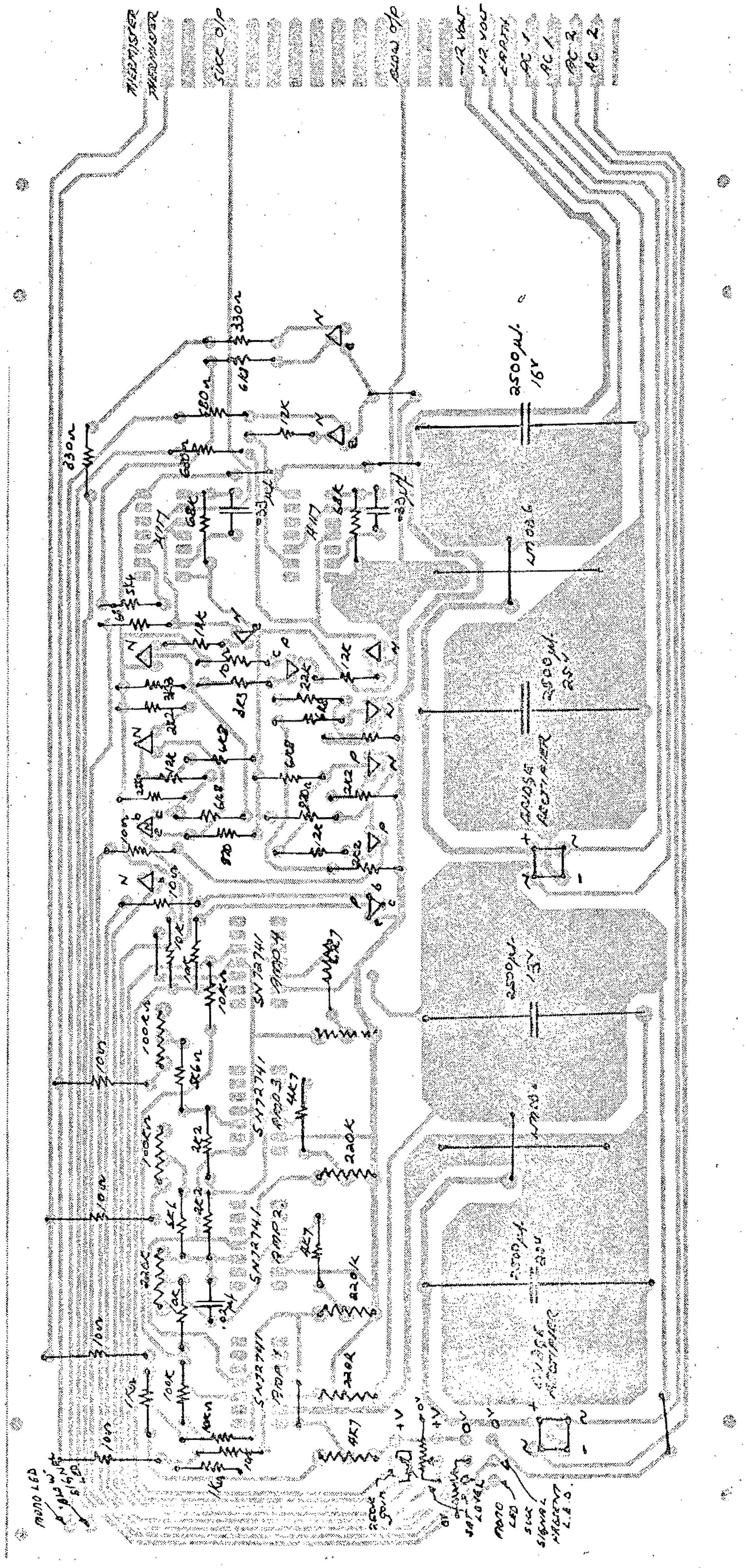

LEVEL DETECTOR
AND GATE
RELAY DRIVE TO REVERSE MOTOR DIRECTION
from C
from B
1N914

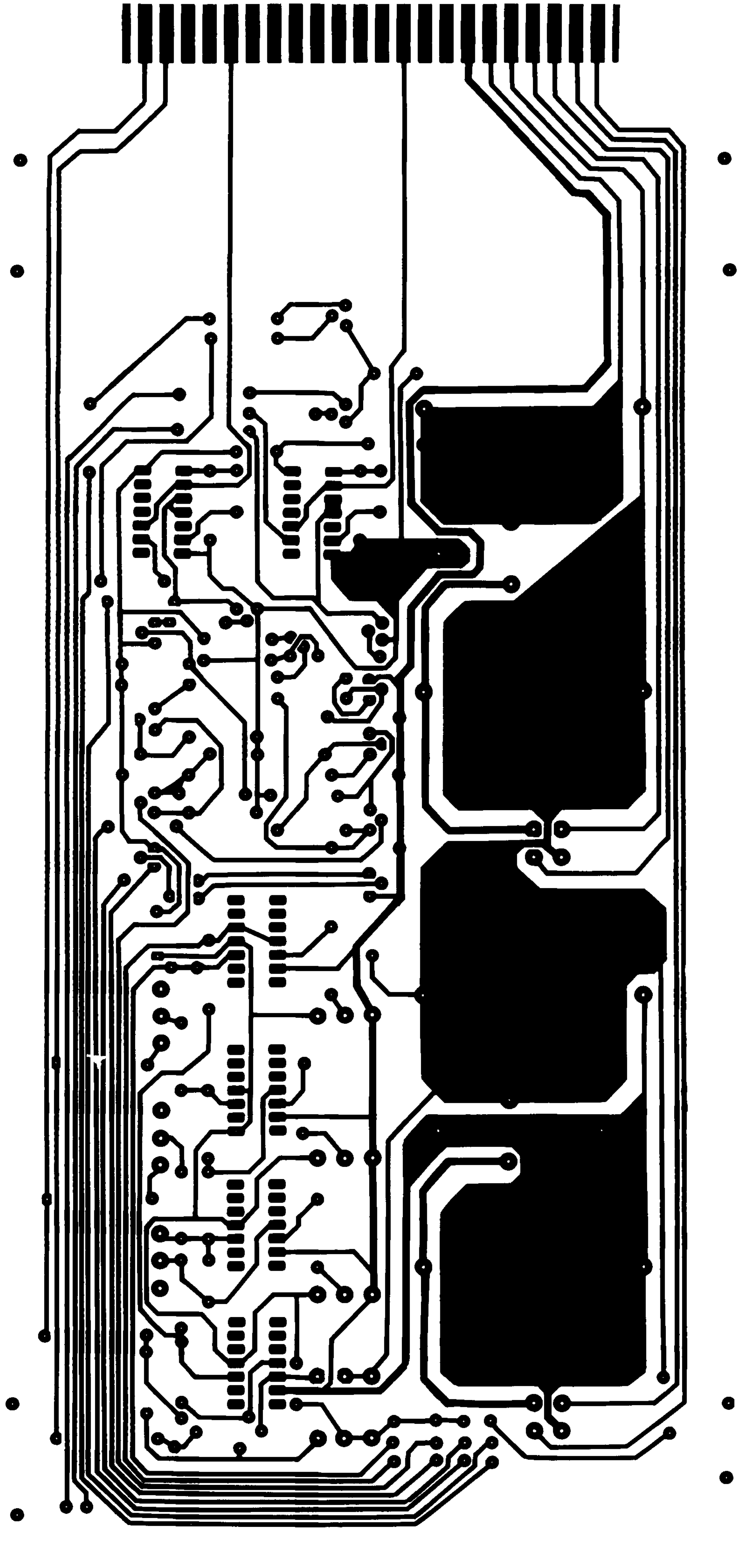
Fig. 3.

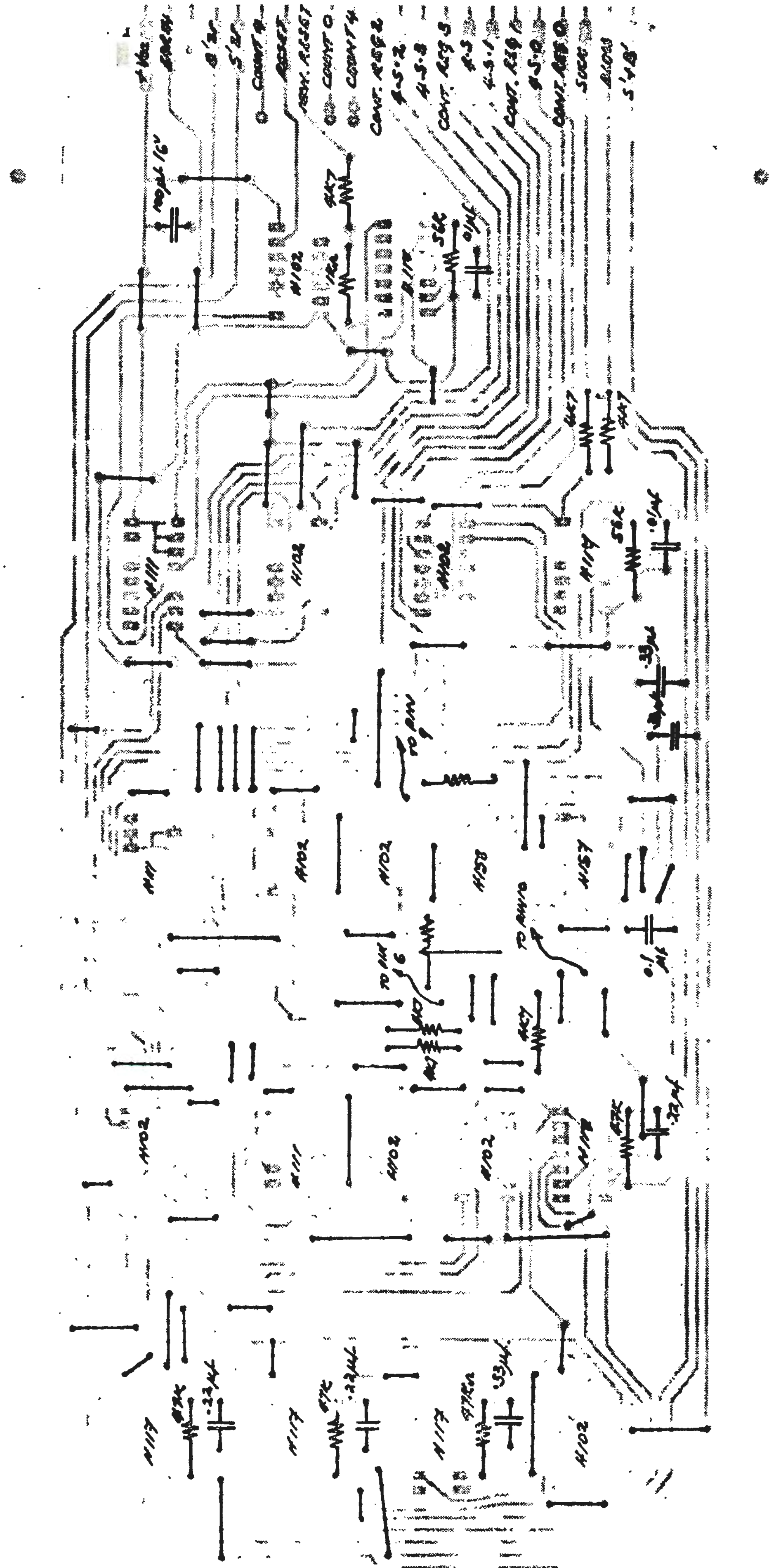
APPENDIX F.

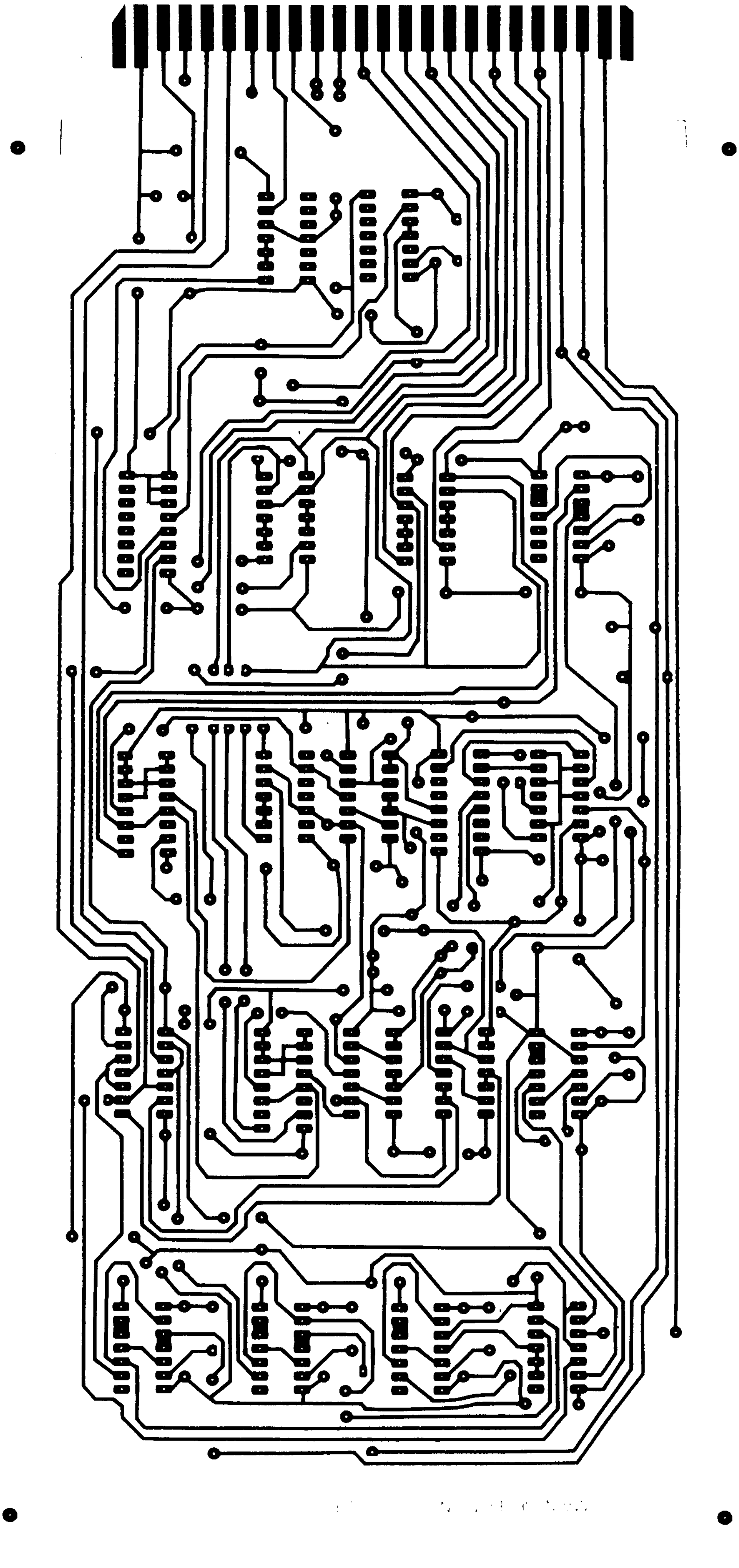
Wiring Diagrams, Circuit Interconnections, Printed Circuit and Component Layout of Suck-Blow Selector System and Touch Button Selector System Environment Controllers.

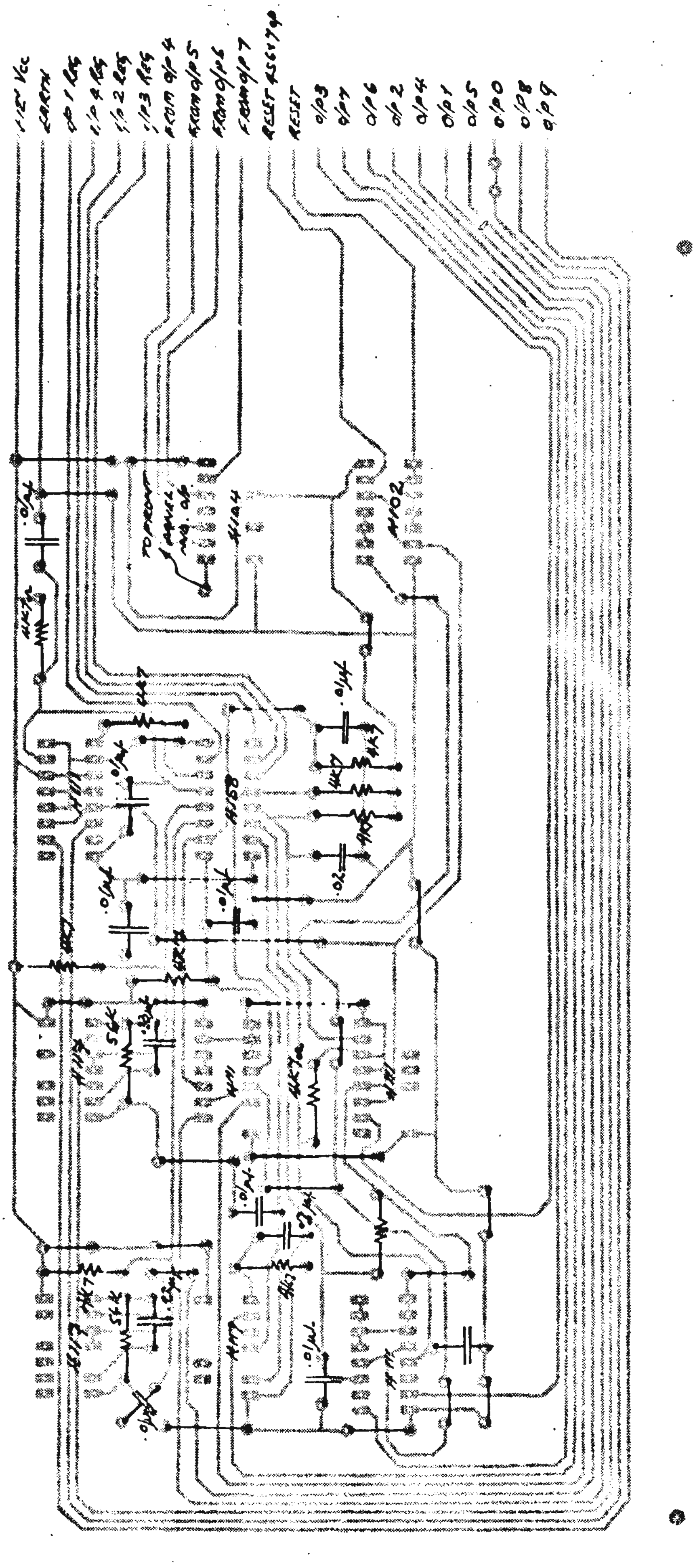
Printed Circuit Diagrams And Component Layout Of Systems.


SUCK O/P
BLOW O/P
EARTH
AC 1
AC 2
SN72741
2500µF
RECTIFIER

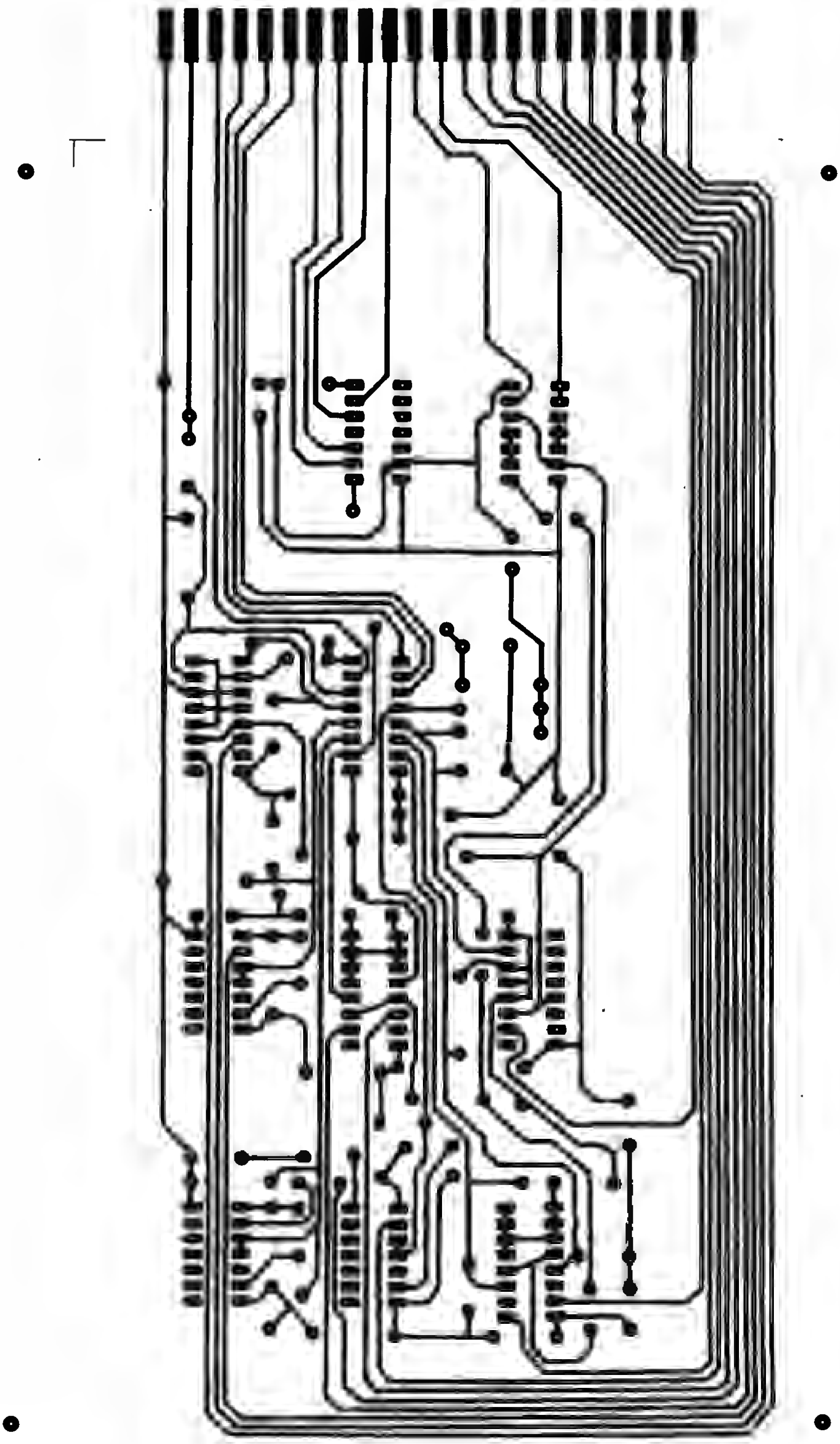


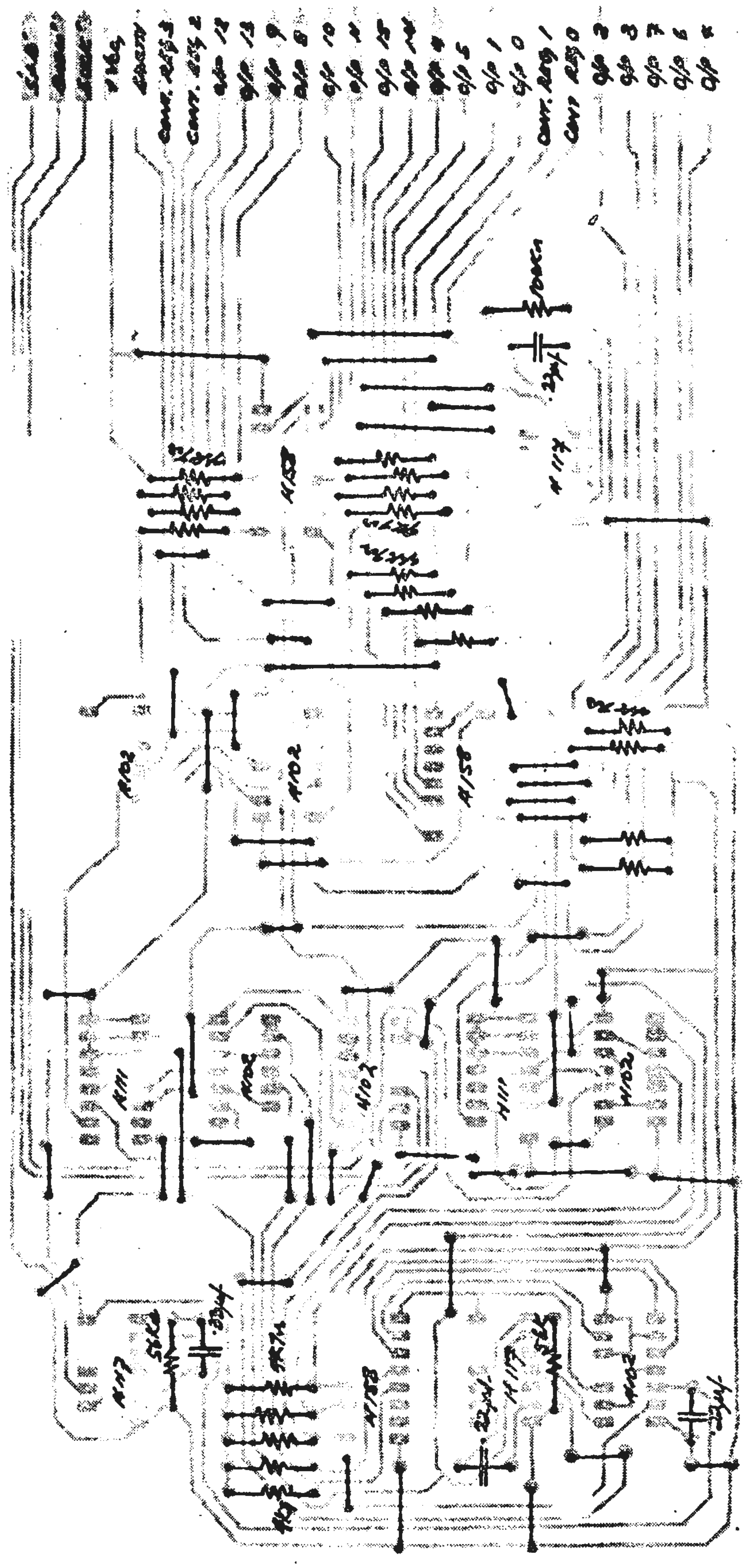


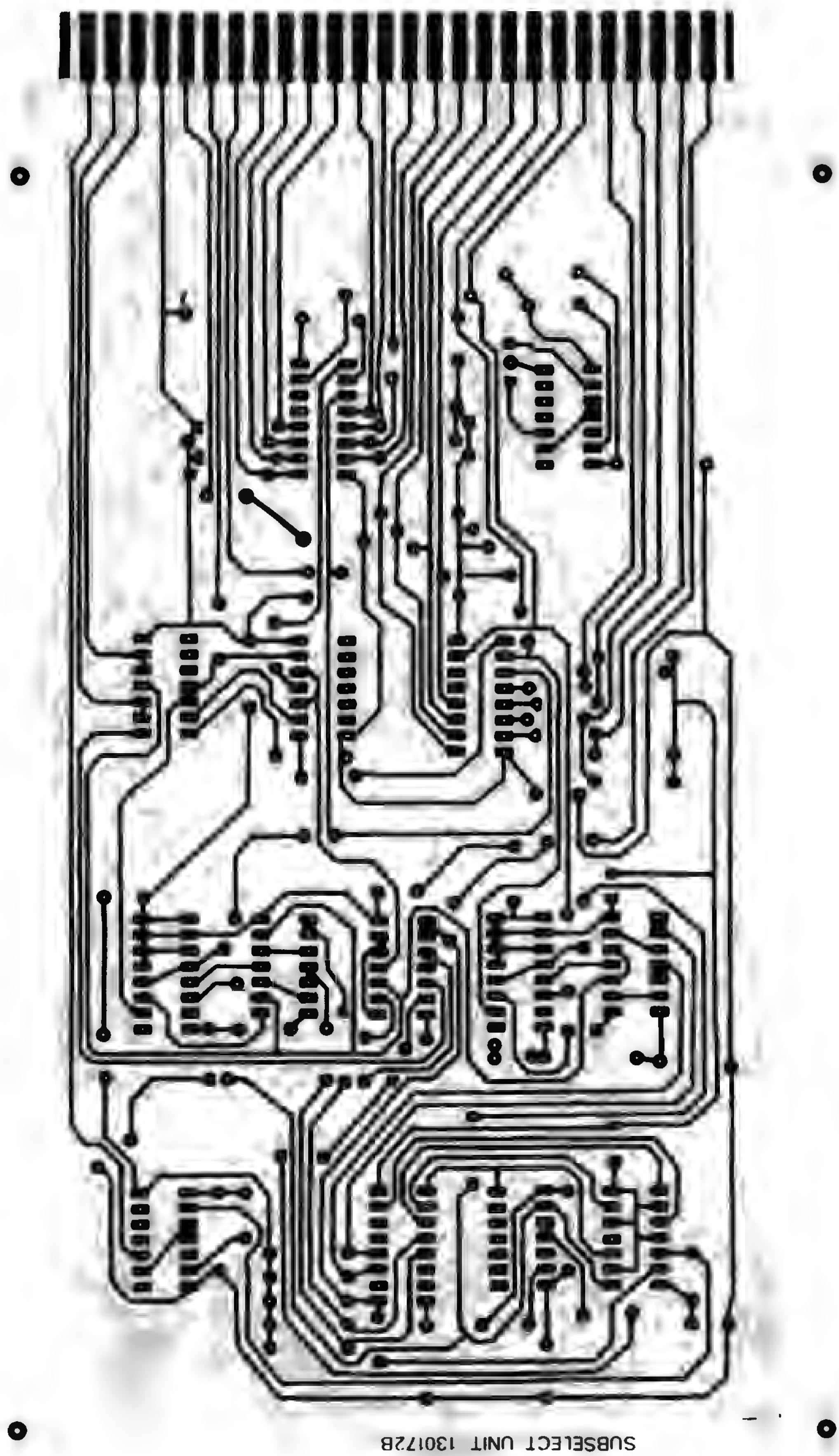


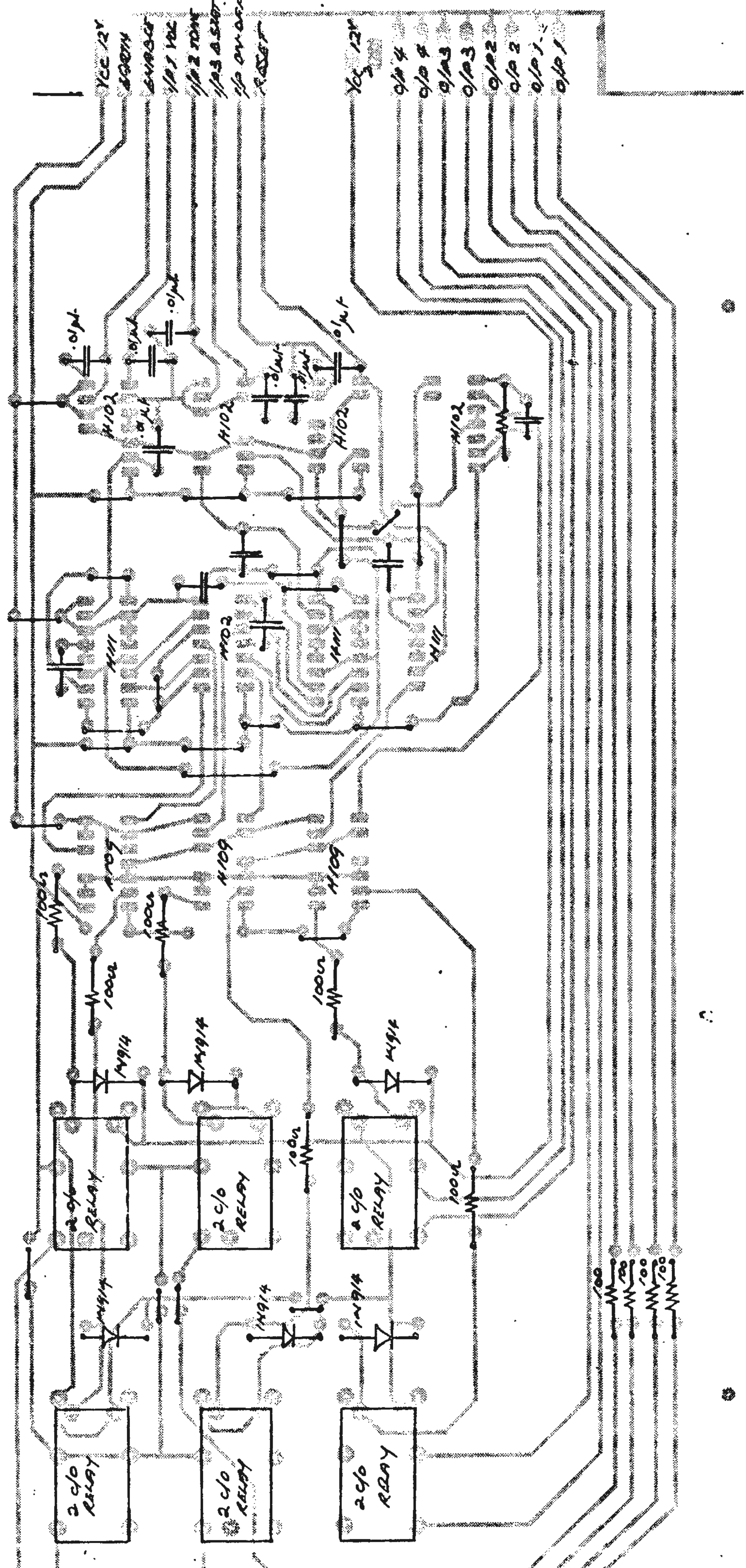


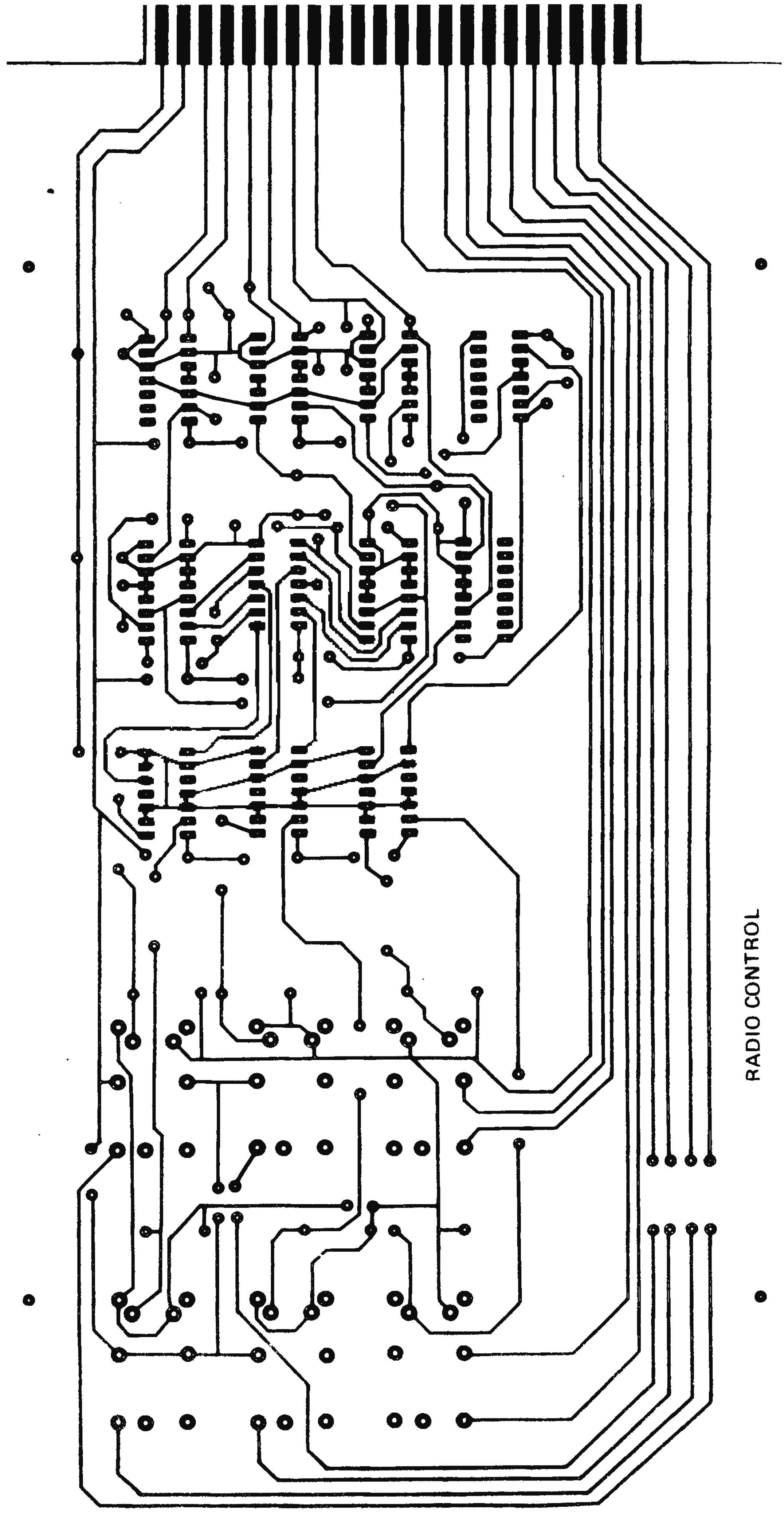
MAIN DECODER UNIT

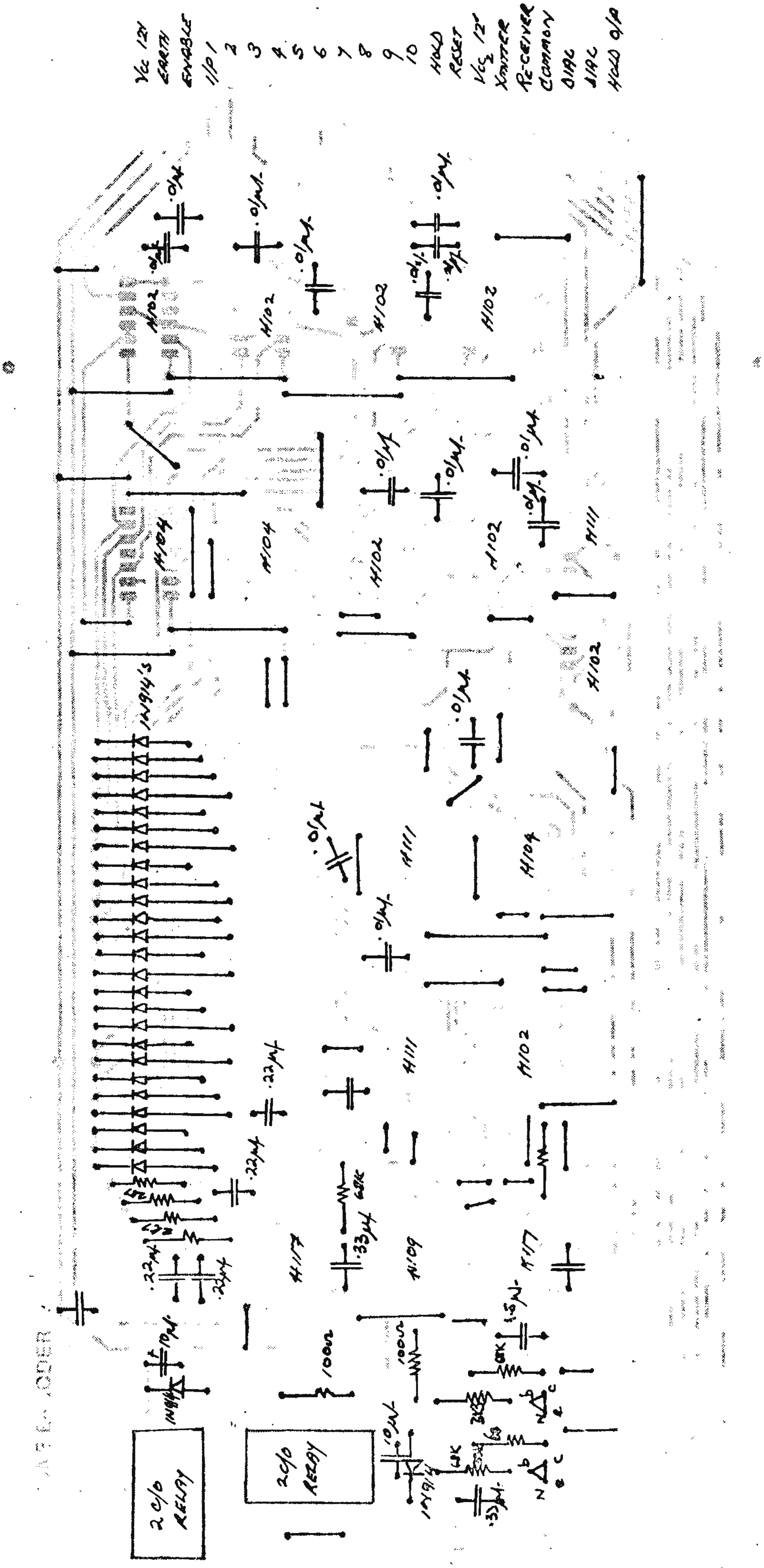


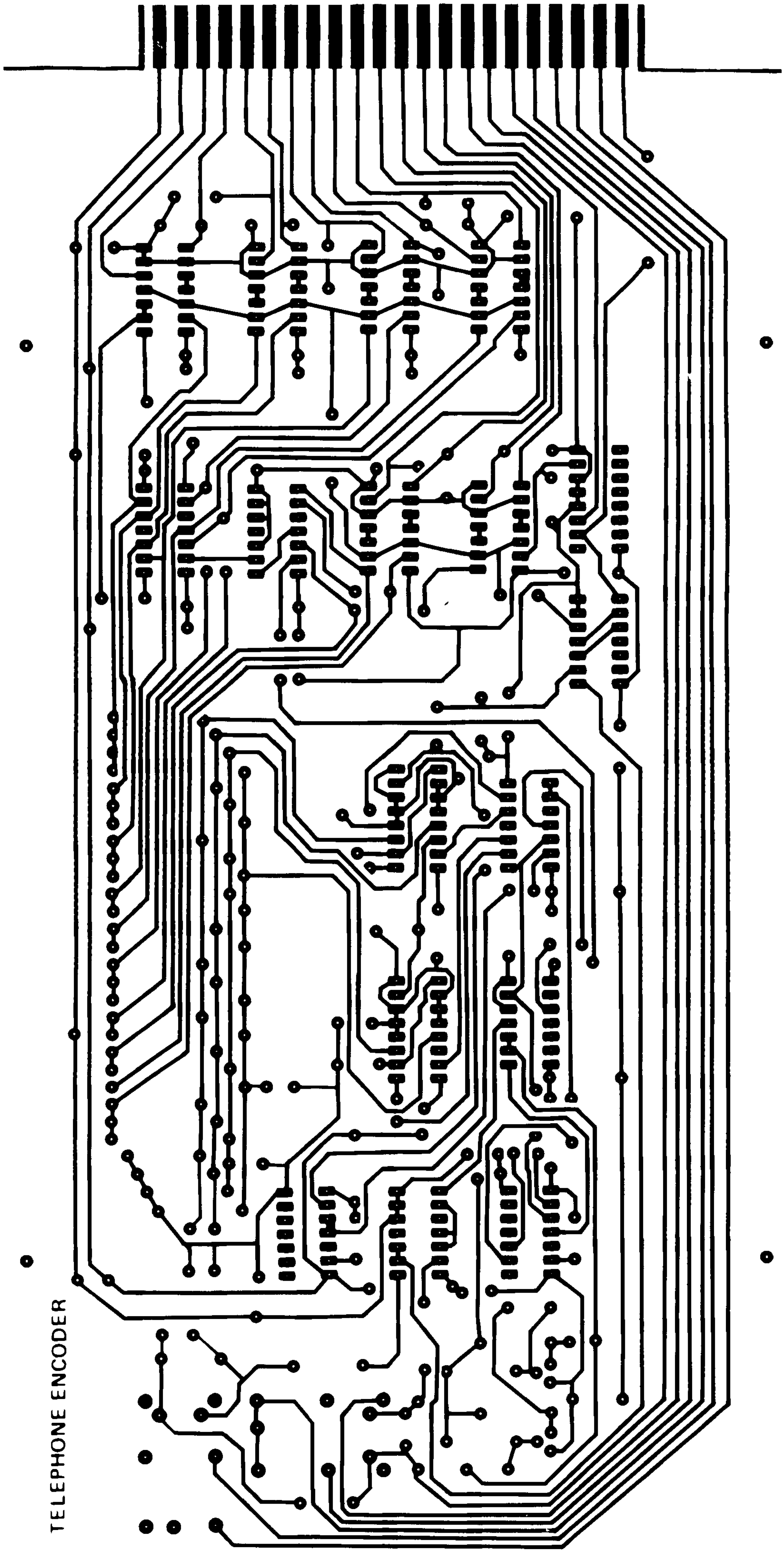


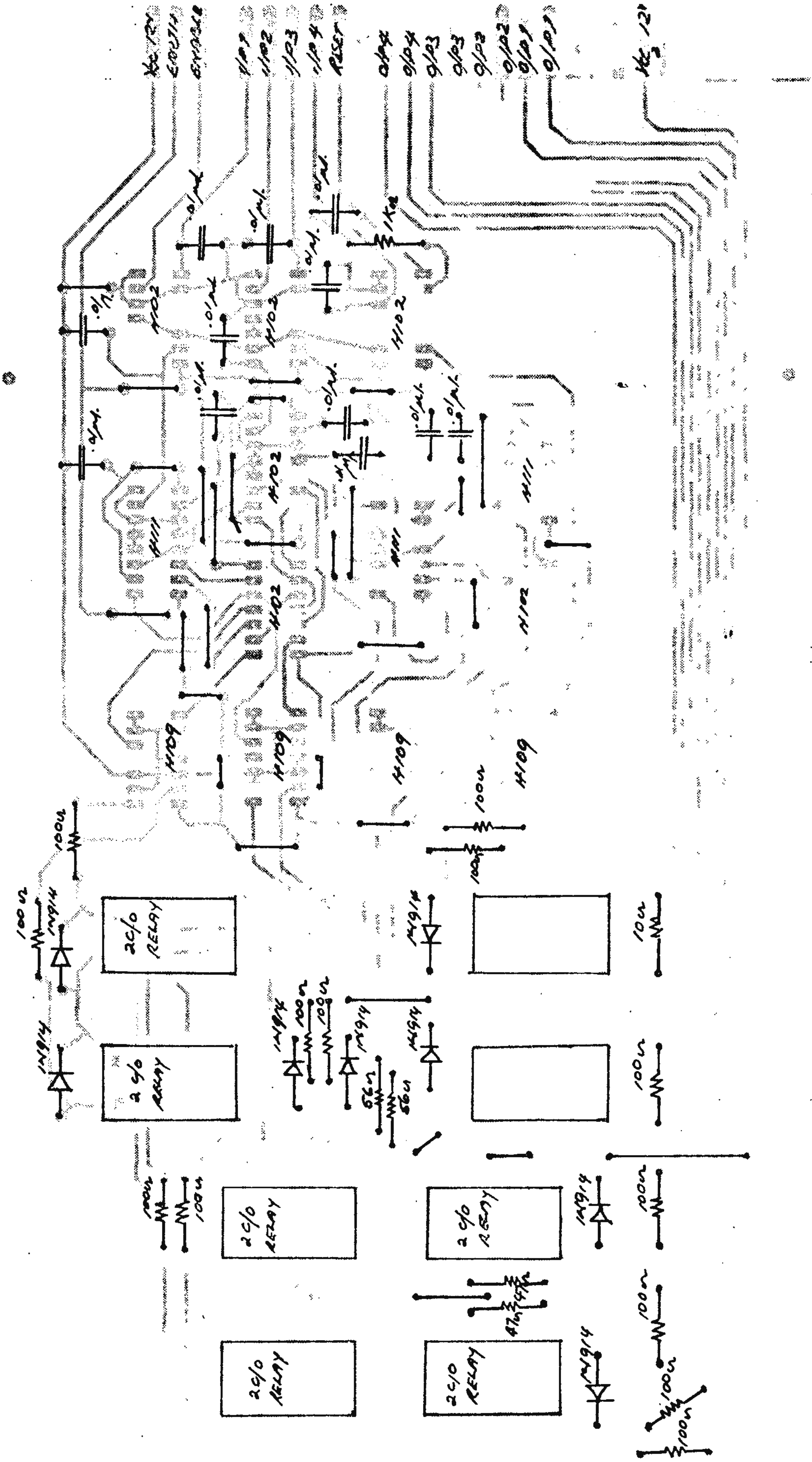

SUBSELECT UNIT 130172B

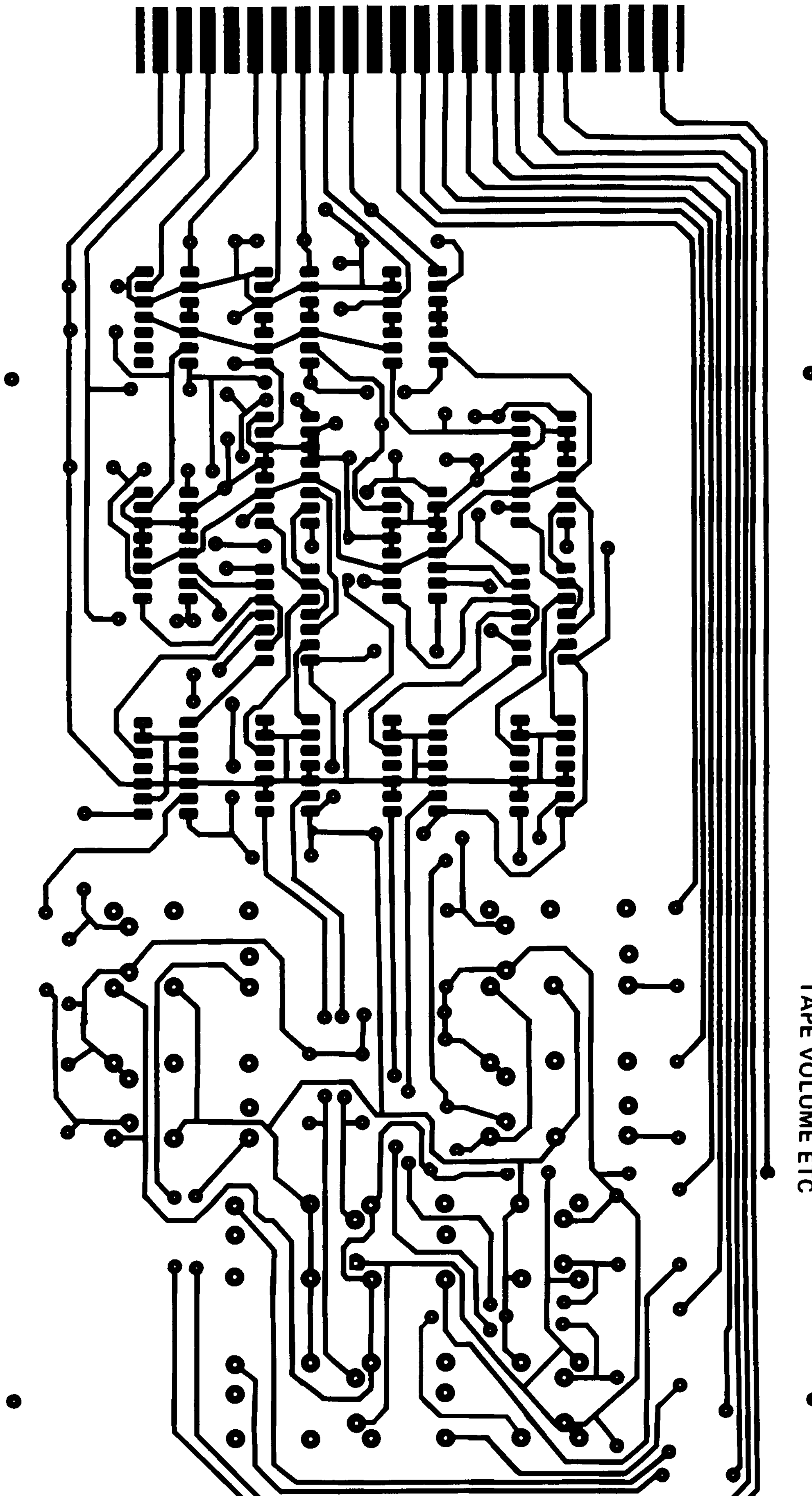

2 C/O RELAY
2 C/O RELAY
2 C/O RELAY
2 C/O RELAY
2 C/O RELAY
H102
H111
H109
1N914
100Ω


RADIO CONTROL


Vcc 12V
EARTH
ENABLE
I/P 1
2
3
4
5
6
7
8
9
10
HOLD
RESET
XMITTER
RECEIVER
COMMON
DIAL
DIAL
HOLD O/P
H102
H104
H111
H117
H109
1N914's
.01µF
.22µF
.33µF
10µF
1.5µF
100Ω
2 C/O RELAY
2C/O RELAY
1N914

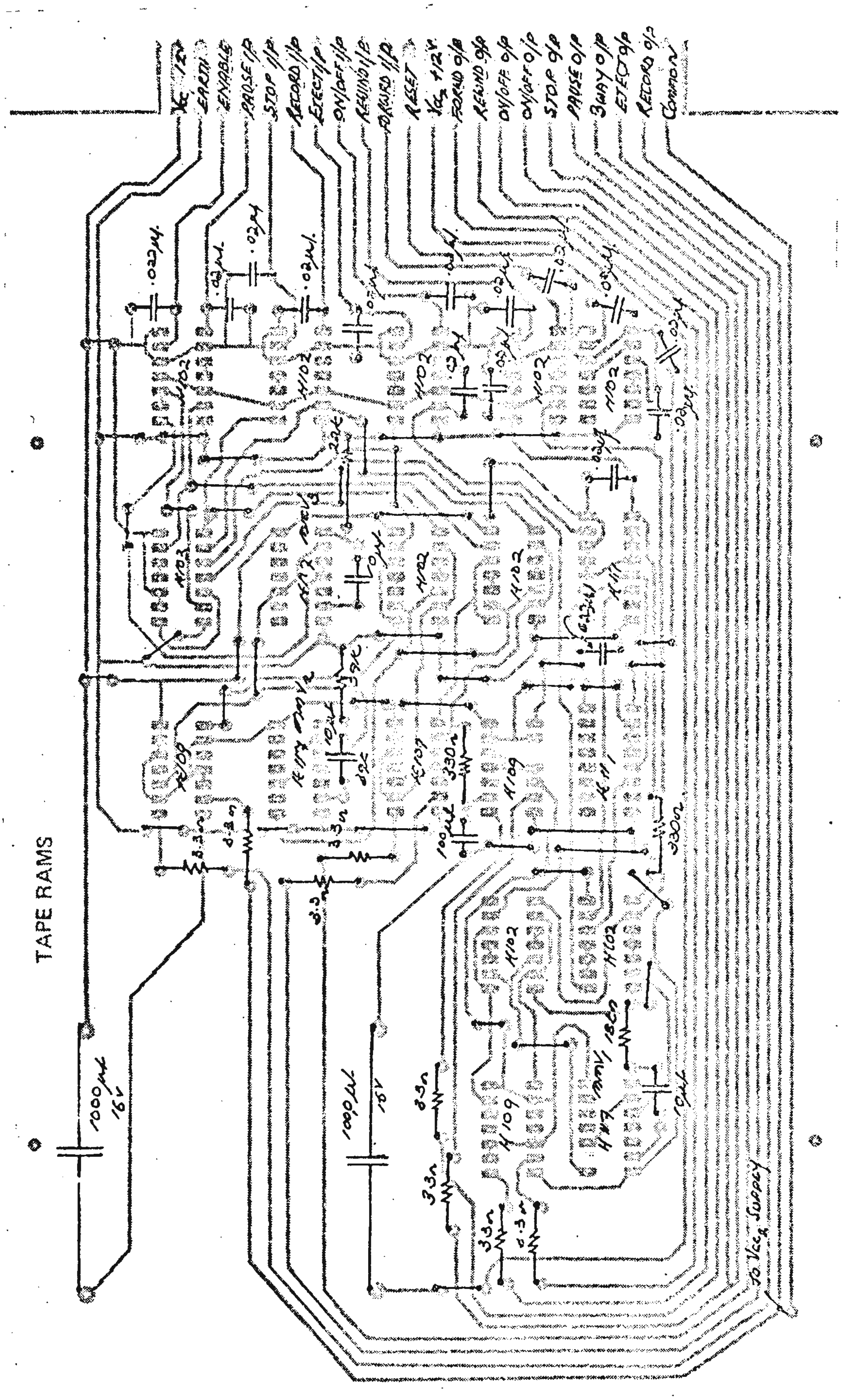

TELEPHONE ENCODER


2C/O RELAY
IN914
H102
H109
H111
RESET

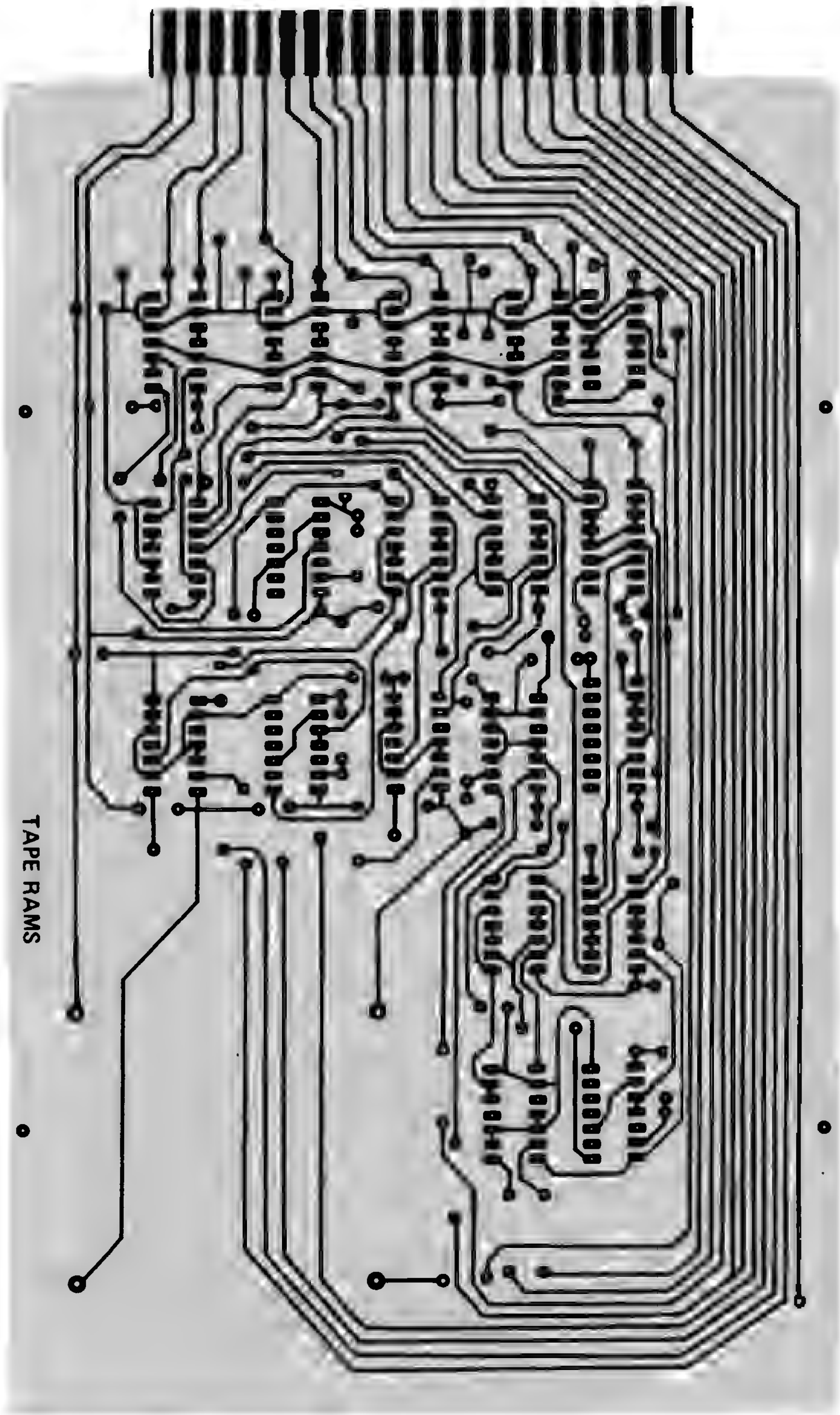


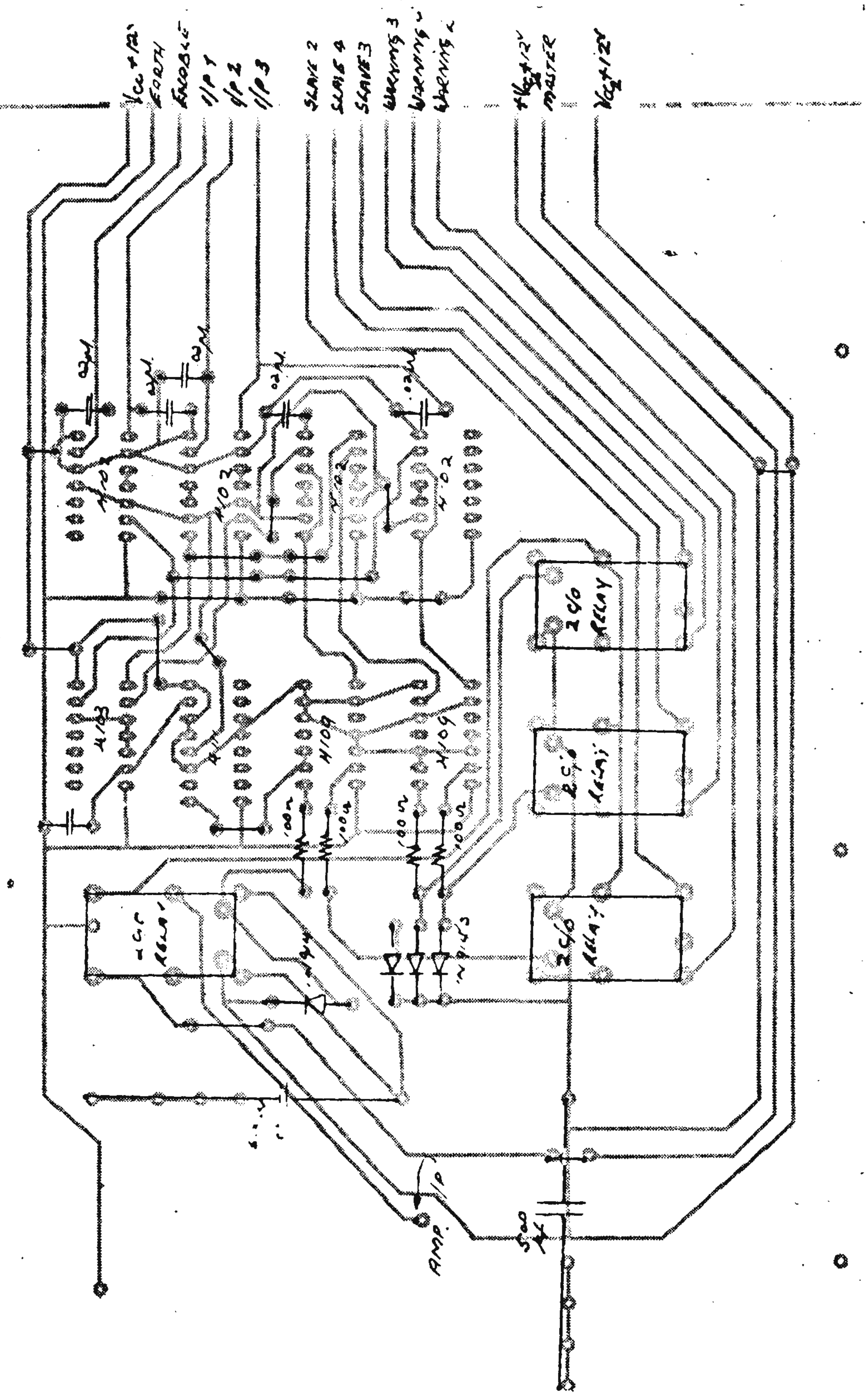
TAPE VOLUME ETC

TAPE RAMS

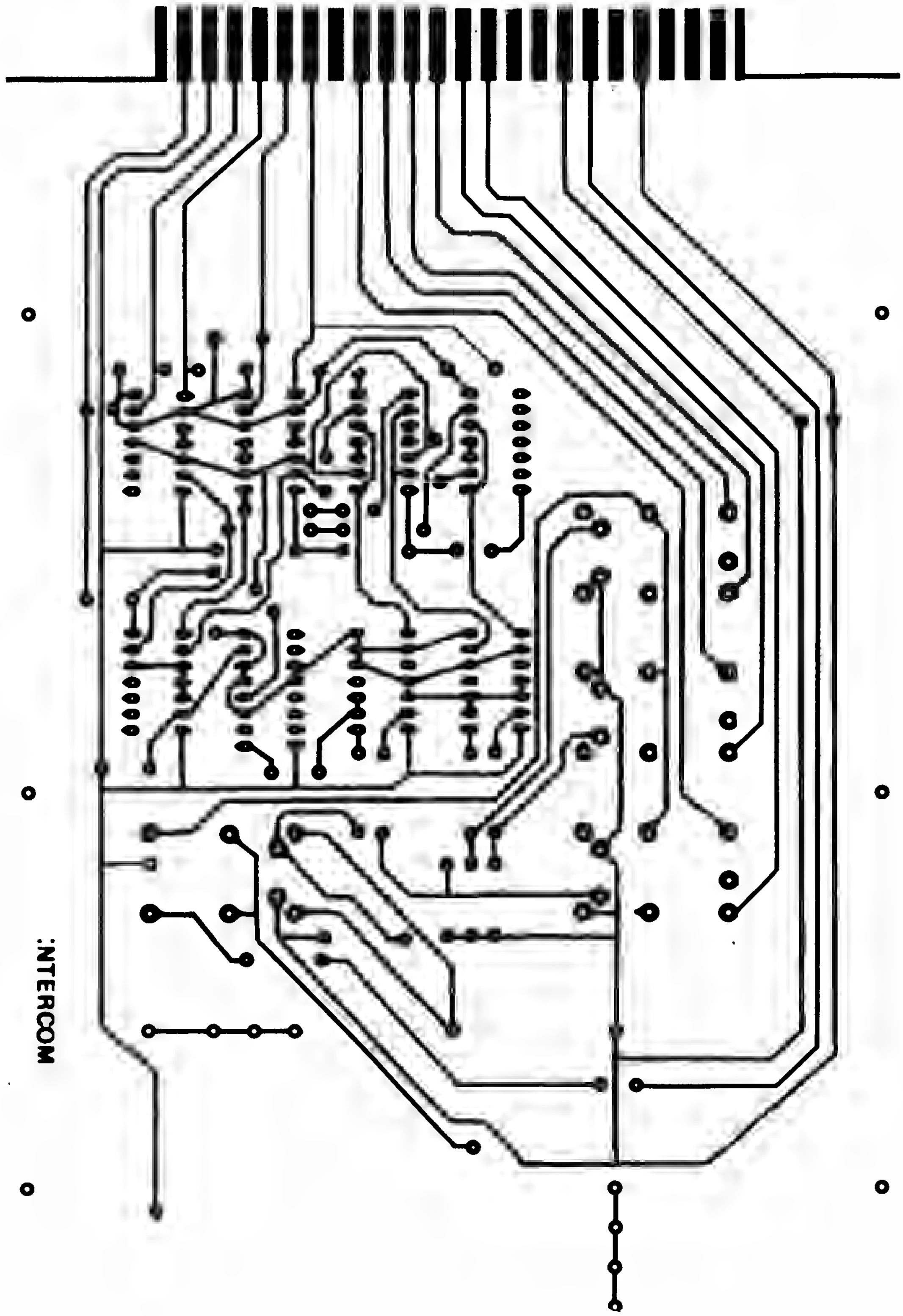


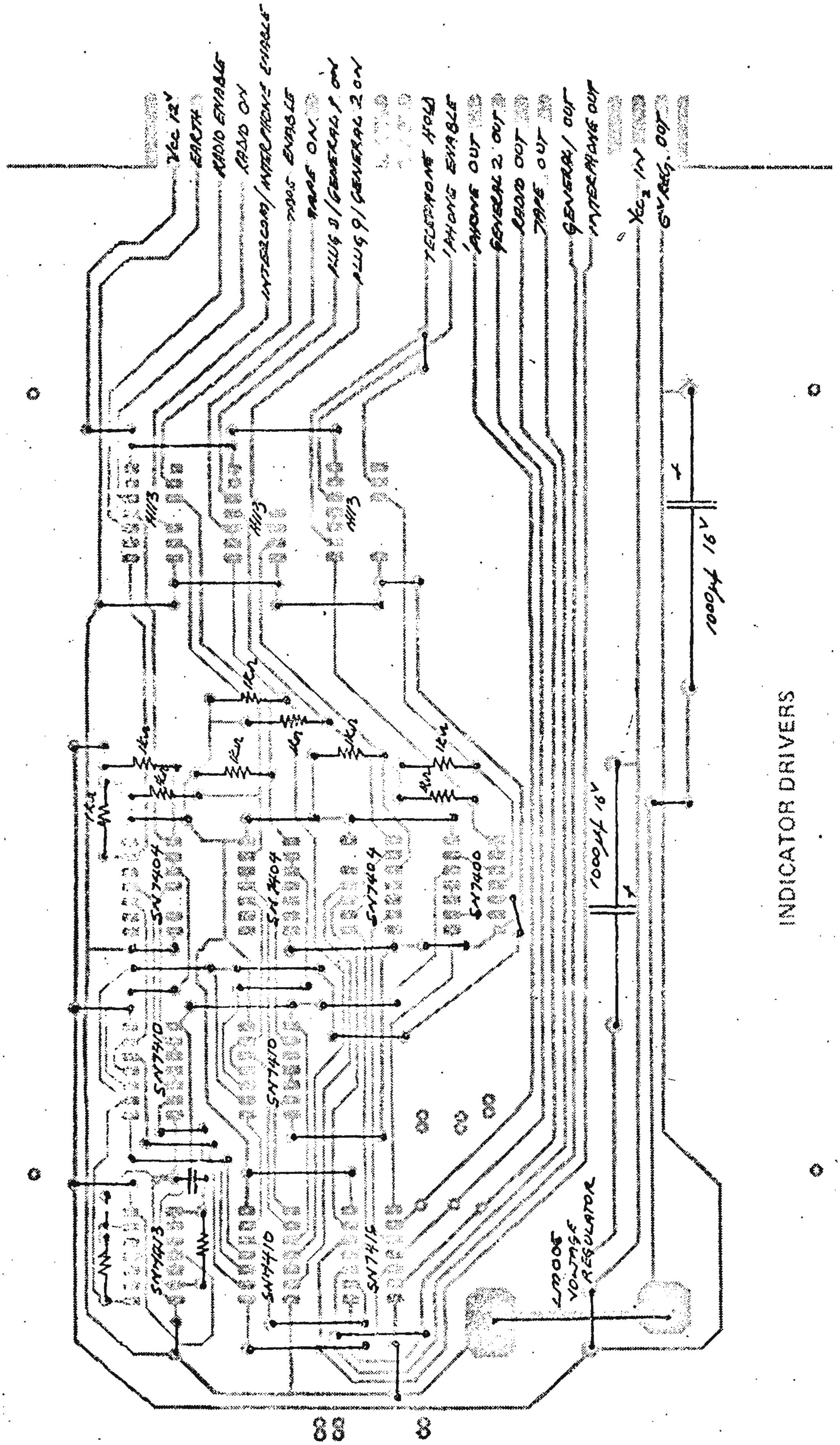
Vcc +12V
EARTH
ENABLE
PAUSE I/P
STOP I/P
RECORD I/P
EJECT I/P
ON/OFF I/P
REWIND I/P
FORWARD I/P
RESET
Vcc +12V
FORWARD O/P
REWIND O/P
ON/OFF O/P
ON/OFF O/P
STOP O/P
PAUSE O/P
3WAY O/P
EJECT O/P
RECORD O/P
COMMON
TO Vcc SUPPLY
1000µF 16V


TAPE RAMS

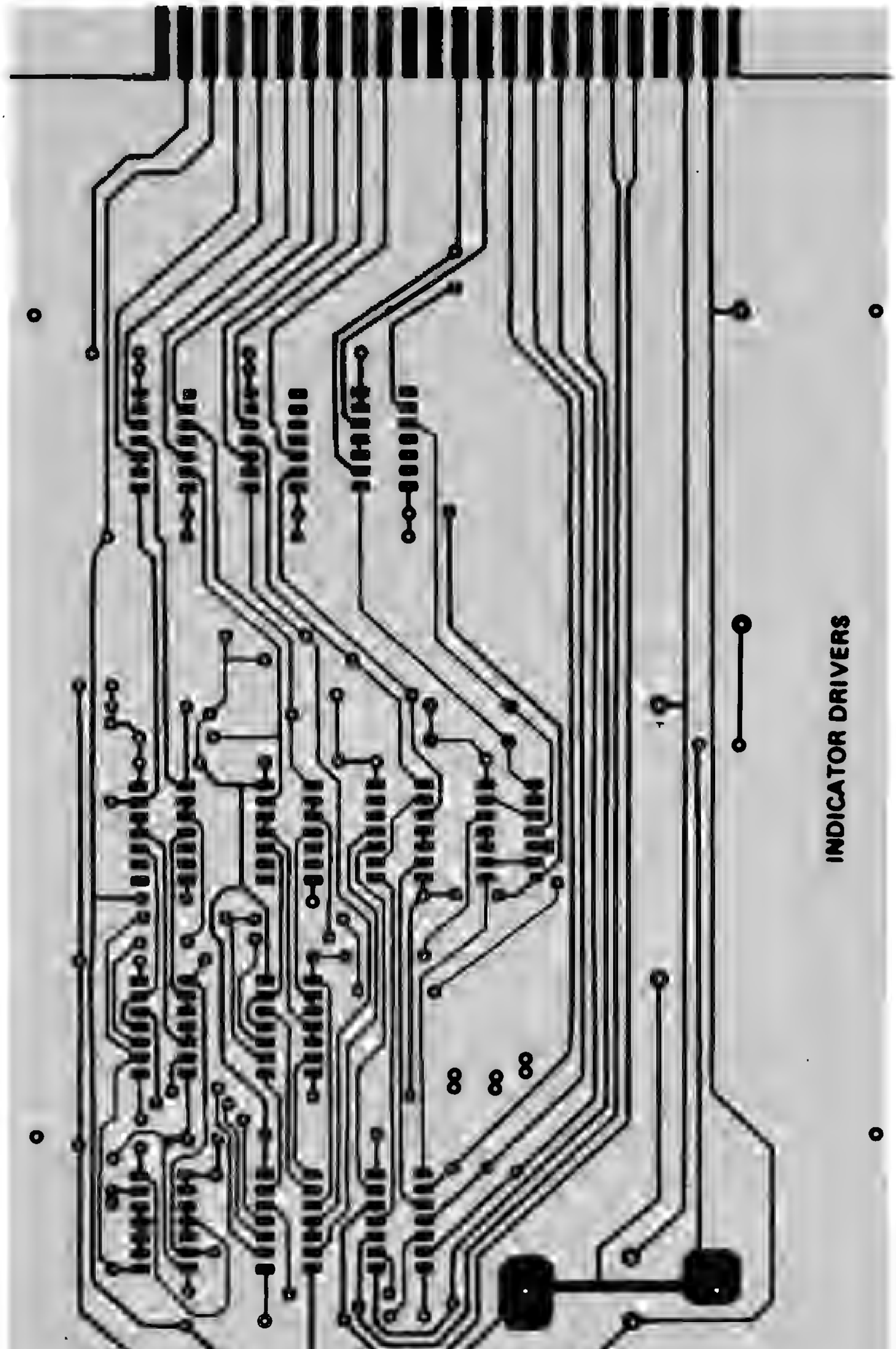


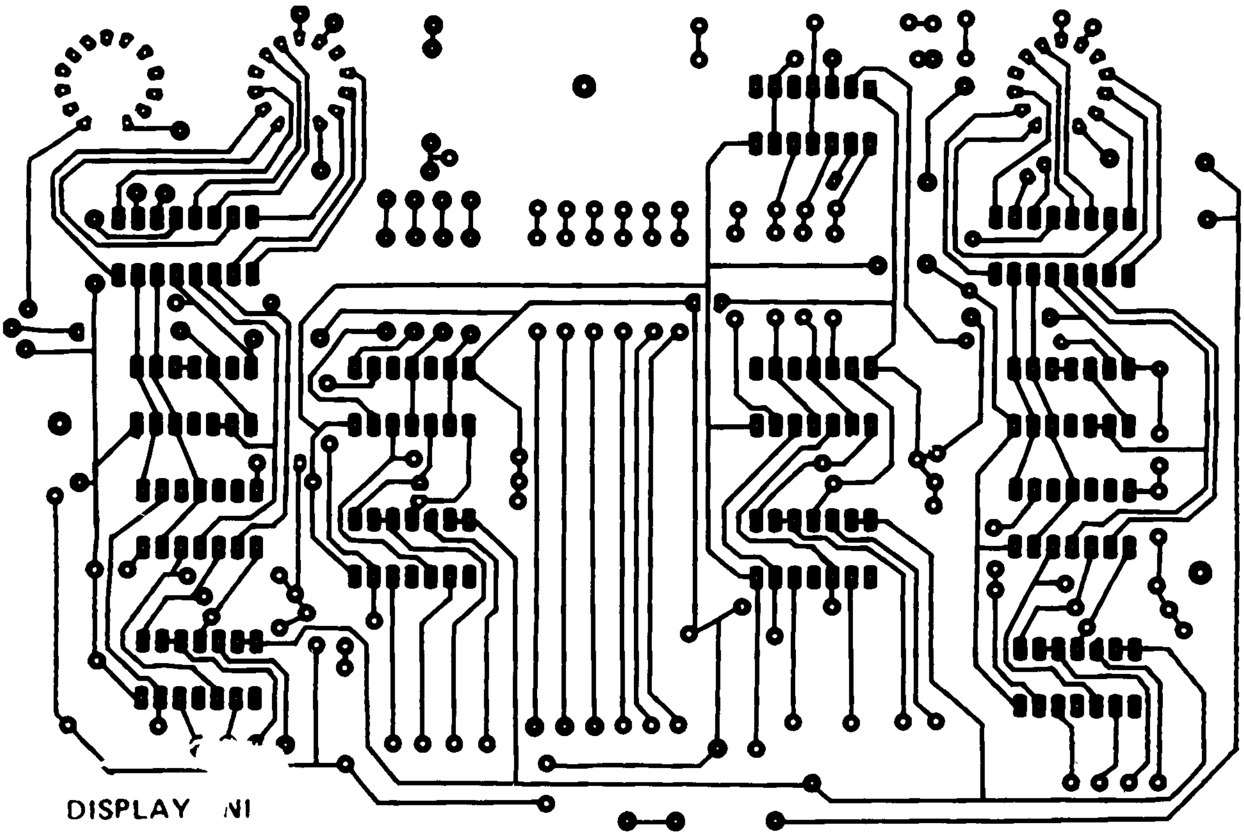
INTERCOM

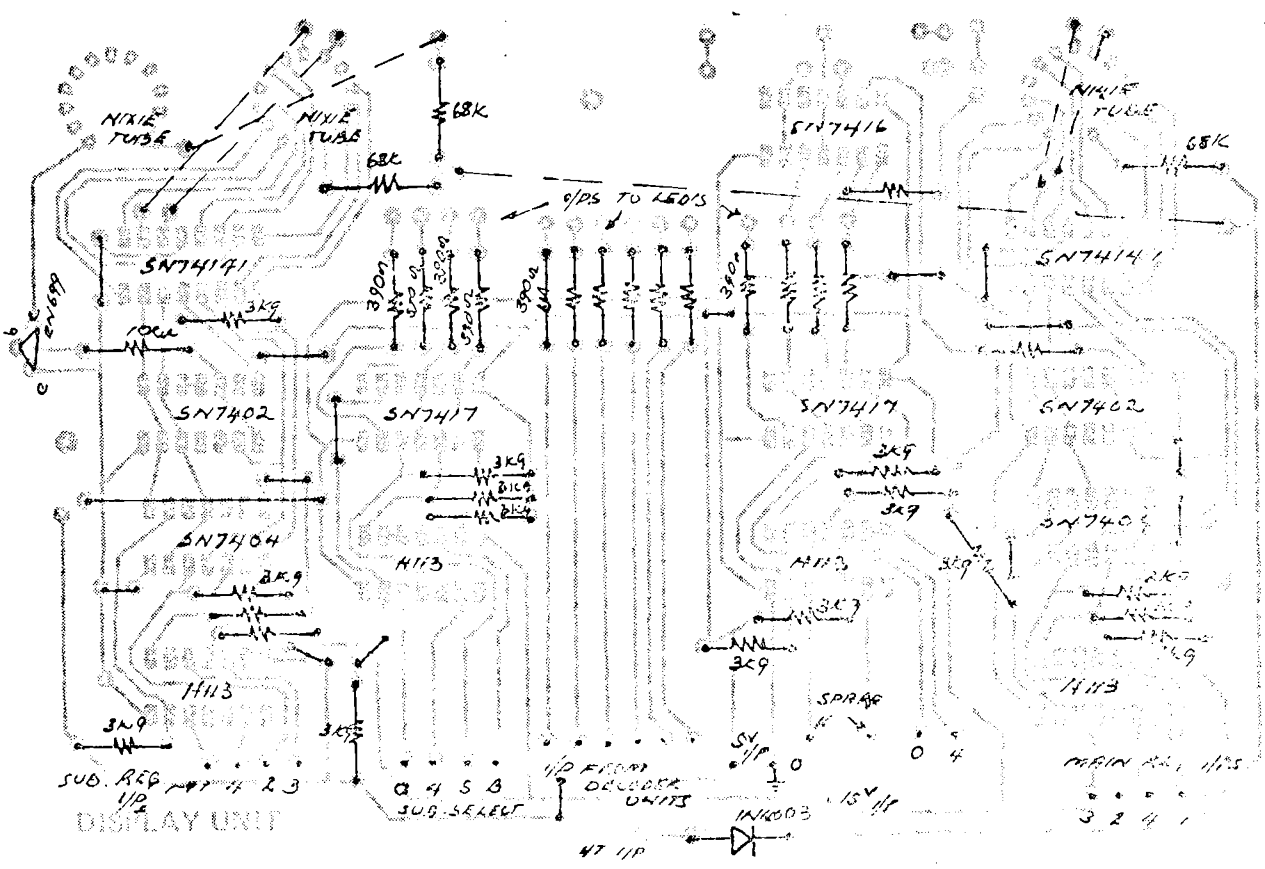

INTERCOM

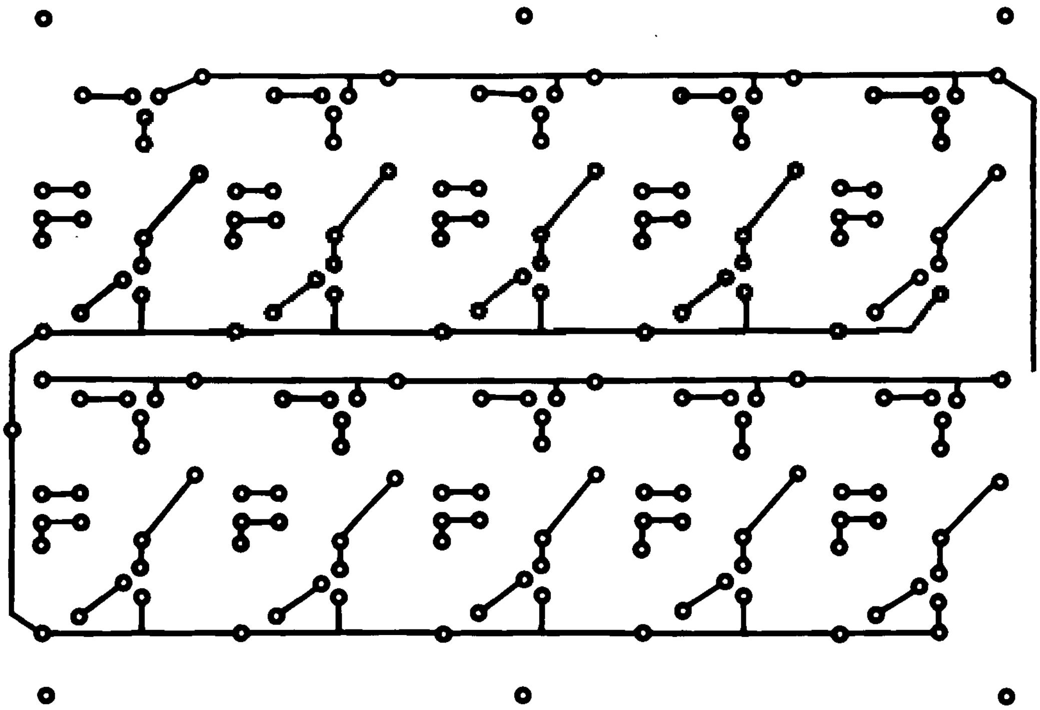


INDICATOR DRIVERS

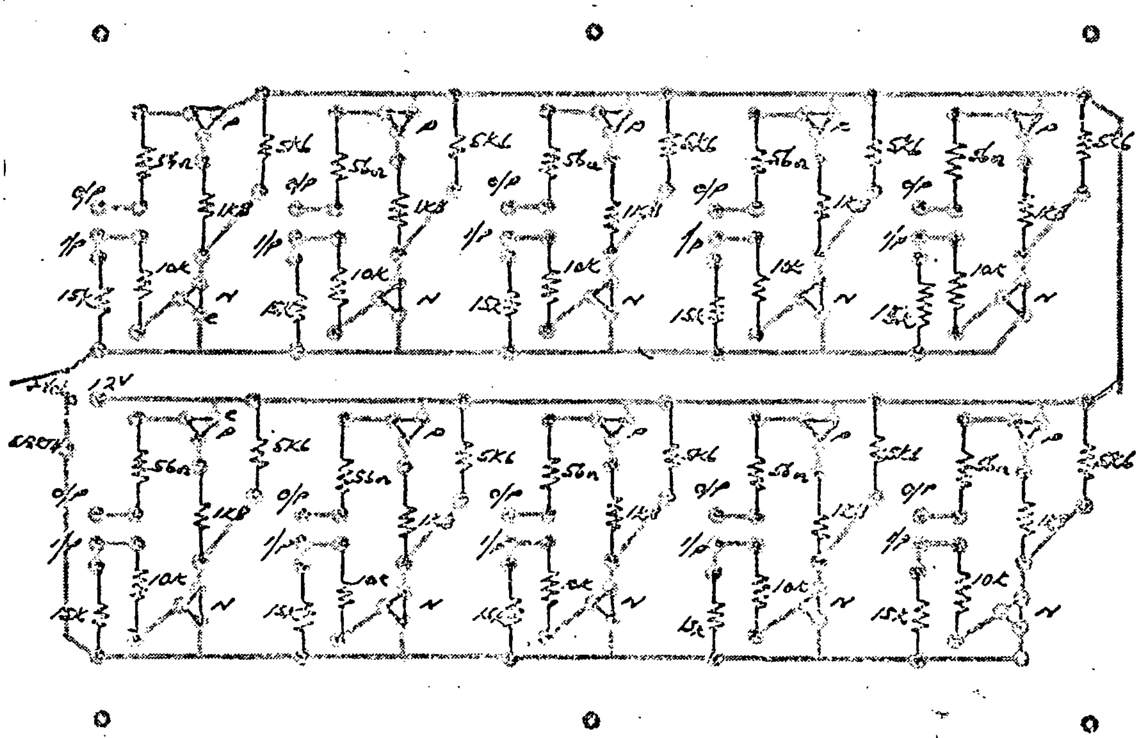

INDICATOR DRIVERS


DISPLAY N1


NIXIE TUBE
NIXIE TUBE
68K
68K
O/PS TO LED'S
390Ω
390Ω
390Ω
390Ω
390Ω
390Ω
SN74141
SN7416
SN74141
68K
EN699
10K
3K9
SN7402
SN7417
SN7417
SN7402
3K9
3K9
3K9
SN7404
SN7404
H113
H113
H113
H113
3K9
3K9
3K9
SPARE
0 4
5V I/P
0
15V I/P
IN4003
SUB. REG I/P 1 2 3
a 4 5 8
SUB SELECT
I/P FROM DECODER UNITS
H7 I/P
MAIN REG I/PS
3 2 4 1
DISPLAY UNIT

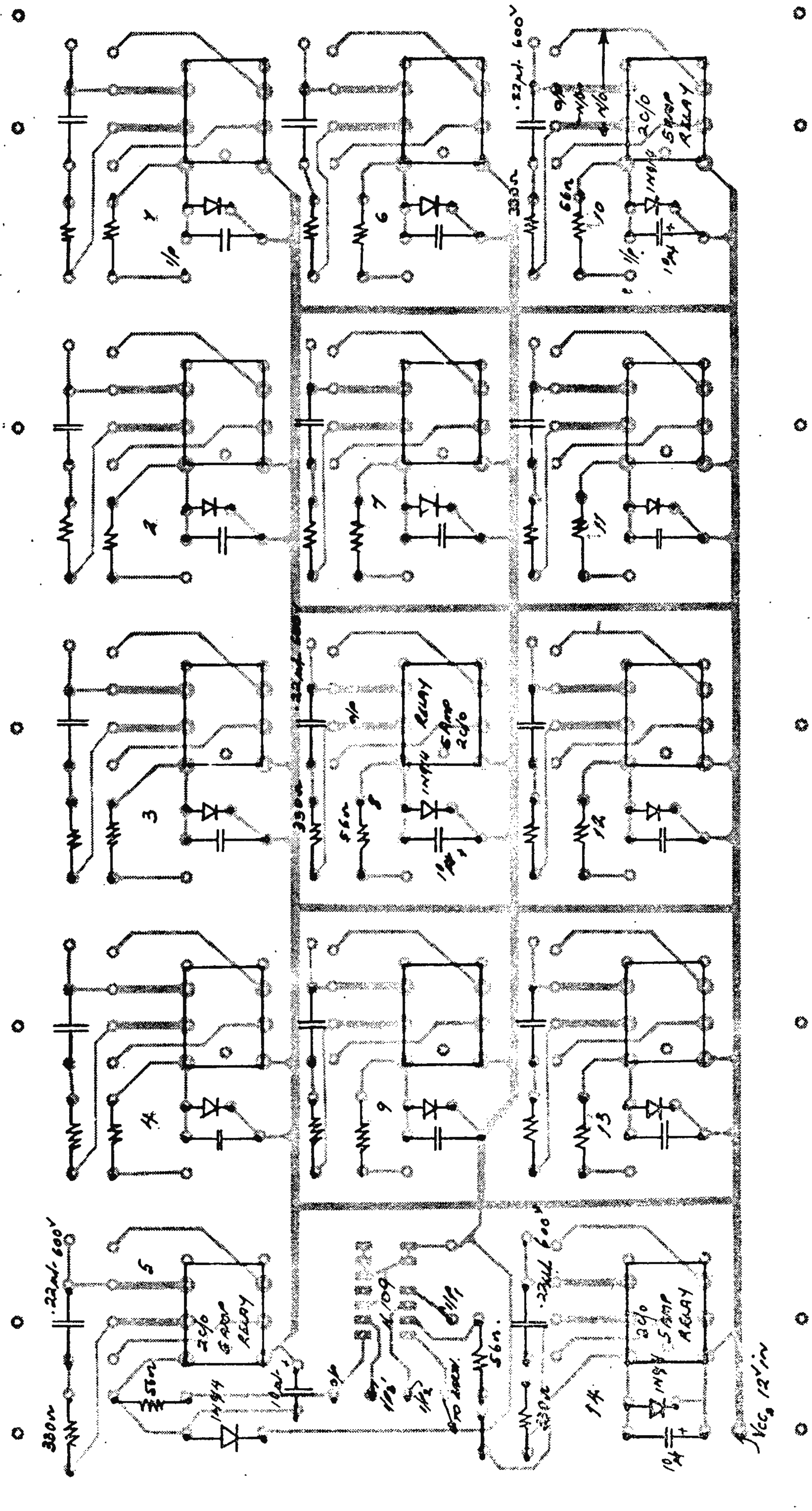


DRIVER X10

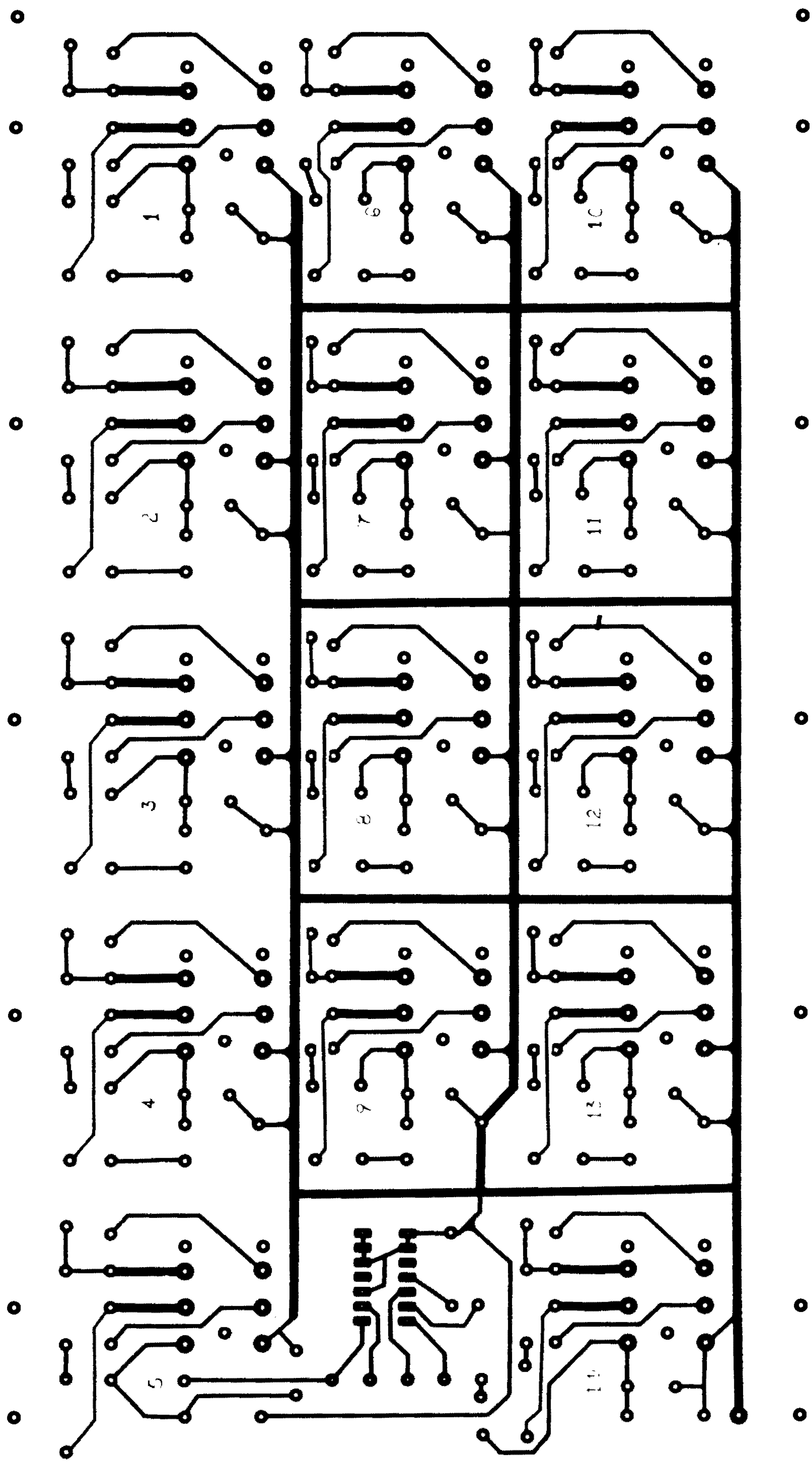


DRIVER X10

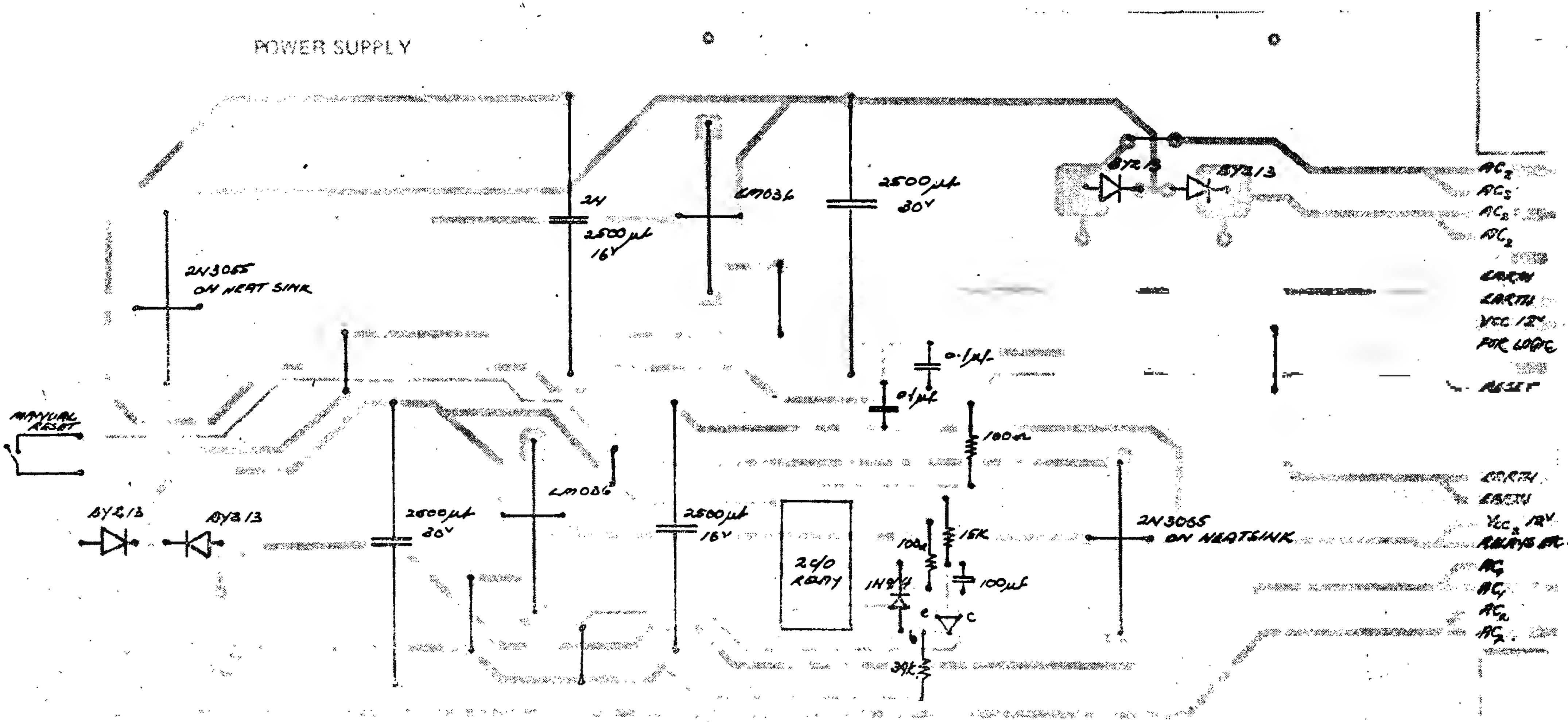
POWER RELAYS

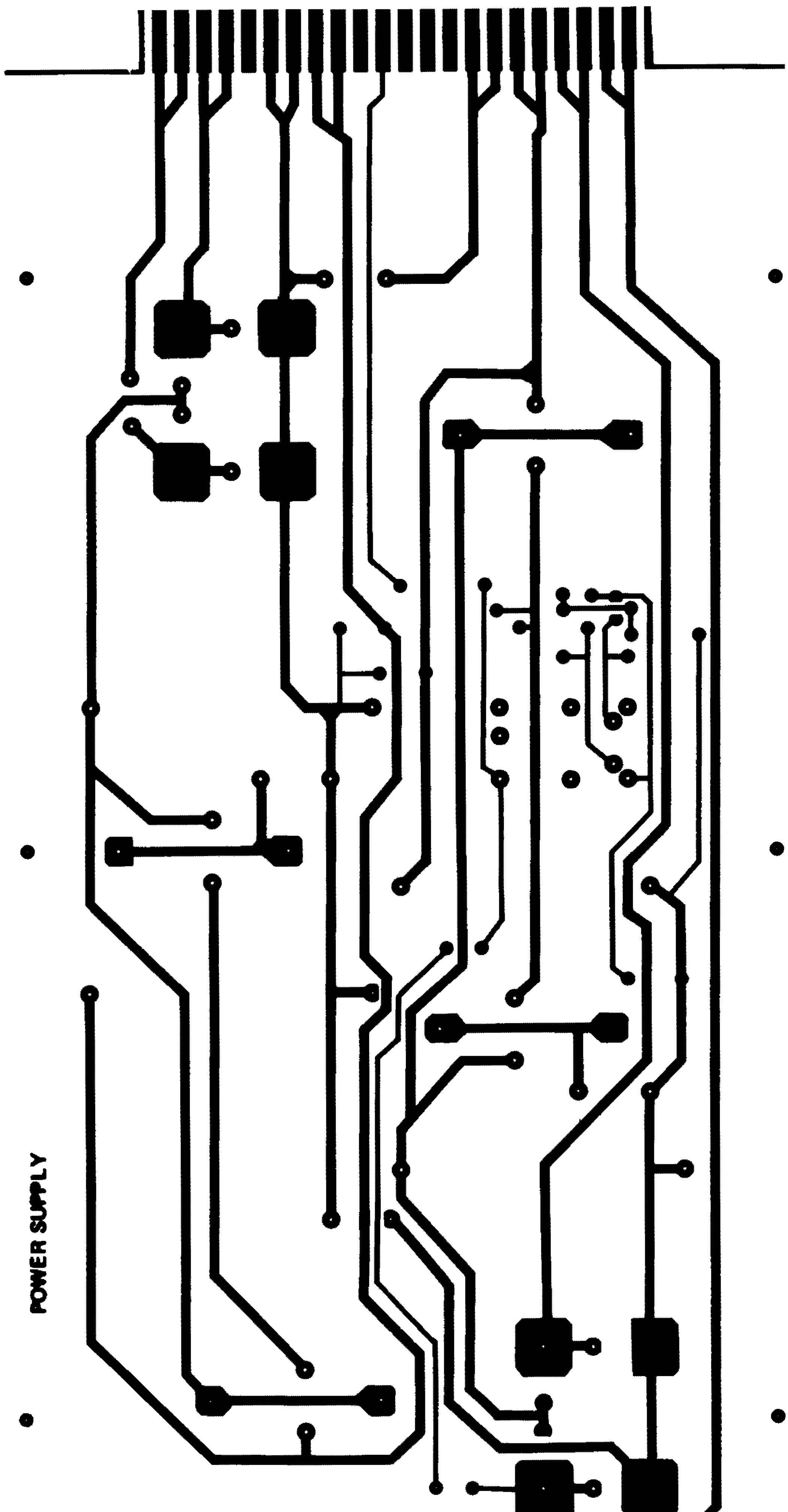


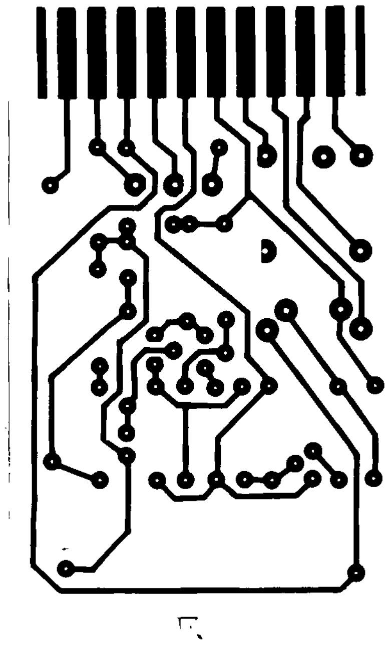
POWER RELAYS

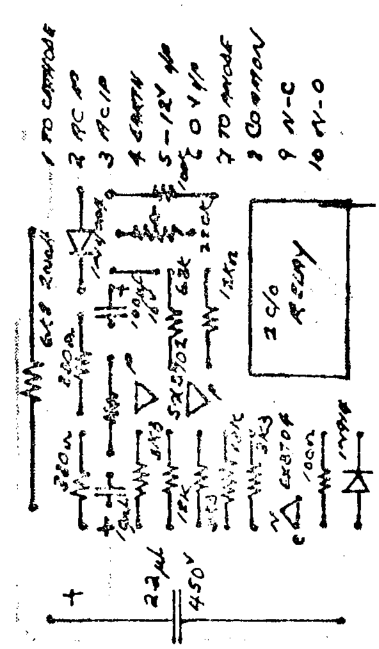


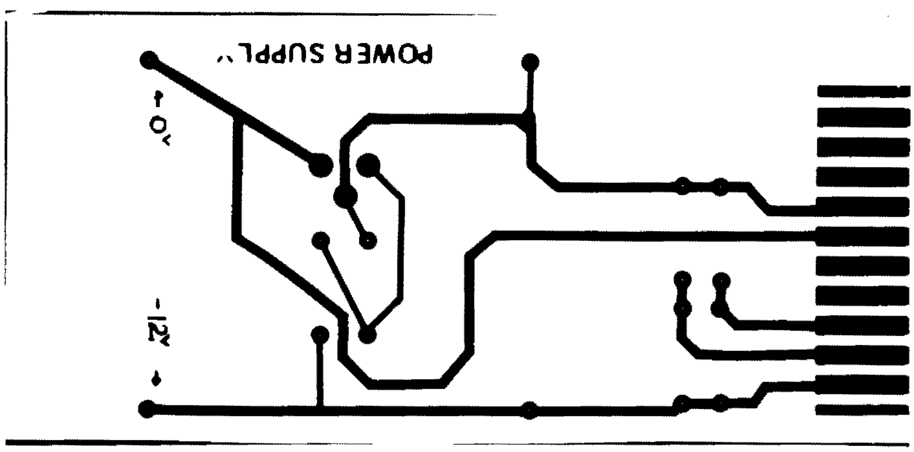
POWER SUPPLY

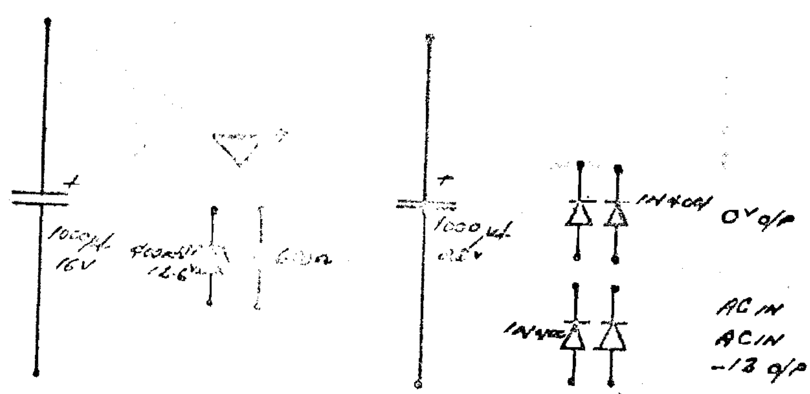


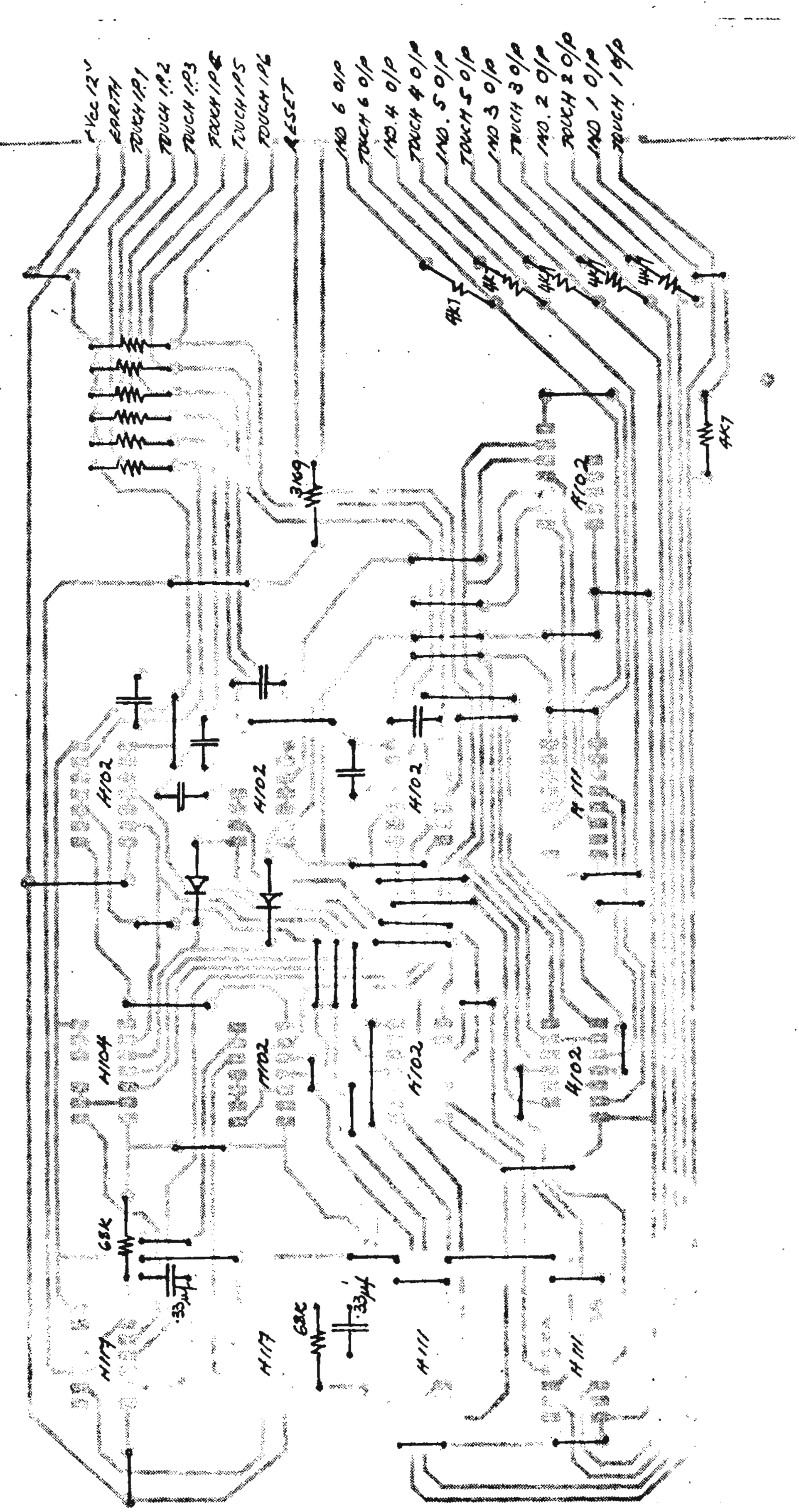

POWER SUPPLY



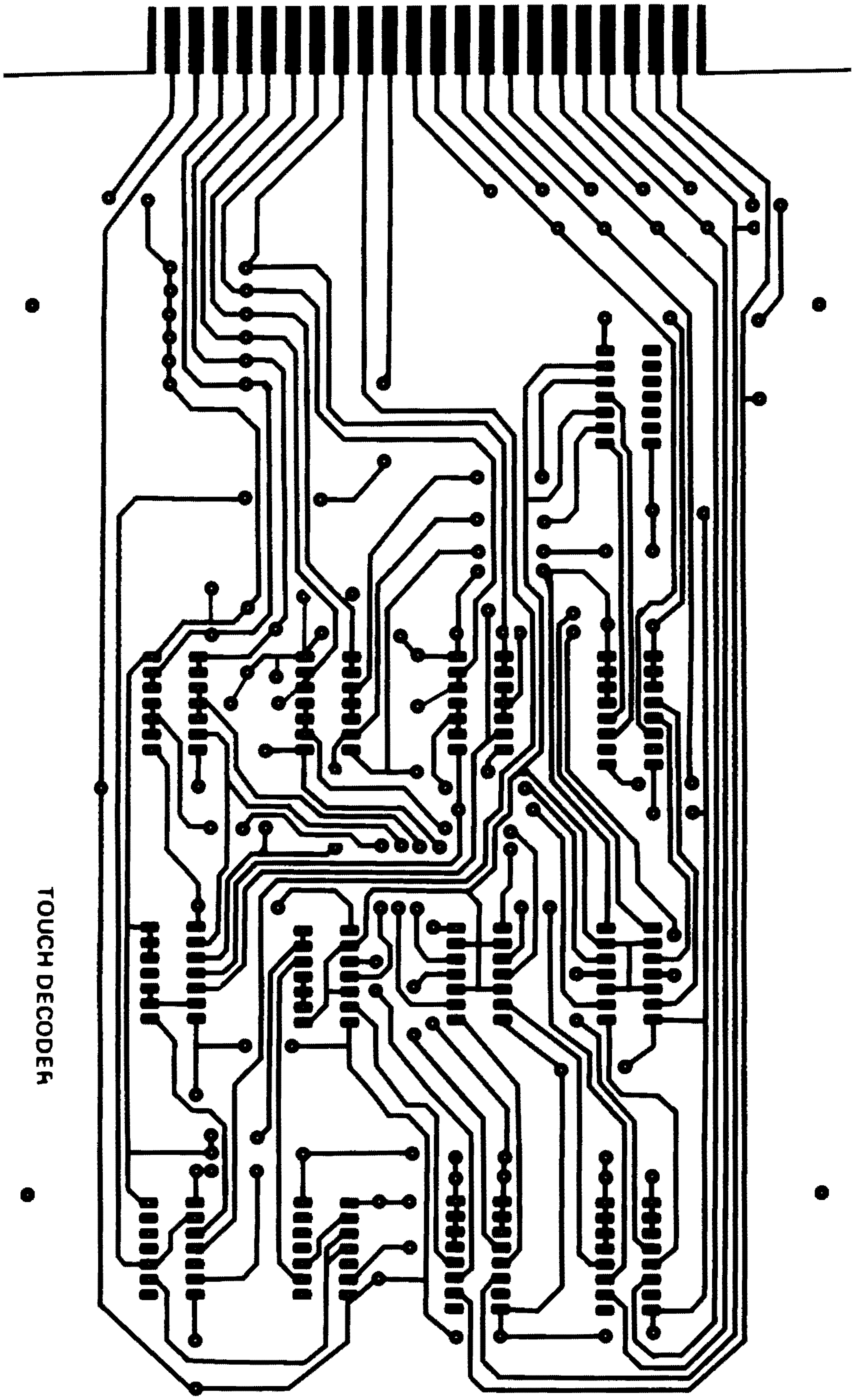

1 TO CATHODE
2 AC I/P
3 AC I/P
4 EARTH
7 TO ANODE
8 COMMON
9 N-C
10 N-O
2 c/o RELAY
22µF
450V

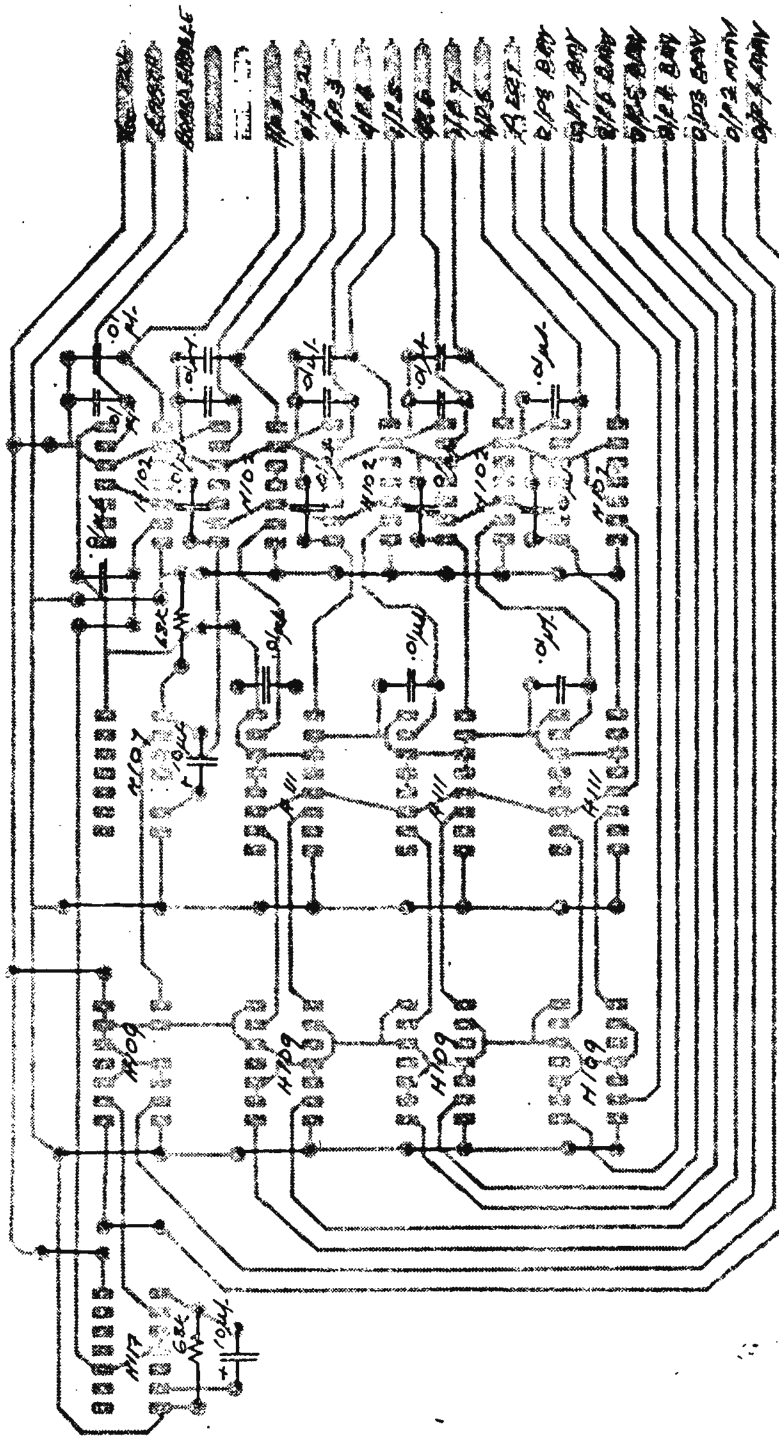

+ 0V
-12V


0V o/p
AC IN
AC IN
-13 o/p

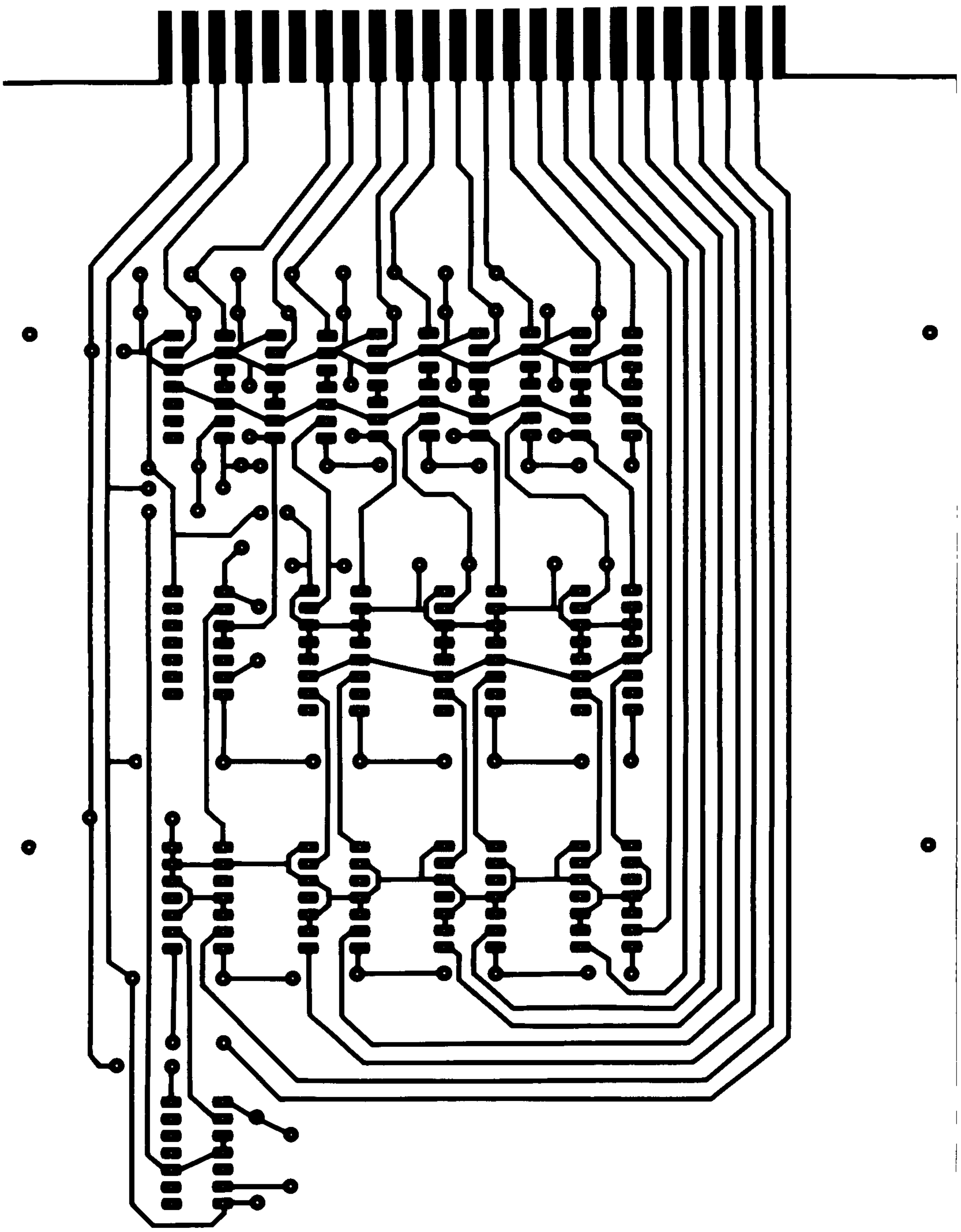


TOUCH DECODER


TOUCH DECODER

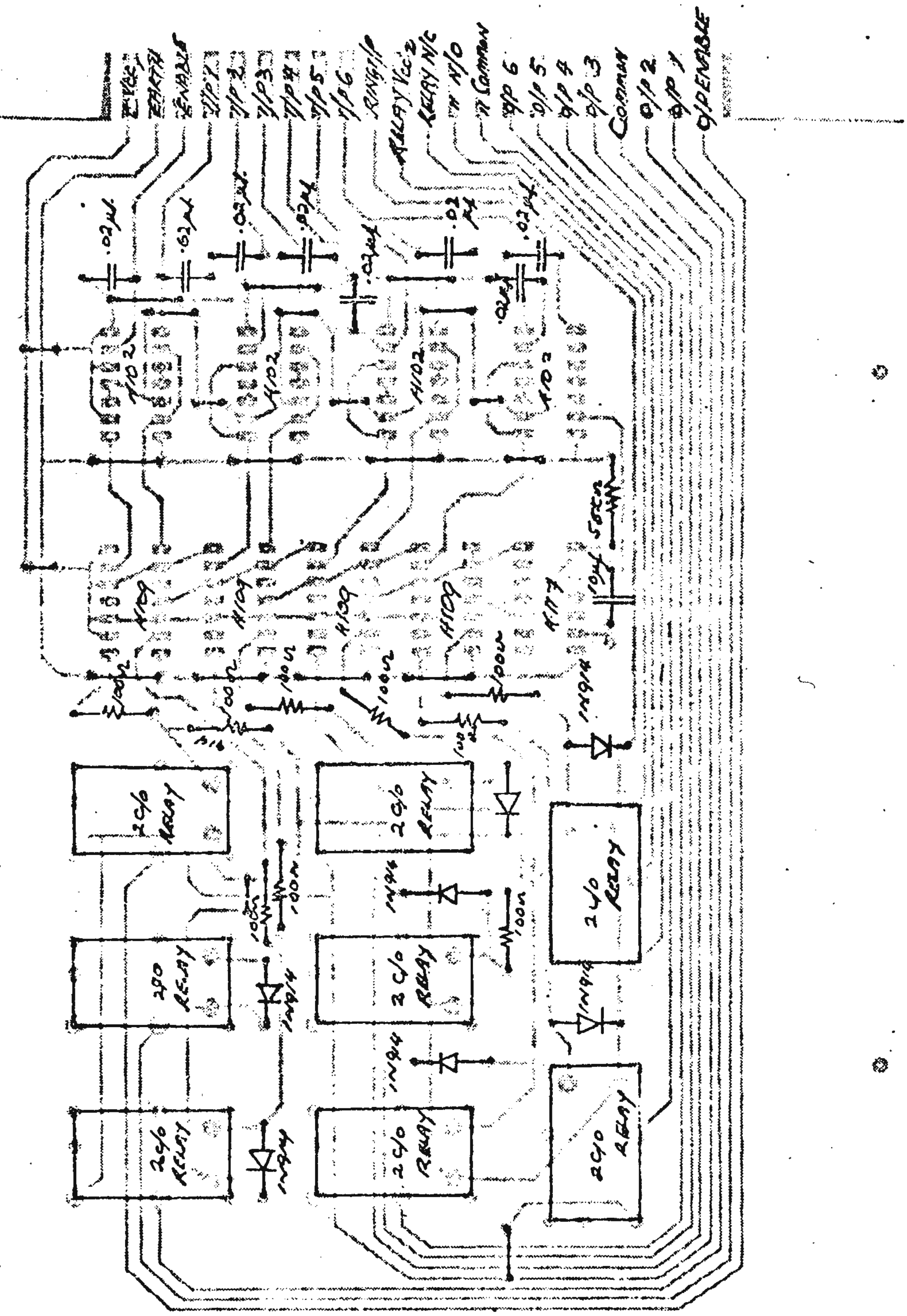


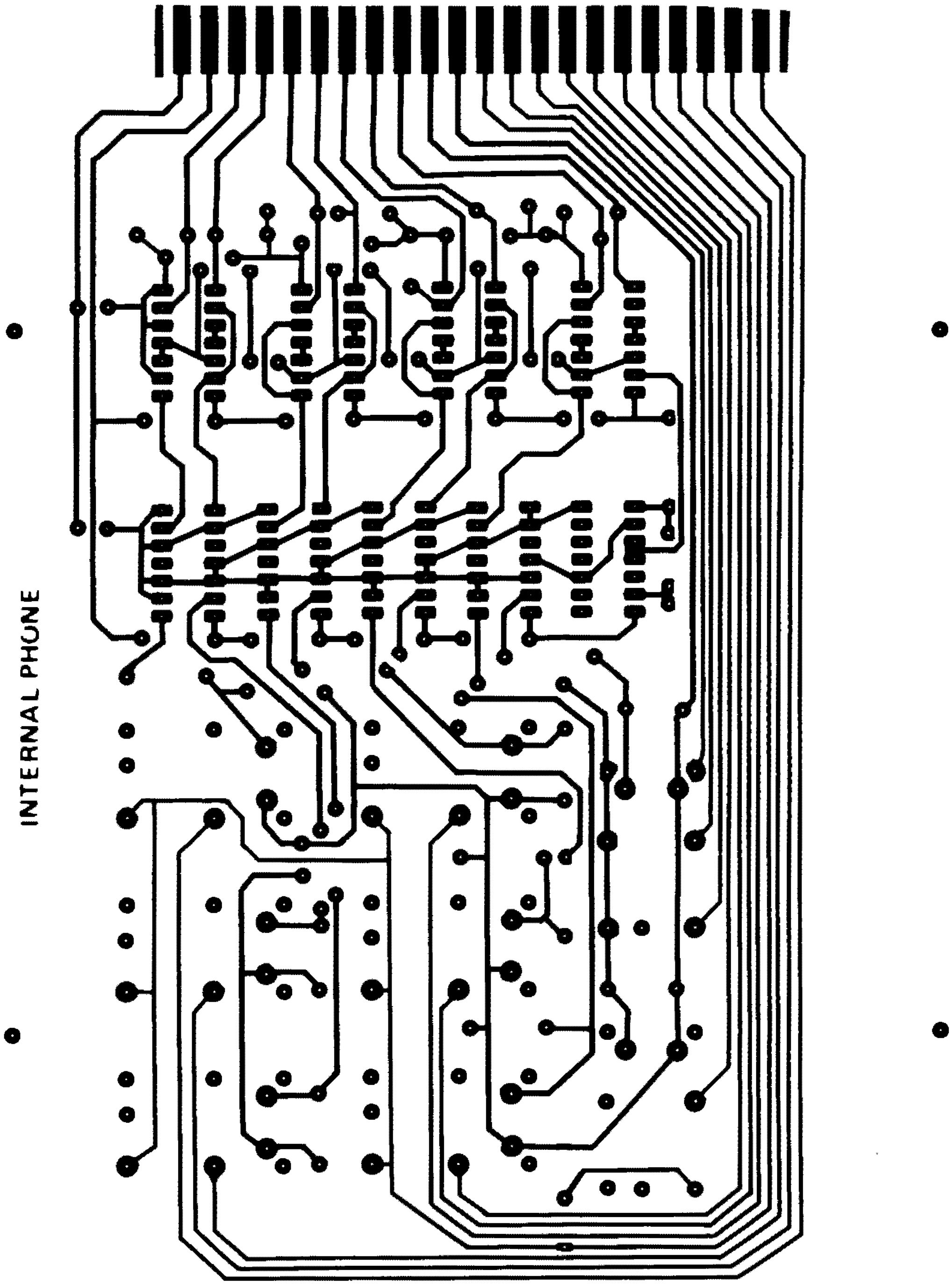
RELAY SELECTOR DECODER DRIVER



RELAY SELECTOR DECODER DRIVER

INTERNAL PHONE



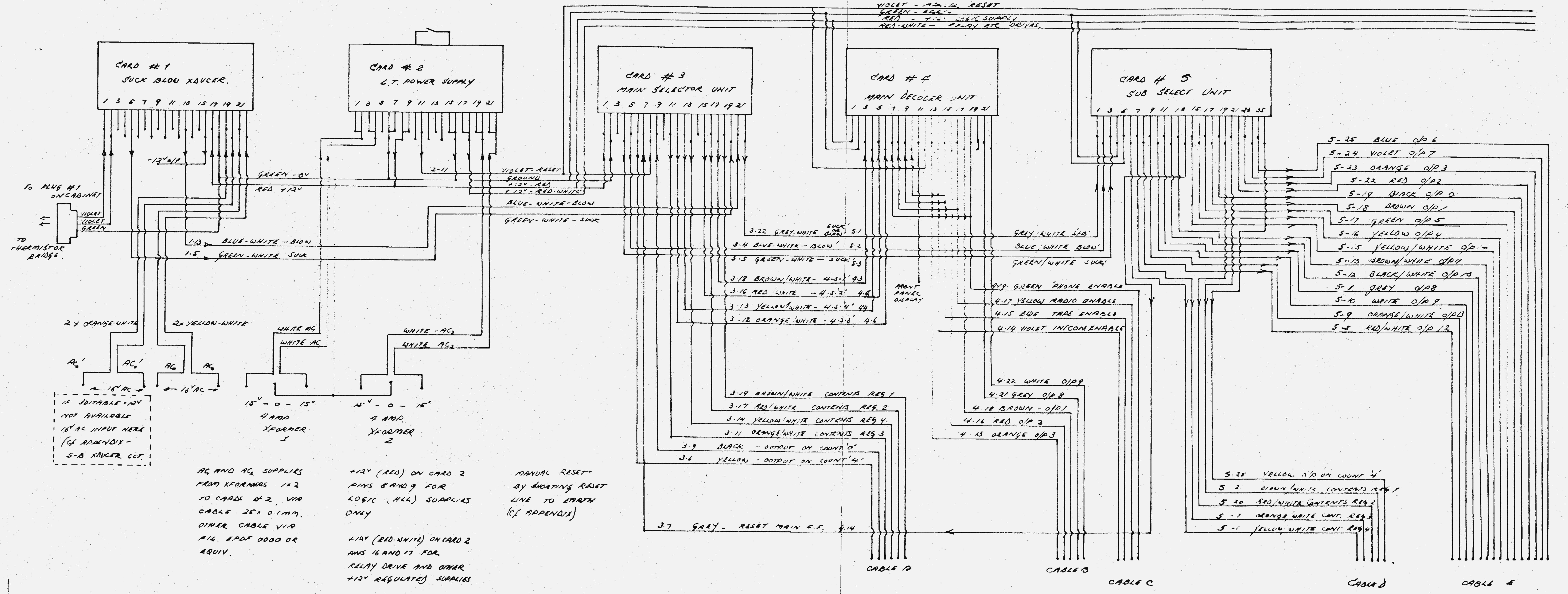

INTERNAL PHONE

Wiring Diagrams Of
Suck - Blow Selector System

pp. 298 - 301

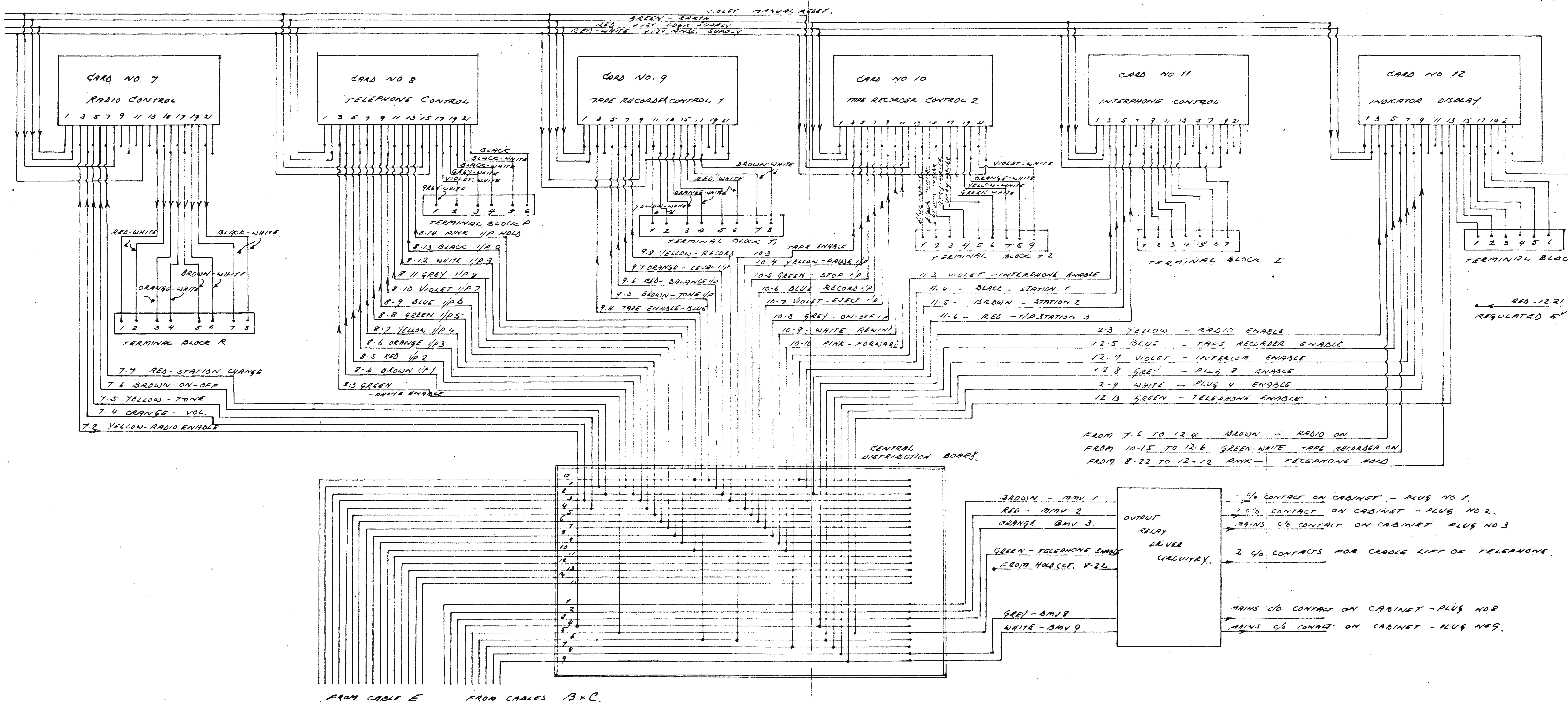
Wiring Diagram
Suck - Blow Selector Unit

No. 1.


CARD #1 SUCK BLOW XDUCER
1 3 5 7 9 11 13 15 17 19 21
CARD #2 L.T. POWER SUPPLY
1 3 5 7 9 11 13 15 17 19 21
CARD #3 MAIN SELECTOR UNIT
1 3 5 7 9 11 13 15 17 19 21
CARD #4 MAIN DECODER UNIT
1 3 5 7 9 11 13 15 17 19 21
CARD #5 SUB SELECT UNIT
1 3 5 7 9 11 13 15 17 19 21 23 25
VIOLET - RESET
GREEN - 0V
RED - +12V LOGIC SUPPLY
RED-WHITE - RELAY ETC DRIVES
TO PLUG #1 ON CABINET
VIOLET
VIOLET
GREEN
TO THERMISTOR BRIDGE.
-12V o/p
GREEN - 0V
RED +12V
1.13 BLUE-WHITE - BLOW
1.5 GREEN-WHITE SUCK
2-11
VIOLET - RESET
GROUND
+12V - RED
+12V - RED-WHITE
BLUE - WHITE - BLOW
GREEN - WHITE - SUCK
2X ORANGE-WHITE
2X YELLOW-WHITE
AC₀'
AC₀'
AC₀
AC₀
16V AC
16V AC
IF SUITABLE +12V NOT AVAILABLE 16V AC INPUT HERE (cf APPENDIX - S-B XDUCER CCT.
WHITE AC
WHITE AC
WHITE - AC₂
WHITE AC₂
15V - 0 - 15V 4 AMP XFORMER 1
15V - 0 - 15V 4 AMP. XFORMER 2
3.22 GREY-WHITE 'SUCK' OR 'BLOW' 5.1
3.4 BLUE-WHITE - BLOW' 5.2
3.5 GREEN-WHITE - SUCK' 5.3
3.18 BROWN/WHITE - 4.5.1' 4.3
3.16 RED/WHITE - 4.5.2' 4.5
3.13 YELLOW/WHITE - 4.5.4' 4.4
3.12 ORANGE/WHITE - 4.5.3' 4.6
FRONT PANEL DISPLAY
GREY WHITE S/B'
BLUE/WHITE BLOW'
GREEN/WHITE SUCK'
4.9 GREEN 'PHONE ENABLE
4.17 YELLOW RADIO ENABLE
4.15 BLUE TAPE ENABLE
4.14 VIOLET INTCOM ENABLE
4.22 WHITE O/P 9
4.21 GREY O/P 8
4.18 BROWN - O/P 1
4.16 RED O/P 2
4.13 ORANGE O/P 3
3.19 BROWN/WHITE CONTENTS REG 1
3.17 RED/WHITE CONTENTS REG. 2
3.14 YELLOW/WHITE CONTENTS REG 4.
3.11 ORANGE/WHITE CONTENTS REG 3
3.9 BLACK - OUTPUT ON COUNT '0'
3.6 YELLOW - OUTPUT ON COUNT '4'
3.7 GREY - RESET MAIN C.F. 4.14
5-25 BLUE O/P 6
5-24 VIOLET O/P 7
5-23 ORANGE O/P 3
5-22 RED O/P 2
5-19 BLACK O/P 0
5-18 BROWN O/P 1
5-17 GREEN O/P 5
5-16 YELLOW O/P 4
5-15 YELLOW/WHITE O/P 11
5-13 BROWN/WHITE O/P 11
5-12 BLACK/WHITE O/P 10
5-11 GREY O/P 8
5-10 WHITE O/P 9
5-9 ORANGE/WHITE O/P 13
5-8 RED/WHITE O/P 12
5.25 YELLOW O/P ON COUNT '4'
5.2 BROWN/WHITE CONTENTS REG 1
5.20 RED/WHITE CONTENTS REG 2
5.7 ORANGE/WHITE CONT. REG 3
5.1 YELLOW/WHITE CONT. REG 4
CABLE A
CABLE B
CABLE C
CABLE D
CABLE E
AC₁ AND AC₂ SUPPLIES FROM XFORMERS 1 & 2 TO CARDS #2, VIA CABLE 25 x 0.1 mm, OTHER CABLE VIA F.G. EPDF 0000 OR EQUIV.
+12V (RED) ON CARD 2 PINS 8 AND 9 FOR LOGIC (ALL) SUPPLIES ONLY
+12V (RED-WHITE) ON CARD 2 PINS 16 AND 17 FOR RELAY DRIVE AND OTHER +12V REGULATED SUPPLIES
MANUAL RESET BY SHORTING RESET LINE TO EARTH (cf APPENDIX)

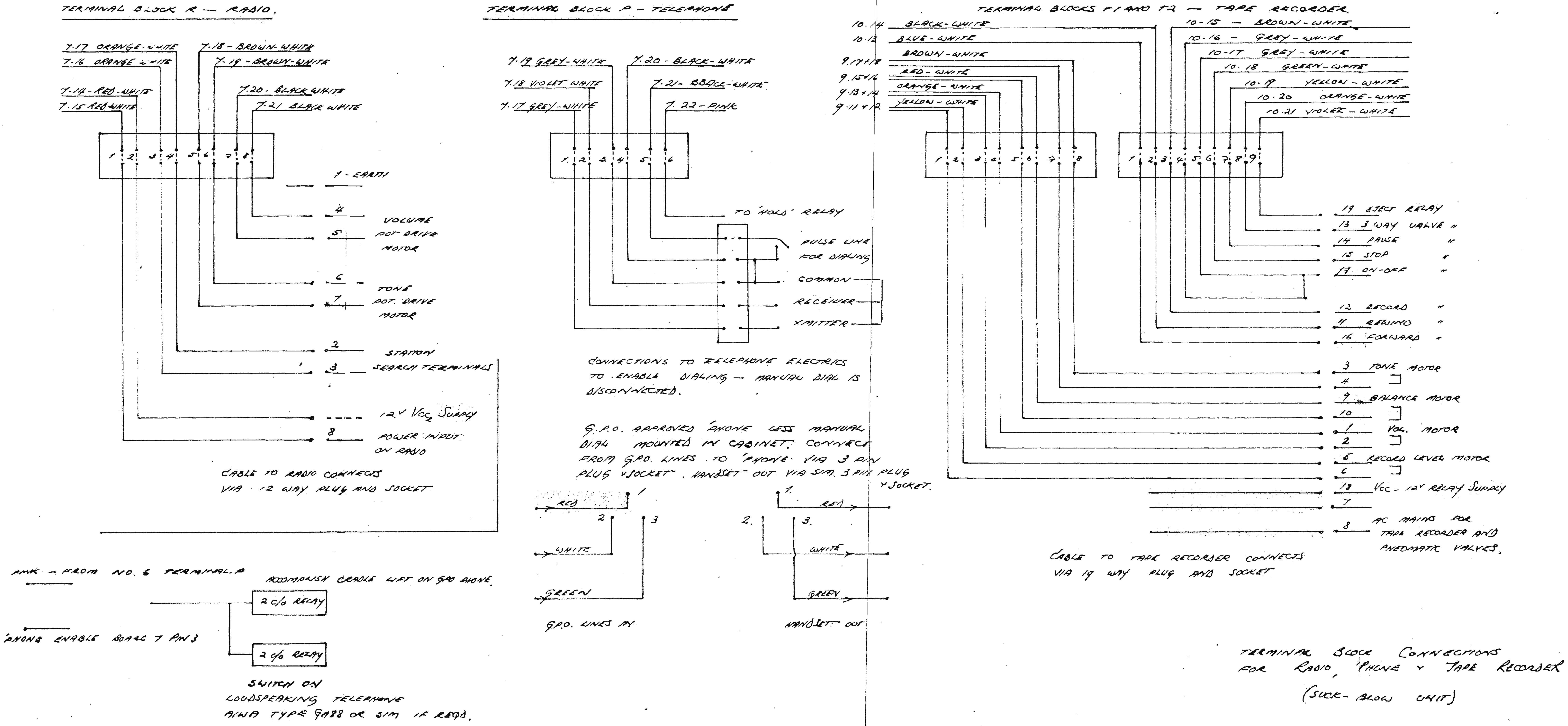
Wiring Diagram
Suck - Blow Selector Unit

No. 2.


VIOLET MANUAL RESET.
GREEN - EARTH
RED +12V LOGIC SUPPLY
RED-WHITE +12V MISC. SUPPLY
CARD NO. 7
RADIO CONTROL
CARD NO 8
TELEPHONE CONTROL
CARD NO. 9
TAPE RECORDER CONTROL 1
CARD NO 10
TAPE RECORDER CONTROL 2
CARD NO 11
INTERPHONE CONTROL
CARD NO 12
INDICATOR DISPLAY
RED-WHITE
BLACK-WHITE
BROWN-WHITE
ORANGE-WHITE
TERMINAL BLOCK R
BLACK
BLACK-WHITE
GREY-WHITE
VIOLET-WHITE
TERMINAL BLOCK P
RED-WHITE
ORANGE-WHITE
YELLOW-WHITE
TERMINAL BLOCK T1
VIOLET-WHITE
ORANGE-WHITE
YELLOW-WHITE
GREEN-WHITE
TERMINAL BLOCK T2
TERMINAL BLOCK I
TERMINAL BLOCK D
8.14 PINK I/P HOLD
8.13 BLACK I/P 0
8.12 WHITE I/P 9
8.11 GREY I/P 8
8.10 VIOLET I/P 7
8.9 BLUE I/P 6
8.8 GREEN I/P 5
8.7 YELLOW I/P 4
8.6 ORANGE I/P 3
8.5 RED I/P 2
8.4 BROWN I/P 1
8.3 GREEN - PHONE ENABLE
7.7 RED - STATION CHANGE
7.6 BROWN - ON-OFF
7.5 YELLOW - TONE
7.4 ORANGE - VOL.
7.3 YELLOW - RADIO ENABLE
9.8 YELLOW - RECORD
9.7 ORANGE - LEVEL I/P
9.6 RED - BALANCE I/P
9.5 BROWN - TONE I/P
9.4 TAPE ENABLE - BLUE
10.3 TAPE ENABLE
10.4 YELLOW - PAUSE I/P
10.5 GREEN - STOP I/P
10.6 BLUE - RECORD I/P
10.7 VIOLET - EJECT I/P
10.8 GREY - ON-OFF I/P
10.9 WHITE REWIND
10.10 PINK - FORWARD
11.3 VIOLET - INTERPHONE ENABLE
11.4 - BLACK - STATION 1
11.5 - BROWN - STATION 2
11.6 - RED - I/P STATION 3
12.3 YELLOW - RADIO ENABLE
12.5 BLUE - TAPE RECORDER ENABLE
12.7 VIOLET - INTERCOM ENABLE
12.8 GREY - PLUG 9 ENABLE
12.9 WHITE - PLUG 9 ENABLE
12.13 GREEN - TELEPHONE ENABLE
RED - 12.21
REGULATED 5V O/P
FROM 7.6 TO 12.4 BROWN - RADIO ON
FROM 10.15 TO 12.6 GREEN-WHITE TAPE RECORDER ON
FROM 8.22 TO 12.12 PINK - TELEPHONE HOLD
CENTRAL DISTRIBUTION BOARD.
BROWN - MMV 1
RED - MMV 2
ORANGE BMV 3.
GREEN - TELEPHONE SWAPS
FROM HOLD CCT. 8.22.
GREY - BMV 8
WHITE - BMV 9
OUTPUT RELAY DRIVER CIRCUITRY.
C/O CONTACT ON CABINET - PLUG NO 1.
C/O CONTACT ON CABINET - PLUG NO 2.
MAINS C/O CONTACT ON CABINET PLUG NO 3
2 C/O CONTACTS FOR CRADLE LIFT OF TELEPHONE.
MAINS C/O CONTACT ON CABINET - PLUG NO 8
MAINS C/O CONTACT ON CABINET - PLUG NO 9.
FROM CABLE E
FROM CABLES B + C.

Wiring Diagram
Suck - Blow Selector Unit

No. 3.

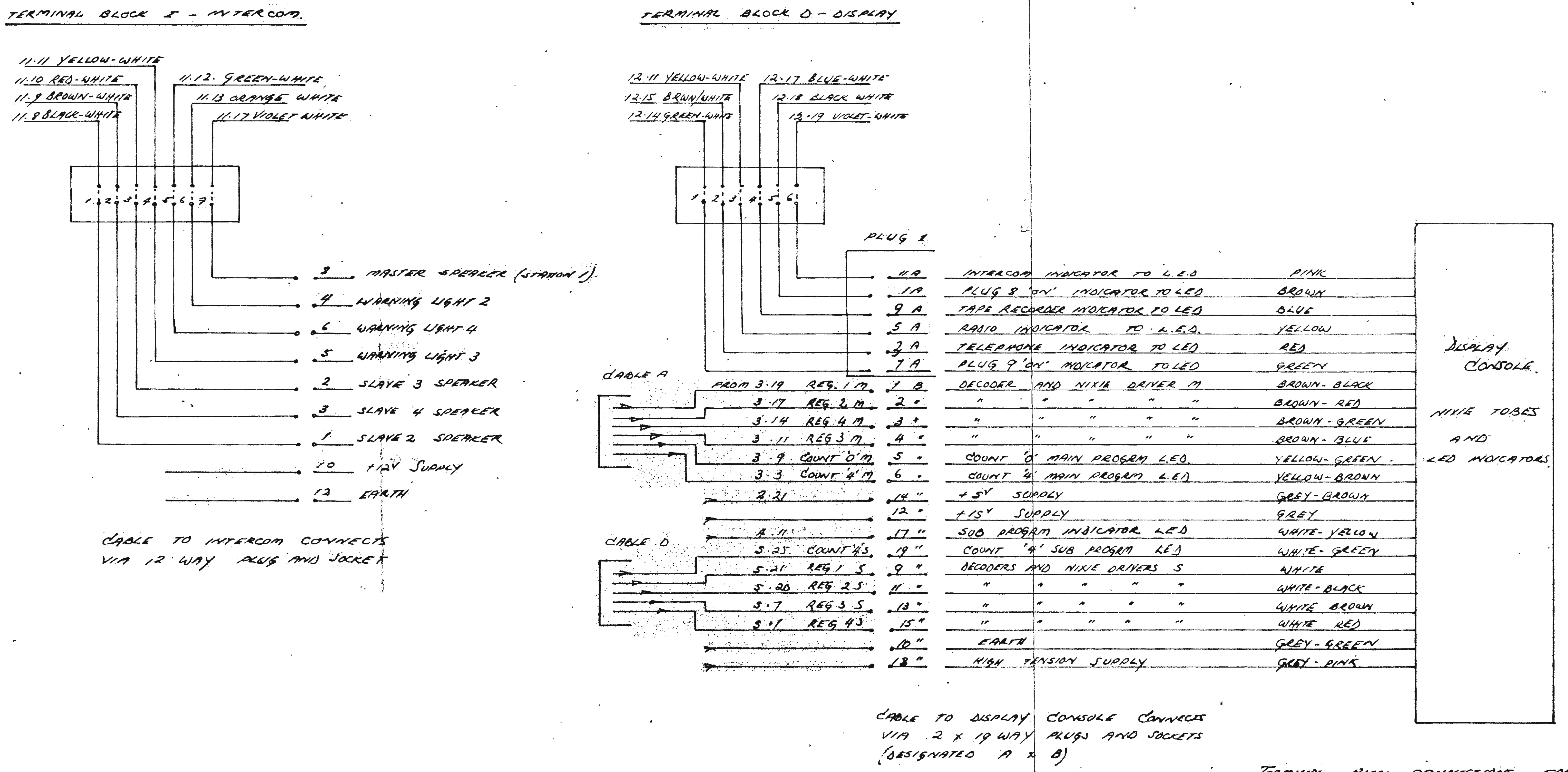


TERMINAL BLOCK CONNECTIONS FOR RADIO, 'PHONE & TAPE RECORDER

(SUCK-BLOW UNIT)

Wiring Diagram
Suck - Blow Selector Unit

No. 4.



TERMINAL BLOCK CONNECTIONS FOR INTERCOM AND DISPLAY FACILITY.

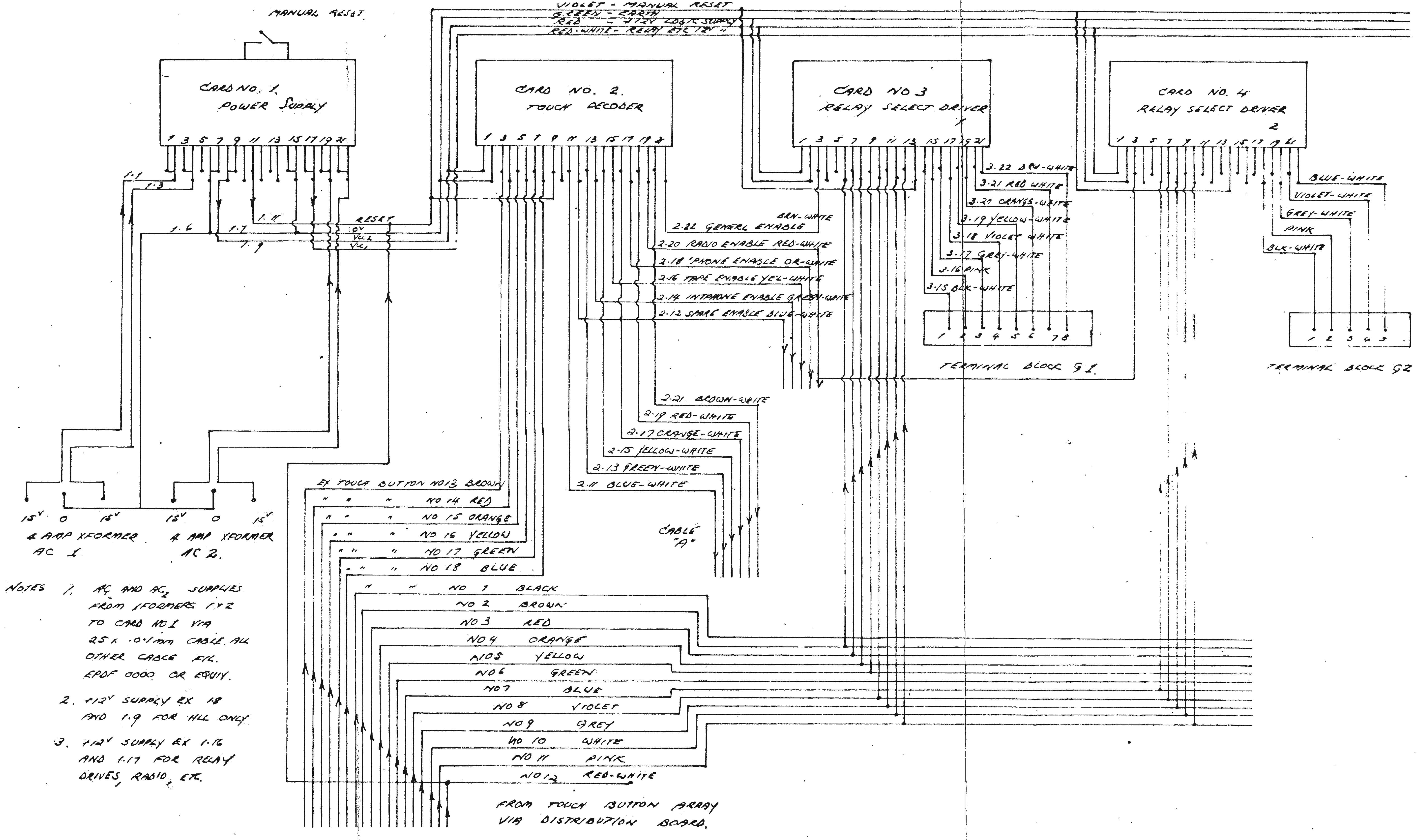
Wiring Diagrams Of
Touch Button Selector System

pp. 303 - 306.

Wiring Diagram

Touch Button Selector Unit

No. 1.

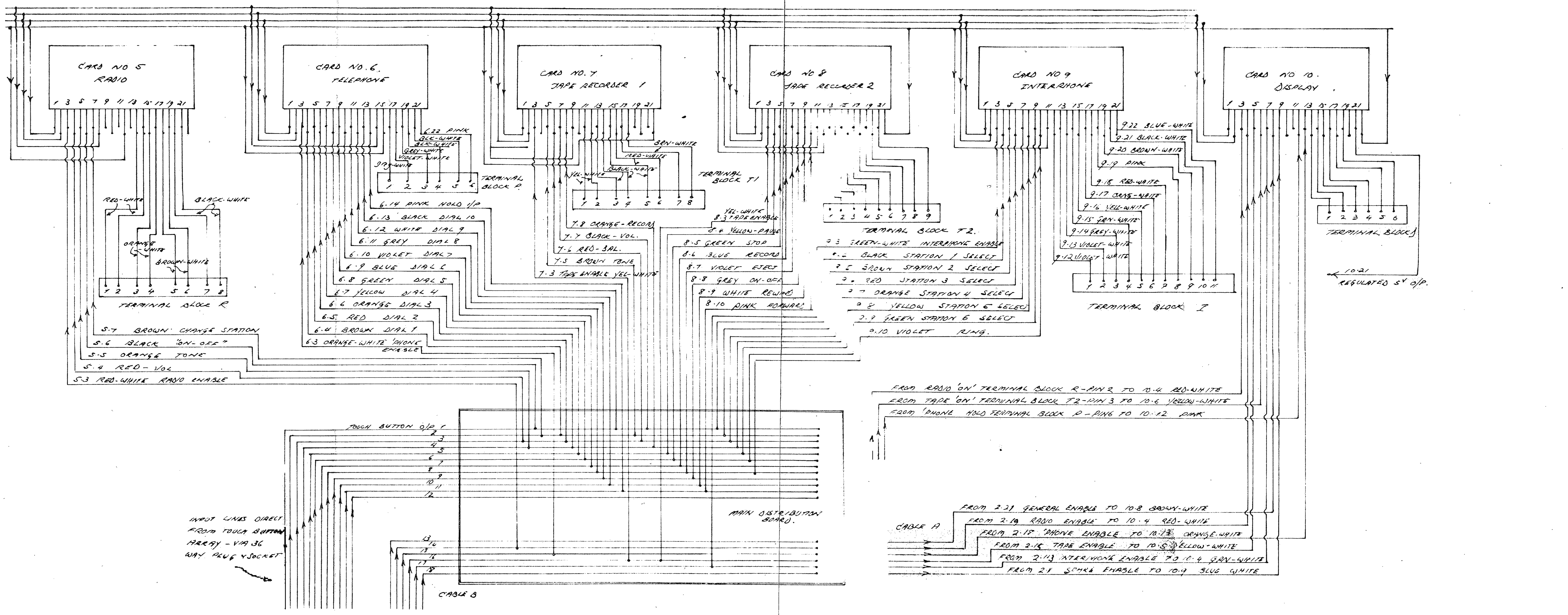


NOTES

1. AC_1 AND AC_2 SUPPLIES FROM XFORMERS 1 & 2 TO CARD NO 1 VIA 25 x ·01mm CABLE. ALL OTHER CABLE P.V.C. EPDF 0000 OR EQUIV.
2. +12V SUPPLY EX 1.8 AND 1.9 FOR ALL ONLY
3. +12V SUPPLY EX 1.16 AND 1.17 FOR RELAY DRIVES, RADIO, ETC.

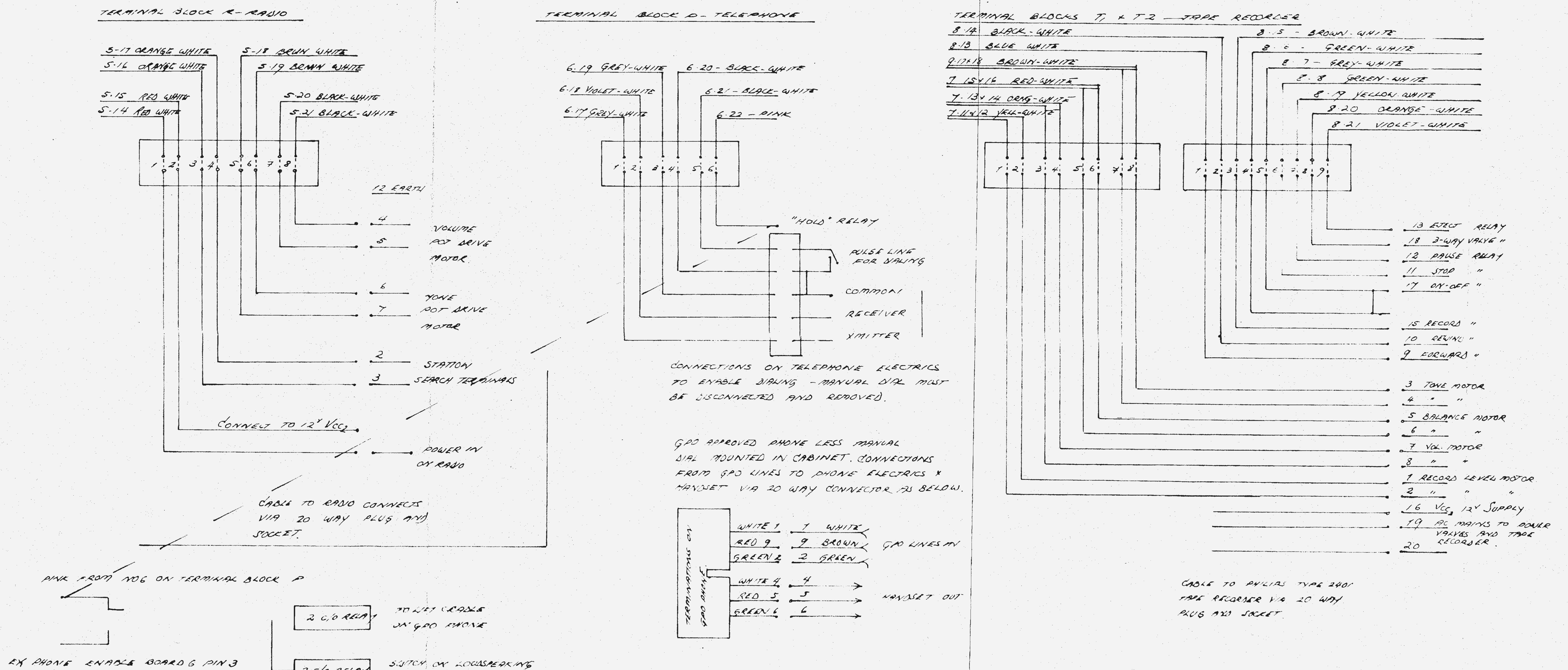
Wiring Diagram
Touch Button Selector Unit

No. 2.


CARD NO 5 RADIO
CARD NO. 6. TELEPHONE
CARD NO. 7 TAPE RECORDER 1
CARD NO 8 TAPE RECORDER 2
CARD NO 9 INTERPHONE
CARD NO 10. DISPLAY
TERMINAL BLOCK R
TERMINAL BLOCK P.
TERMINAL BLOCK T1
TERMINAL BLOCK T2.
TERMINAL BLOCK I
TERMINAL BLOCK J
RED-WHITE
BLACK-WHITE
ORANGE-WHITE
BROWN-WHITE
5.7 BROWN CHANGE STATION
5.6 BLACK "ON-OFF"
5.5 ORANGE TONE
5.4 RED - VOL
5.3 RED-WHITE RADIO ENABLE
6.22 PINK
BLK-WHITE
GREY-WHITE
VIOLET-WHITE
GRN-WHITE
6.14 PINK HOLD I/P
6.13 BLACK DIAL 10
6.12 WHITE DIAL 9
6.11 GREY DIAL 8
6.10 VIOLET DIAL 7
6.9 BLUE DIAL 6
6.8 GREEN DIAL 5
6.7 YELLOW DIAL 4
6.6 ORANGE DIAL 3
6.5 RED DIAL 2
6.4 BROWN DIAL 1
6.3 ORANGE-WHITE 'PHONE ENABLE
BRN-WHITE
RED-WHITE
BLACK-WHITE
YEL-WHITE
7.8 ORANGE - RECORD
7.7 BLACK - VOL.
7.6 RED - BAL.
7.5 BROWN TONE
7.3 TAPE ENABLE YEL-WHITE
YEL-WHITE 8.3 TAPE ENABLE
8.4 YELLOW - PAUSE
8.5 GREEN STOP
8.6 BLUE RECORD
8.7 VIOLET EJECT
8.8 GREY ON-OFF
8.9 WHITE REWIND
8.10 PINK FORWARD
9.3 GREEN-WHITE INTERPHONE ENABLE
9.4 BLACK STATION 1 SELECT
9.5 BROWN STATION 2 SELECT
9.6 RED STATION 3 SELECT
9.7 ORANGE STATION 4 SELECT
9.8 YELLOW STATION 6 SELECT
9.9 GREEN STATION 6 SELECT
9.10 VIOLET RING.
9.22 BLUE-WHITE
9.21 BLACK-WHITE
9.20 BROWN-WHITE
9.9 PINK
9.18 RED-WHITE
9.17 ORNG-WHITE
9.16 YELL-WHITE
9.15 GRN-WHITE
9.14 GREY-WHITE
9.13 VIOLET-WHITE
9.12 VIOLET-WHITE
10.21 REGULATED 5V O/P.
FROM RADIO 'ON' TERMINAL BLOCK R-PIN 2 TO 10.4 RED-WHITE
FROM TAPE 'ON' TERMINAL BLOCK T2-PIN 3 TO 10.6 YELLOW-WHITE
FROM 'PHONE HOLD TERMINAL BLOCK P-PIN 6 TO 10.12 PINK
TOUCH BUTTON O/P
MAIN DISTRIBUTION BOARD.
INPUT LINES DIRECT FROM TOUCH BUTTON ARRAY - VIA 36 WAY PLUG & SOCKET
CABLE B
CABLE A
FROM 2.21 GENERAL ENABLE TO 10.8 BROWN-WHITE
FROM 2.19 RADIO ENABLE TO 10.4 RED-WHITE
FROM 2.17 'PHONE ENABLE TO 10.13 ORANGE-WHITE
FROM 2.15 TAPE ENABLE TO 10.5 YELLOW-WHITE
FROM 2.13 INTERPHONE ENABLE TO 10.4 GRN-WHITE
FROM 2.11 SPARE ENABLE TO 10.9 BLUE-WHITE

Wiring Diagram
Touch Button Selector Unit

No. 3.

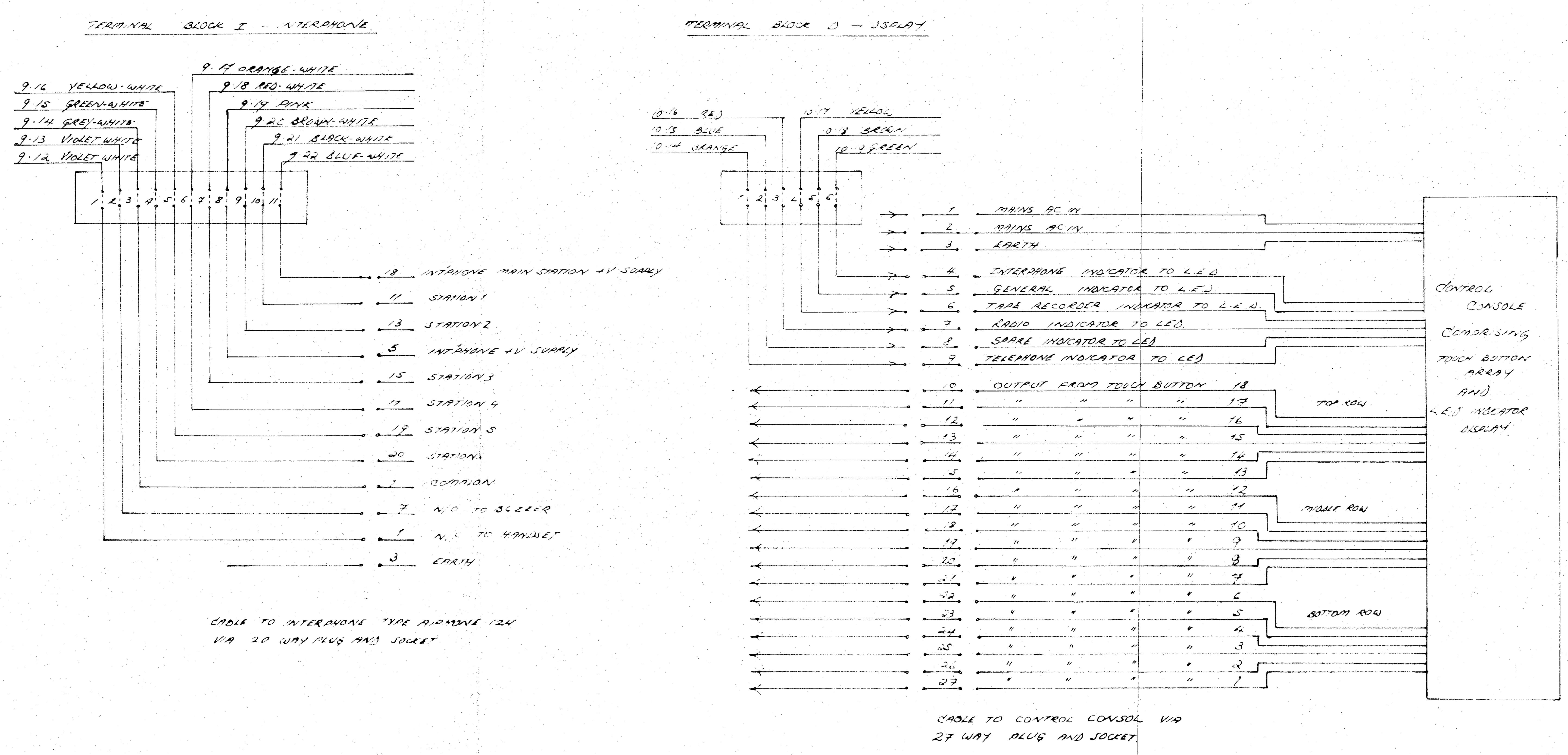


TERMINAL BLOCK - PLUG SOCKET
CONNECTIONS FOR RADIO,
'PHONE AND TAPE RECORDER
(TOUCH BUTTON UNIT)

Wiring Diagram

Touch Button Selector Unit

No. 4.


TERMINAL BLOCK I - INTERPHONE
9·16 YELLOW-WHITE
9·15 GREEN-WHITE
9·14 GREY-WHITE
9·13 VIOLET-WHITE
9·12 VIOLET-WHITE
9·17 ORANGE-WHITE
9·18 RED-WHITE
9·19 PINK
9·20 BROWN-WHITE
9·21 BLACK-WHITE
9·22 BLUE-WHITE
1 2 3 4 5 6 7 8 9 10 11
18 INT'PHONE MAIN STATION +V SUPPLY
11 STATION 1
13 STATION 2
5 INT'PHONE +V SUPPLY
15 STATION 3
17 STATION 4
19 STATION 5
20 STATION
2 COMMON
7 N.O. TO BUZZER
1 N.C. TO HANDSET
3 EARTH
CABLE TO INTERPHONE TYPE AIRPHONE 12N
VIA 20 WAY PLUG AND SOCKET
TERMINAL BLOCK D - DISPLAY
10·16 RED
10·15 BLUE
10·14 ORANGE
10·17 YELLOW
10·8 BROWN
10·9 GREEN
1 2 3 4 5 6
1 MAINS AC IN
2 MAINS AC IN
3 EARTH
4 INTERPHONE INDICATOR TO L.E.D.
5 GENERAL INDICATOR TO L.E.D.
6 TAPE RECORDER INDICATOR TO L.E.D.
7 RADIO INDICATOR TO L.E.D.
8 SPARE INDICATOR TO L.E.D.
9 TELEPHONE INDICATOR TO L.E.D.
10 OUTPUT FROM TOUCH BUTTON 18
11 " " " " 17
12 " " " " 16
13 " " " " 15
14 " " " " 14
15 " " " " 13
16 " " " " 12
17 " " " " 11
18 " " " " 10
19 " " " " 9
20 " " " " 8
21 " " " " 7
22 " " " " 6
23 " " " " 5
24 " " " " 4
25 " " " " 3
26 " " " " 2
27 " " " " 1
TOP ROW
MIDDLE ROW
BOTTOM ROW
CONTROL CONSOLE COMPRISING TOUCH BUTTON ARRAY AND L.E.D. INDICATOR DISPLAY.
CABLE TO CONTROL CONSOL VIA
27 WAY PLUG AND SOCKET.