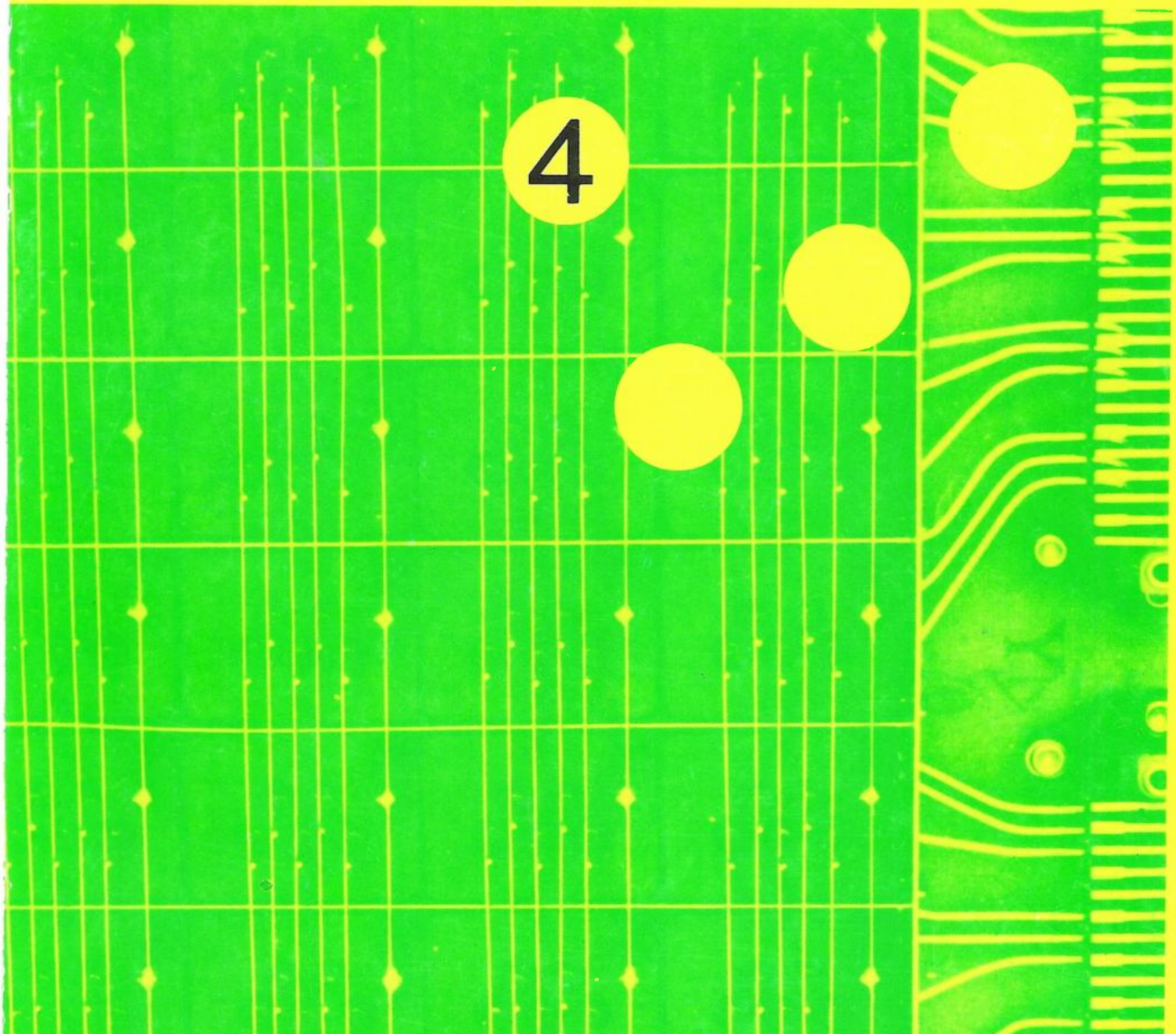
AUTOMATIC TELEPHONY IN THE AUSTRALIAN POST OFFICE

AUSTRALIAN TELECOMMUNICATION MONOGRAPHS



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Australian Telecommunication Monograph No. 4

Automatic Telephony in the Australian Post Office

By A. H. FREEMAN

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The General Secretary,
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Foreword

During the past 15 years the Australian telephone traffic switching network has evolved from being an installation of step-by-step, dial controlled separate local networks, each serving a relatively small geographical area, to an integrated register controlled network covering the whole country. The main switching device now in use is the crossbar switch, controlled by circuitry of a centralised form referred to as "Common Control".

The pace at which the network is developing has outstripped the production of technical literature which would serve to describe the integrated system as a whole rather than as an agglomeration of separate parts.

It may be useful at this point to discuss briefly what is meant when the word "system" is used in its present context. The Shorter Oxford Dictionary defines a system as "a set or assemblage of things connected, associated or interdependent so as to form a complex unity; a whole composed of parts in an orderly arrangement according to some scheme or plan". The definition goes on to say that the word, system, is "rarely applied to a simple or small assemblage of things".

The relatively small consideration which still remains is to appreciate that when we speak of a system we do not always have the whole Australain network in mind. There are times when we could consider, quite correctly, that a single telephone exchange is within itself a system. Indeed, we would be justified in some instances in regarding the group selector stage (GV) in a crossbar exchange as being a system. In my view it would be preferable to regard exchanges in most instances, as being components in a sub-system, the sub-system being in this context the local switching network which by various linkages, is a sensitive part of the whole system. The word sensitive is used to indicate that with the integrated system which covers Australia, it is becoming increasingly important to recognise that large scale malfunctionings at one point in the system are reflected back into the network to produce further difficulties.

The monograph for which this foreword is written is an attempt to describe switching systems in general, at least in basic outline, but with sufficient depth to serve as a very useful introduction to the switching system used in Australia. The author's intention is that it will serve those young engineers and other technical people who are encountering switching systems for the first time as something more than an introduction to basics. It is hoped that it will put the subject in perspective and thus lead to a better understanding of the complexities of network design, remembering that the designer is always looking for a least cost solution which satisfies all the service requirements.

Mr A. H. Freeman is well qualified to undertake the difficult job of writing a text which is complete in itself but which necessarily has to omit detailed circuitry and descriptive material. He is the possessor of a fertile mind capable of innovatory ideas and also capable of clearly understanding the ideas of others. I am proud to be associated, even subliminally, with this work which will fill a decided need and provide information which is not, to my knowledge, available in a single publication.

R. T. O'Donnell.

R. T. O'Donnell, F.I.E. (Aust.)
Director, Posts and Telegraphs
New South Wales.

December, 1973

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Preface

The last ten to fifteen years have seen changes in the Australian telephone systems that may well be described as revolutionary. The effect of this revolution is apparent to the subscriber, who now accepts almost without comment that he can dial his own trunk calls almost anywhere in Australia. It is equally evident to the staff who are confronted with crossbar switches, broadband carrier systems, and other new and complex items of equipment.

The nature of the revolution, of which the above facets are symbolic, is rather less obvious, but far more dramatic. Fifteen years ago Australia had a multitude of independent manual and step by step automatic exchanges and a number of city networks, loosely tied together by a trunk network. The trunk network was partly automatic and had a variety of different types of equipment and signalling methods. It had to rely heavily on the skill of operators trained to understand and use complex traffic routing patterns, special dialling codes, and a number of different operating procedures, depending on the destination of the call and the nature of the equipment at that destination.

This network which relied heavily on human intelligence to link together a diversity of equipment has been largely replaced by a unified system, relying on, and built around the much more limited capabilities of "machine intelligence". The elements of this system interwork in a highly disciplined and complex manner over the whole extent of the telephone network.

This new system cannot be comprehended in the same terms as the older step by step networks. In fact, the contrast is so great that it is not unreasonable to describe the older networks as comprising components (i.e. group selectors, final selectors, junctions and repeaters) capable of being assembled into a system, whose characteristics are the outcome of the components' properties; while the common control crossbar network is a unified system, in which the system design defines the necessary characteristics of the components.

Consequently, whereas the natural approach to understanding step by step is to start with the components and develop the network from them, this must be replaced in common control crossbar with an approach which defines the overall system strategy, and develops the properties of the components as a consequence of the system design. Attempts to describe common control crossbar in the same way as step by step have proved to be very time consuming, and obscure the fundamental pattern behind the system.

In this book, therefore, emphasis has been given to the system design, and the overall strategy developing this in sufficient detail to identify the main structural elements. These have been described, usually in terms of block diagrams, but where necessary some functions have been illustrated with detailed circuits.

In this way it presents the basic foundation of system knowledge which should be acquired by anyone whose work is associated in any way with the technology of common control crossbar. It is sufficiently complete to form a manual for those who have no need for detailed knowledge, particularly men in managerial positions who have an extensive step by step background. It is also intended as a starting point for further study, which may take one of several divergent paths; one path leads to more detailed knowledge of circuits and the circuit operation of components; another leads to a study of the interactions and interworking between the components, while a third is concerned with traffic aspects, and network design. In the modern world such specialisation is unavoidable; it is the author's hope that he has done something to ensure that the specialists have a substantial area of common ground.

It is also hoped that it will be of assistance to those who may never work in the switching field but who nevertheless need to appreciate the whole telecommunication system of which their own speciality is but a part.

The preparation of this book would have been impossible without substantial help from many and varied quarters. In particular the author wishes to acknowledge the assistance of Messrs. R. Langevad and J. F. McCarthy who devoted many hours of their time to detailed constructive criticism of the text.

A. H. FREEMAN.

Chapter 1 — Introduction

THE EARLIEST DAYS

THE TELEPHONE TODAY

THE TELEPHONE INDUSTRY

THE AUSTRALIAN ENVIRONMENT

THE EARLIEST DAYS

On March 25, 1878 Alexander Graham Bell made a bold prediction of the future development of the telephone when he said:

> *"It is conceivable that cables of telephone wires could be laid underground, or suspended overhead, communicating by branch wires with private dwellings, country houses, shops, manufactories, etc., uniting them through the main cable with a central office where the wires could be connected as desired, establishing direct communication between any two places in the city. Such a plan as this, though impracticable at the present moment, will, I firmly believe, be the outcome of the introduction of the telephone to the public. Not only so, but I believe, in the future, wires will unite the head offices of the Telephone Company in different cities, and a man in one part of the country may communicate by word of mouth with another in a distant place.*
>
> *I am aware that such ideas may appear to you Utopian . . . Believing, however, as I do that such a scheme will be the ultimate result of the telephone to the public, I will impress upon you all the advisability of keeping this end in view, that all present arrangements of the telephone may be eventually realized in this grand system . . . "*

Seldom has an infant industry been given a more precise blueprint of its future development. The statement is even more remarkable when one realises the limited amount of solid achievement that had been demonstrated at that time. There were two telephone companies in America, and none in the rest of the world. Of these companies the Bell company had a satisfactory magnetic receiver but a very insensitive transmitter which greatly limited the range of effective conversation; the competing company, Western Union, had Edison's carbon microphone but no satisfactory receiver. Hence the use of the telephone had not progressed beyond establishing direct lines between two points, such as from an office to a warehouse, and the "central office" of his prediction, better known in Australia as a telephone exchange, was no more than an idea. Development, however, was remarkably rapid. Within 12 months Bell had acquired the rights to the carbon microphone and combined it with the magnetic receiver to produce a telephone instrument essentially the same as is used today. By 1882 telephone exchanges were working in many cities around the world, and the "Utopian" predictions of only four years earlier were generally accepted as the manifest destiny of the telephone, even though it took many years to achieve, and in a sense is still not entirely fulfilled.

THE TELEPHONE TODAY

Nearly a century has passed since the prediction above was made, and in Australia alone, there are some 4,000,000 telephones. Most of these are rented from the Australian Post Office (APO) by 2,700,000 lessees or subscribers, and the telephones of any two of these can be connected together on demand, usually without any delay, and often by the subscriber dialling the wanted number so that the assistance of a trained operator is not required. As many as 100,000 simultaneous conversations may be found to be in progress at one time between these subscribers.

A large amount of equipment is needed to allow this to be done. The usual subscriber is a private householder, a farmer, or a small business man with a single telephone. Each of these telephones is connected by a pair of wires to the nearest telephone exchange. In city or suburban areas the distance to this exchange will seldom be more than 5 km and it may have 20,000 or more telephone subscribers connected to it, while in some country areas an exchange may serve subscribers out to a distance of many kilometres and yet have less than 20 subscribers connected.

A network of lines known as trunks or junctions links all these exchanges which contain switching equipment to allow any two subscribers to be connected together. In addition there is a "Gateway Exchange" at Sydney which allows calls to be made to telephones in most parts of the world, and even to ships at sea.

This collection of telephones, lines, and exchanges is known as the "APO Telephone System" or "APO Network" and sometimes as the "Switched Telephone Network", and its components take a wide variety of forms. The lines connecting subscribers to the exchange are sometimes bare wires on poles, such as in Fig. 1-1, but if there are more than about 10 pairs of wires they are usually formed into a cable. These cables may be carried on poles, buried in the ground, or drawn into pipes (called conduits) and Fig. 1-2 shows a typical installation. Where the number of cables is very large they may be carried on racks on the walls of a tunnel, particularly in inner city areas, or those parts of the network close to the exchange where the tunnel often forms an extension of the basement of the exchange building. Fig. 1-3 shows a typical cable tunnel and Fig. 1-4 shows a typical cable tunnel entry to a large exchange.

Telephone exchanges encompass a wide variety of sizes and types. About 10% of APO subscribers are still connected to manual exchanges where the switching of a call requires the assistance of a trained operator, and two of these are shown in Figs. 1-5 and 1-6, but manual exchanges are being steadily replaced by automatic exchanges. These latter range from large installations in

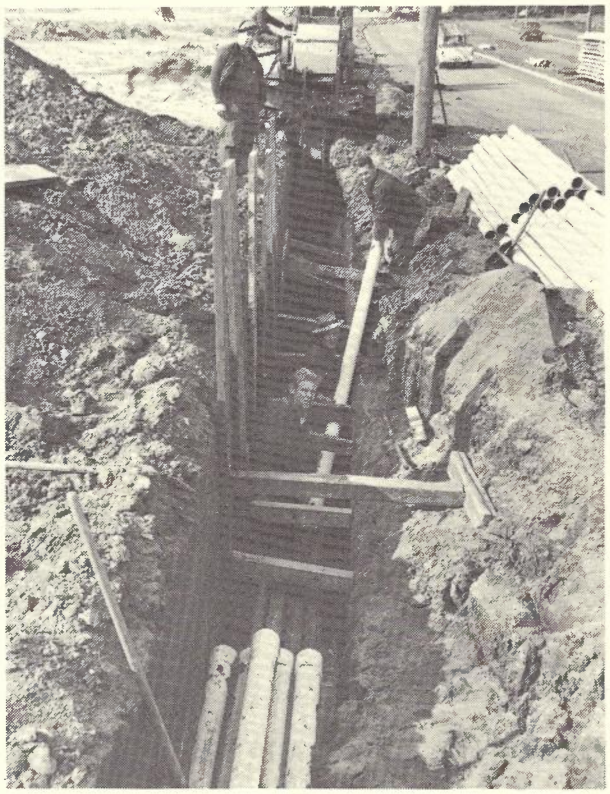

Fig. 1-2 — Installing Conduits.

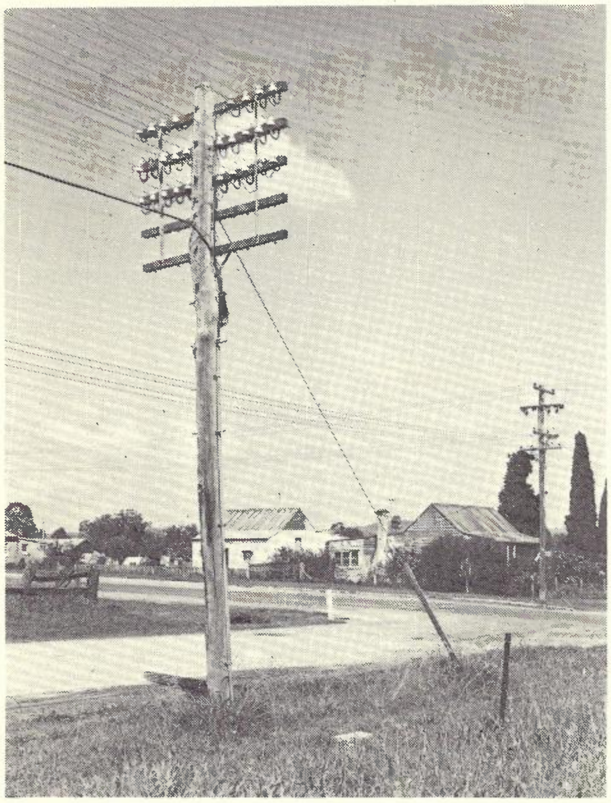

Fig. 1-1 — Pole with Wires and Cables.

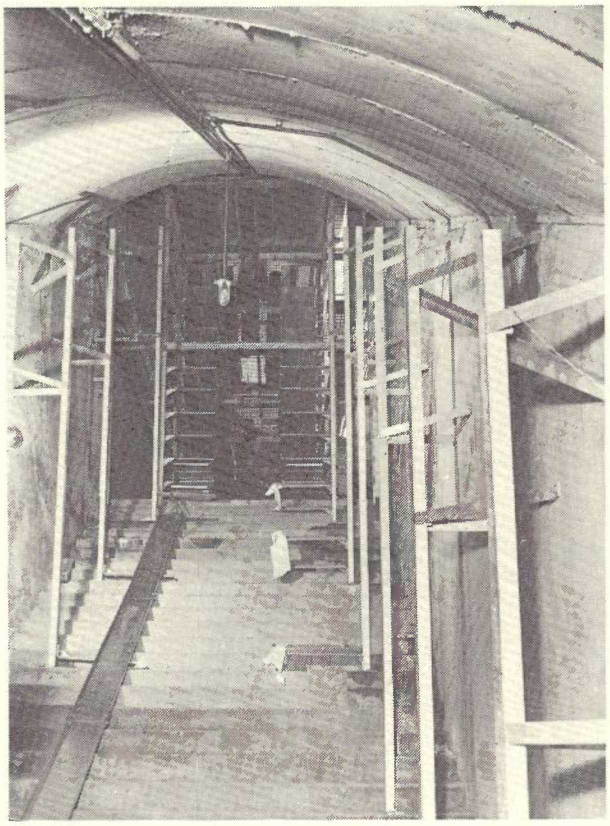

Fig. 1-3 — Cable Tunnel.

multi-storey buildings to small standardised units in portable buildings and some typical examples are shown in Figs. 1-7 to 1-10. Several different types of equipment are used, some of it over 50 years old.

For short distances, up to 60 kilometres in some cases, trunk and junction lines between exchanges use aerial wires or cables, similar to the subscribers lines. Over the longer distances it is necessary to overcome the effects of attenuation in the lines by fitting amplifiers using valves or transistors and in many cases equipment known as a carrier system is used which allows one pair of wires to carry many simultaneous conversations. This is possible because a single conversation requires a bandwidth of only about 4 kHz, and an aerial or cable pair transmission line can be so designed that with suitable amplifiers it can transmit a much wider bandwidth, which is then subdivided by filters into many separate channels of approximately

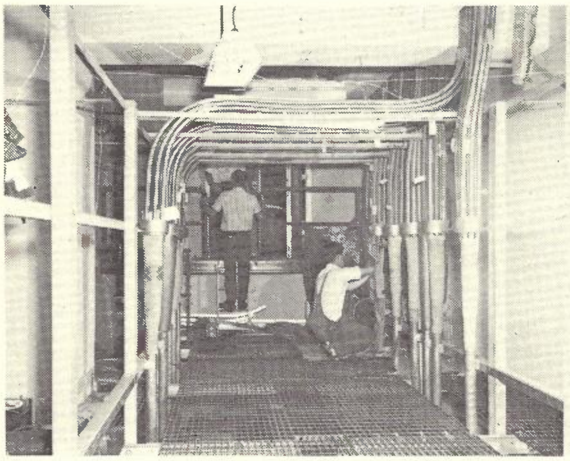

Fig. 1-4 — Cable Entry to a Large Exchange.

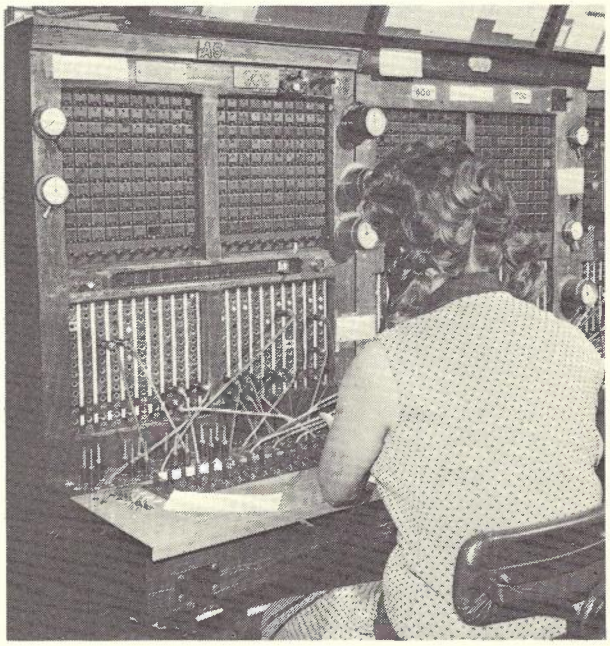

Fig. 1-5 — Small Manual Exchange.

Fig. 1-6 — Large Manual Exchange.

Fig. 1-7 — Transportable Telephone Exchange.

4 kHz bandwidth. Special cables are used for this purpose, manufactured to very stringent limits to give satisfactory performance over wide bandwidths. A cable capable of transmitting 120 simultaneous calls over 4 wires is shown in Fig. 1-11. For the widest bandwidth and therefore highest capacity a cable is used in which one conductor is a cylindrical tube and the other is a wire located centrally within the tube. Such cables are called co-axial cables and two tubes of this type in a cable of the form shown in Fig. 1-12 can carry 2700 simultaneous calls.

An alternative method of transmission with similar properties to co-axial cables can be provided by microwave radio systems which can carry up to 1800 simultaneous calls per system (or bearer) with the possibility of a number of parallel systems being installed on the one route.

It is obvious that every thing described above is in line with Bell's original prediction, even if it goes beyond it in some directions. The sheer size of the network would perhaps surprise the inventor, and automatic switching could hardly have been foreseen that early, nor was he bold enough to predict international telephony, but all these developments are only logical extensions of what he forecast.

Although the APO system includes most of the telephones in the country, and is the most important single entity, there are many applications of the telephone which are more or less independent of it.

For example, many subscribers have a need for several telephones which are used mainly for internal communication between employees in the one building, with only a limited amount of calling to other subscribers in the external APO network.

In these situations a number of telephones can share a much smaller number of lines to the APO network by providing a switchboard at the subscribers premises. This switchboard will have lines to each of the subscribers telephones, known as extension lines, as well as a sufficient numbers of lines to the nearest APO telephone exchange, and known as exchange lines. The switchboard can connect any two extensions, or an extension to an exchange line. It may be a manual switchboard, known as a Private Manual Branch Exchange (PMBX) or an automatic exchange, known as a Private Automatic Branch Exchange (PABX). Since these installations have access to the APO network they must be designed and installed to standards set by the APO and are in fact integral parts of the APO network located in private premises.

Fig. 1-8 — Crossbar Exchange Racks.

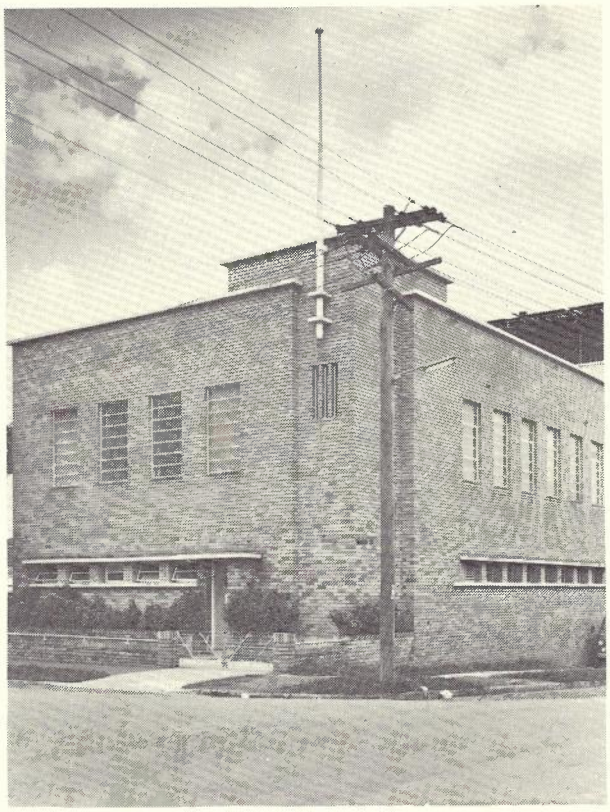

Fig. 1-9 — Telephone Exchange Building.

In some cases most of a company's telephone needs can be satisfied by a network with no access to the APO system. Thus some large retail stores have a fairly extensive independent telephone network linking the sales staff and the stock room, while a limited number of office staff have additional telephones connected to a separate PBX with exchange access. Then again, a large factory may have many specialised communication needs which are best satisfied by a separate and independent system. Such installations can be designed with various special signalling and other facilities. A typical modern application is the annunciator system used to talk from the foyer of a block of home units to the occupants, and which also allows control of the front door lock. In Australia, the Post and Telegraph Act sets out conditions applying to private systems, the most important being that if they extend beyond the boundaries of a single property the APO can require them to use APO facilities. Thus some APO cables sometimes have a significant part of their capacity used for such purposes. There is also a relatively small amount of telecommunication line plant which is privately owned, and most of this is associated with the railways and electricity supply authorities and the defence forces, all of whom have special needs.

A relatively new development is the use of telephone lines for transmitting digital data signals between com-

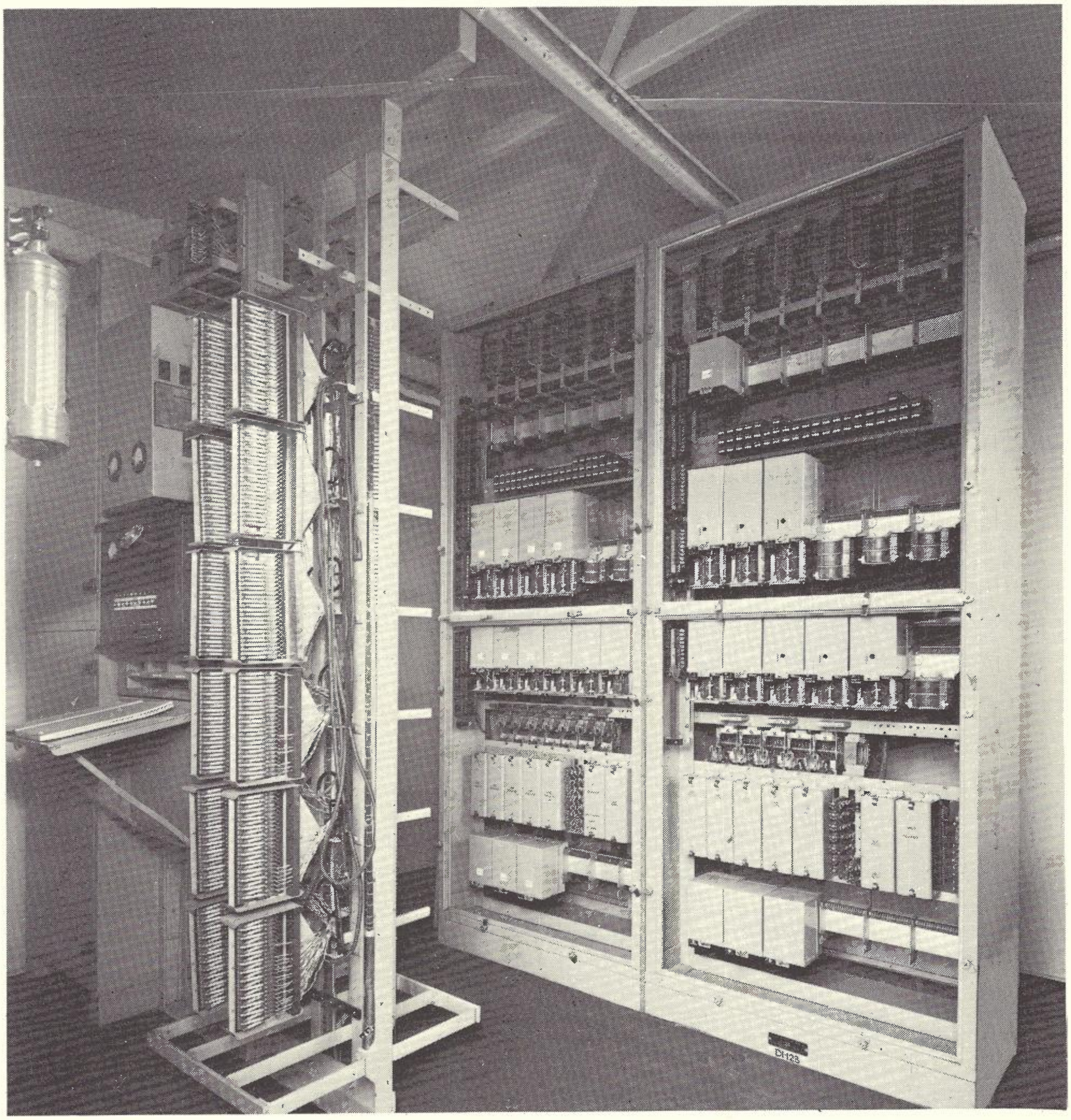

Fig. 1-10 — Small Country Automatic Exchange.

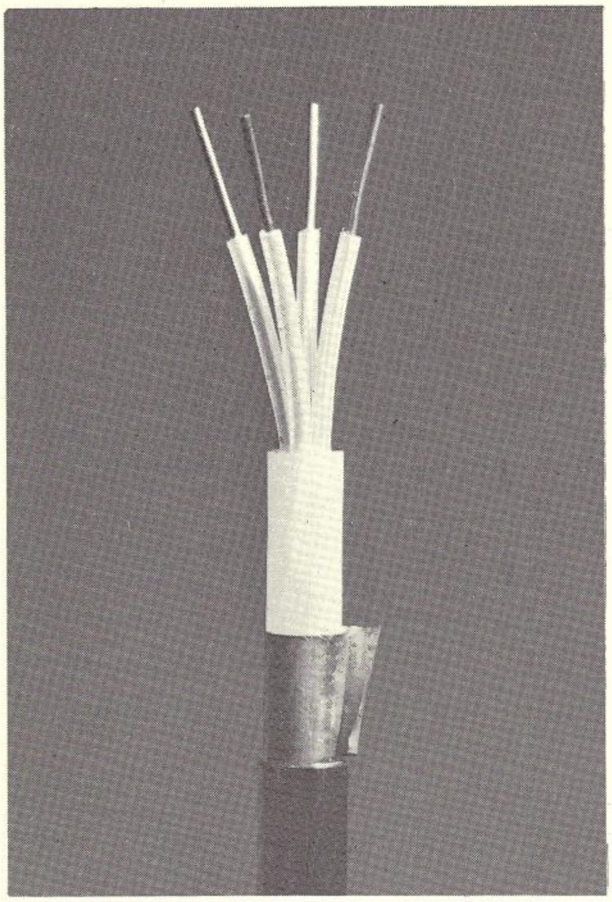

Fig. 1-11 — Single Quad Carrier Cable.

puters, or from remote terminals to a computer. These signals can be transmitted over the switched network, but higher data transmission speeds are possible on lines provided between two points with special characteristics to suit data transmission.

THE TELEPHONE INDUSTRY

This complex assembly of telephone lines and switching equipment represents the end product of several generations of development, which has shaped not only the physical plant but also the people responsible for it, so that the industry as a whole has some unique characteristics. Perhaps one of the most fundamental features is that a history of successful achievement has led to a confident approach to new developments. So much so that automatic dialling of international calls by subscribers or the use of the telephone to carry facsimile transmissions to private homes tend to be taken for granted as facilities which will come along in due course, and usually sooner rather than later.

For example, it was a major achievement in organisation and technology to carry a telecast of President Johnson's inauguration on 1st April, 1968 from America to Australia in real time, yet in 1972 similar international telecasts are set up as a matter of course, at a few hours notice and the only problems in presenting the 1972 Olympic games in Australia related to the costs of the television rights, and sharing of the charges between the television networks. Moreover, these programme costs are much greater than the cost of programme transmission.

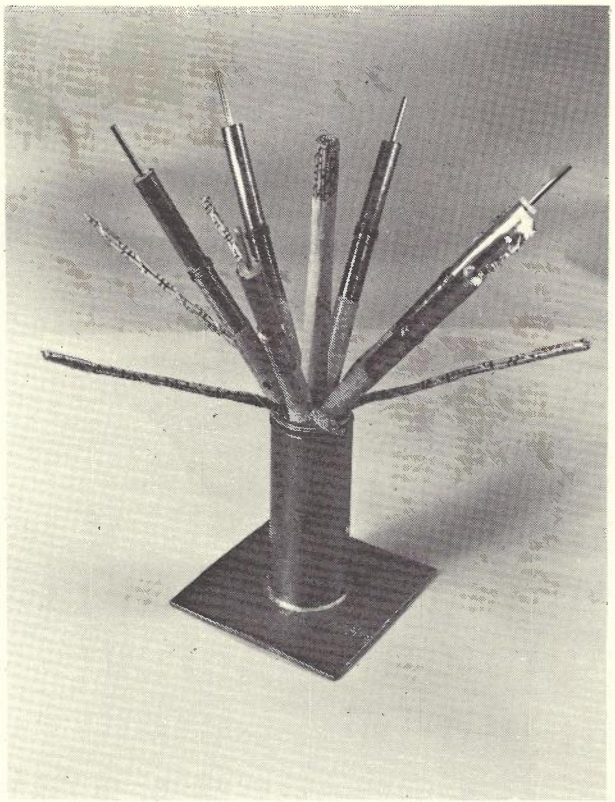

Fig. 1-12 — Six-Tube Co-axial Cable.

Another feature is the ease with which telephone engineers manipulate large systems and system concepts. By any standards, the APO telephone network is a very large system, without equal in Australia in any other field of engineering. To a large degree this was imposed from outside, by the demands of the customer. Even though Bell could foresee that the advantages of a switched network would make it inevitable, the rapid rate of acceptance by the public far exceeded expectations, and ever since then telephone engineers have been in the position of the man in the "old Chinese proverb" who is riding a tiger and cannot dismount.

The early developments make a fascinating historical study and inventions were often produced only just in time to satisfy a growing need. The development of an automatic telephone system suitable for New York for example occurred only a few years ahead of the time when the manual system simply could not have coped because of inherent physical limitations. Much more recently, the APO decision to introduce subscriber trunk dialling (STD) was to some degree forced by the problems encountered in building progressively larger manual trunk exchanges while the new demand released by introducing STD in turn almost overwhelmed the equipment designed for the purpose, and led to the purchase of computer controlled trunk exchanges for Sydney, Melbourne and Adelaide. Similar explosive growth in data signalling and international telephone traffic is already creating new problems while no doubt further fields as yet only dimly seen or even not yet recognised will follow the same pattern.

On the way, the telephone industry has often encountered new problems that were later to become important in other fields of engineering. Queueing theory, for example, is now an important part of many engineering disciplines, but the earliest work in the 1920's was related to telephone traffic problems and switchboard operation.

The practice of Quality Control was born in the telephone industry because of the problems of producing very large numbers of similar high quality components and this development was greatly assisted by the common use of mathematical statistics in telephone traffic engineering and statistical quality control.

A major difficulty in telephone engineering is that systems are so large that updating by complete replacement is impossible. Instead it is necessary for any new equipment to continue to work with the old until the old is worn out, or replaced for some other reason. Consequently equipment installed today is subject to constraints arising from the design of earlier plant, while it in turn will place similar constraints on equipment which has not yet even been conceived. This applies both to the components themselves and their physical placement in the network. For example, of 26 exchanges in service in Sydney at the turn of the century, only 6 have been closed or moved to new sites, although almost 100 additional ones have been established. Similarly cable tunnels, or ducts usually have an expected lifetime of at least 50 years. The telephone industry is thus a strange mixture of conservatism and progressiveness with the progressive side usually winning out against apparently insuperable odds.

THE AUSTRALIAN ENVIRONMENT

The specific forces influencing a particular country's telephone system are unique to that country, being influenced by population density and distribution, Government policy in respect of ownership of the system, and the ability to manufacture equipment within the country.

A result of this is that every country has its own telephone system, with its own peculiarities. In the case of the APO, some features are the concentration of most of the population in capital cities, with no very large provincial towns. As a result, the capital cities started to introduce automatic switching at a very early date (1914) using the only developed system of the time — Strowger step by step, while the country areas remained largely manual for another forty years, waiting for the availability of more versatile switching equipment.

An indication of the magnitude of the difference between countries is that it took nearly a decade to adapt the L. M. Ericsson (LME) crossbar system to the needs of the APO network, and the end result is a specific design to APO requirements. Similar LME crossbar supplied to other countries has a close family resemblance, particularly in its component parts and broad circuit functions, but is sufficiently different not to be interchangeable as a system.

If this is true for one manufacturer's family of crossbar systems, the differences between different manufacturers and countries are even more extensive. Nevertheless, all these are subject to many constraints and limitations arising from natural causes, and the fundamental nature of telephone traffic, so that, no matter how different these equipments may be, they still have many common characteristics.

This book is intended as an introduction to the engineering principles in the APO switched telephone network with particular reference to crossbar equipment. An attempt has therefore been made to identify and isolate those principles which are fundamental to telephony but it is inevitably coloured by APO viewpoints. Moreover, in order to give some concrete basis to the presentation it is necessary to describe equipment in varying degrees of detail and this equipment is inevitably that used by the APO. Most of the treatment in Chapters 2, 3 and 4 relating to network design and switching principles is valid for any telephone system and while the subsequent chapters are more closely related to specific equipment, some of this is also of general application.

The equipment descriptions use many abbreviations and technical expressions which are specific to one type of equipment, namely LME Crossbar. As many of the readers will be familiar with these, they have been introduced in the text without explanation. In Chapters 5, 6 and 7, circuits are used, employing standard conventions which are explained in an Appendix.

Chapter 2 — Basic Concepts

THE TELEPHONE SYSTEM

TELEPHONE ENGINEERING:

- Traffic Engineering
- Network Design
- Transmission Engineering
- Switching Equipment Engineering
- External Plant Engineering
- Transmission Equipment Engineering

TRAFFIC ENGINEERING

NETWORK DESIGN

THE TELEPHONE SYSTEM

The purpose of a telephone system is to allow conversations to take place between the telephones connected to it in accordance with the requirements of the users. Each conversation normally involves two of the telephones in the system and many conversations may be taking place simultaneously.

The most important telephone system in Australia is the Australian Post Office network described in Chapter 1 to which over 2,700,000 telephones are connected, and which covers virtually the whole of the continent. There are also numerous private systems serving the internal communication needs of individual organisations, with no means of access to the APO network. (These should not be confused with Private Branch Exchanges which provide access to the APO network as well as internal communication and which are in fact privately owned or leased extensions of the APO system).

A telephone system can usefully be considered as being made up of two components as shown in Fig. 2-1. Firstly, there is a "switching machine" which has a number of external terminations, and is capable of setting up many simultaneous speech transmission paths between pairs of these terminations on the receipt of appropriate signals. Secondly, there is a number of "subscribers' local ends" each consisting of a telephone (or some complex equipment), a speech transmission path to a termination of the switching machine, and signalling devices to allow requests for service to be passed to the switching machine.

A subscriber's local end is of necessity provided for the exclusive use of one subscriber and its nature and cost are substantially independent of the amount of use made of it. On the other hand, the components of the switching machine are available for the use of more than one subscriber, and a particular subscriber does not use any part of it at all until he makes a call, at which time a speech path is established through the machine using suitable portions of the equipment idle at that time. The various parts of the switching machine need therefore only be provided in sufficient quantities to handle the greatest number of simultaneous demands likely to be made. The measurement and forecasting of this demand (known as telephone traffic) and the determination of the number of devices needed is clearly an important activity in the operation of a telephone system.

Unless the telephones connected to a system are confined to a small area, it is usual for the "switching machine" to be broken up into a number of geographically

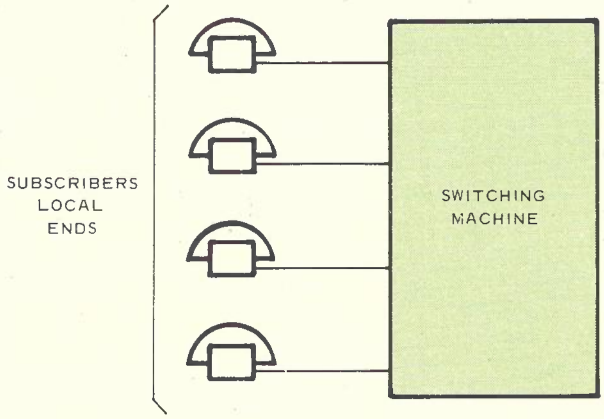

Fig. 2-1 — Telephone System

separate units, with transmission lines between them to allow speech transmission paths to be set up between terminations appearing on different units. Each individual switching installation is called a "Telephone Exchange" or "Exchange", and the transmission lines between them are called "Trunks" or "Junctions" (the difference between a junction and a trunk is of commercial rather than engineering significance, and as the majority of links are junctions, that term will be generally used throughout this book except where confusion would result otherwise).

Fig. 2-2 shows a telephone system in which the "switching machine" includes four exchanges A,B,C and D with groups of junctions between Exchange A and Exchanges B,C and D. Calls may be established between any two telephones, whether connected to the same, or different exchanges and, depending on their location, may require switching in up to three exchanges and may use up to two junctions. Two typical connections are shown on the figure.

The reason for building the complete switching machine out of a number of exchanges is one of economics, i.e. by having a number of exchanges suitably located, the average distance between a telephone and the nearest switching machine termination is reduced, with a resultant saving in the cost of subscribers' local ends. However, the costs of the switching machine are increased at the same time, for two main reasons. Firstly, there are cost penalties involved in spreading the switching over several locations, both in the switches themselves and in such ancillary items as power plant, land and buildings. Secondly, there are the costs of the junctions between the several exchanges, which are not needed if all switching is performed in one building. These junctions can be considered (very loosely) as a pool of extensions to subscribers' local ends, used only when calling between particular groups of subscribers, and therefore replacing that portion of the subscribers' local ends saved by using a multi-exchange network. This is seen most clearly in the star type network of Fig. 2-2. If exchange B were deleted from this network, all the subscribers would have to be connected to exchange A using individual lines. By providing exchange B, the number of junctions needed between A and B would be only a fraction of the number of subscribers (perhaps in a ratio of about 1:10) because only enough are needed to carry the number of simultaneous calls between telephones on exchange B and the rest of the system. The relationship between subscribers' local ends and the number of junctions (on a cost basis) is not always as clear cut as this, but invariably a network change which reduces the average length (and hence the cost), of subscribers' local ends results in corresponding, but usually smaller, increases in junction (or trunk) costs. As might be expected, there is an optimum size of exchange area, in any particular situation, where a balance is achieved between the savings in subscribers' plant from reduced areas, and the extra costs involved in distributing the switching plant between more and more smaller exchanges.

TELEPHONE ENGINEERING

A large telephone network is a complex entity, and the engineering associated with it is of necessity broken up into a number of specialities each covering a particular facet of the total field of telephone engineering. At the same time, there is interaction between the different specialities and, in general, a broad knowledge of the whole range is required by the telephone engineering practitioner. An outline of these different specialities follows.

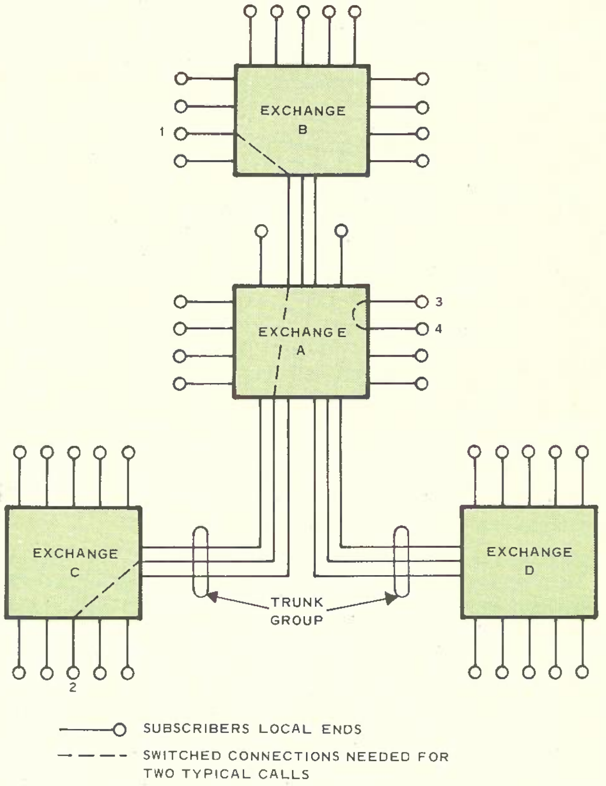

Fig. 2-2 — Multi-exchange Network

Traffic Engineering

This is concerned with measuring telephone traffic and determining the quantities of equipment needed to carry the traffic. This includes the number of trunks or junctions between exchanges, and the number of switches needed in various parts of the internal structure of a telephone exchange.

Network Design

This is concerned with determining the optimum location of exchanges and the form of the trunk or junctions network by which they are to be interconnected. Network design is the unifying discipline which links together the various specialities into a coherent whole. It is concerned firstly with selecting local exchanges and deciding the areas they will serve in such a way as to achieve an optimum balance between the costs of external plant and switching equipment. It is concerned again with the design of the junction or trunk network between exchanges, and the network discipline, i.e. the way a particular type of call will be switched, so that an economical trunk network is obtained. It uses traffic engineering as one of its major tools in determining optimum networks, and indeed the boundary between network design and traffic engineering is not very well defined.

Transmission Design

The whole object of the telephone system is to provide satisfactory speech transmission paths between subscribers' telephones. In order to achieve this, standards of transmission performance must be defined for all the links which form part of the telephone system. Moreover, the way these standards allocate (for example) transmission loss to different links has a significant influence on network economics. The oversighting of existing plant performance relative to these standards, and the determination of new plant transmission parameters, is a constant design activity in the transmission engineering field in the APO.

Switching Equipment Engineering

This is concerned with the physical exchange equipment, including design, installation and maintenance. It deals with both the switching process and provision of signalling facilities between exchanges and between subscribers and the exchange required to establish the various connections.

External Plant Engineering

This is concerned with the provision of cable and aerial wire plant linking telephone exchanges together, and linking subscribers to telephone exchanges. This plant collectively represents the greater part of the assets of a telephone system, and its installation and maintenance employ considerable staff resources. While this work is broadly communications engineering it incorporates civil engineering practices to a large degree.

Transmission Equipment Engineering

This covers the use of electronic equipment either as amplifiers to reduce the attenuation of trunk circuits or as multiplexing (carrier) equipment allowing one transmission path to be used to carry many simultaneous conversations. Radio transmission, of course, forms a very important part of the trunk network in Australia, but it is a highly specialised field and apart from this reference is not dealt with further in this book. There is considerable interaction between this field and external plant work, since the transmission line and the amplifiers or multiplex equipment must suit each other, and there is a wide range of options with different combinations of cable types and carrier systems.

Thus, if it is necessary to provide several hundred trunks between two points, it is possible to do this with a multi-pair cable with one (or two) pairs for each circuit, a higher quality cable with carrier equipment providing 12 circuits per cable pair, and therefore a smaller number of pairs, or a coaxial cable with two coaxial tubes, and more elaborate carrier systems providing up to 2700 circuits.

As this book deals mainly with the switching equipment component of the overall telephone system, the reader will require certain basic knowledge of traffic engineering and network design; the remainder of this chapter is devoted to this purpose.

TRAFFIC ENGINEERING

Telephone traffic is the consequence of individual calls by all the subscribers connected to the system, each acting independently for a myriad of personal reasons. The result, measured on any of the junction routes, or other parts of the system, is an apparently random fluctuation of the number of calls present with, however, indications of some kind of underlying pattern.

As an example of this, Fig. 2-3 is a recorder chart of the number of simultaneous calls present on a small trunk route over a period of 4 hours, and Fig. 2-4 is a chart of the same route over a period of 24 hours on a compressed time scale. It can be seen that the 24 hour chart exhibits a clear trend for the calls to be more numerous during business hours, but superimposed on the trend are apparently random fluctuations. The gradual trend (as seen in the 24 hour chart) is the result of factors which affect all subscribers similarly, while the fluctuations are the result of individual differences. For example, in business districts there is always a rush of calls from about 9 am to 11 am, as people arrive at work, read their mail and make telephone calls. Likewise, there is often a peak in the hour before the close of business, while lunch hour is a slack time. A residential exchange, on the other hand, may exhibit a busy period in the evenings around 8 pm.

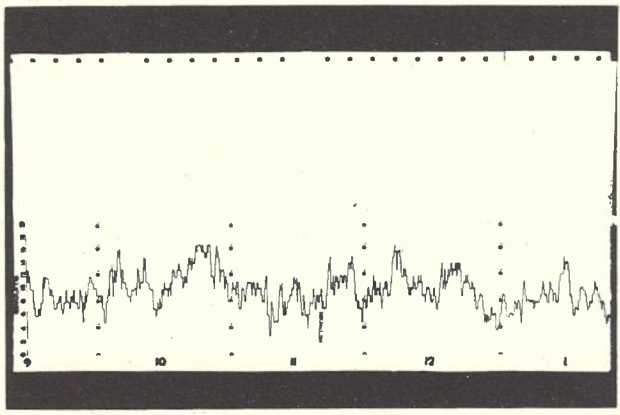

Fig. 2-3 — Traffic for 4 Hour Period

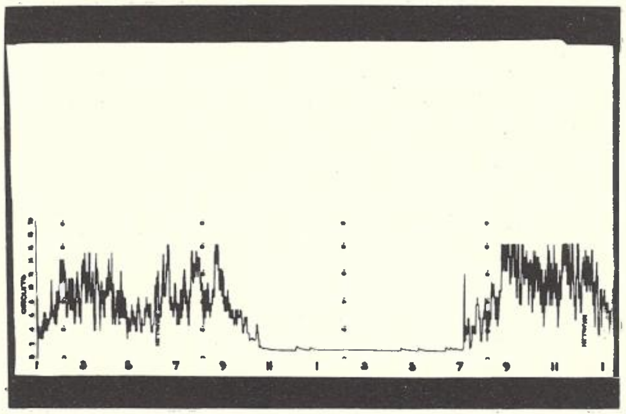

Fig. 2-4 — Traffic for 24 Hour Period

A junction route has to be provided on the basis of the traffic at the busiest period of the day, and the number of junctions is determined by measurements at the busy time. Traffic engineers have established that the busy periods usually last for an hour or more during which the intensity of traffic is reasonably constant, and the behaviour of the traffic can be described quite accurately by a particular kind of statistical variation around the average value.

They are therefore concerned with the average number of busy devices (junctions or switches) over the "busy hour". This average number is called the "busy hour traffic intensity" and the unit of traffic is the "Erlang" which in this case is an average of one circuit in use.*

For example, consider a hypothetical junction route with 24 junctions, and assume that over the busiest hour of the day the number of simultaneously busy junctions was counted on 20 occasions 3 minutes apart. The result of this could be as in Table 2-1.

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* More strictly, the traffic intensity in Erlangs is the number of calls in progress simultaneously. This can be measured instantaneously or averaged over some prescribed period. The averaging process is not fundamental to the definition, but is used so frequently in practical measurements that "traffic" is widely used where "average traffic" is a more correct description.

TABLE 2-1

Test No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Average
No. of busy junctions	7	9	9	10	9	13	18	16	15	14	9	12	7	7	7	11	5	4	11	7	10

The average number of busy junctions over this period is 10 and therefore the traffic intensity is 10 erlangs.

Clearly 10 circuits would not be enough to carry 10 erlangs of traffic, because of the fluctuations. In fact, on the basis of the above figures, since on one occasion there were 18 junctions busy, at least 18 junctions would be needed. However, 20 measurements is a very small sample, and repeated measurements over successive days would show occasional values even higher. If a very large number of samples were taken it would be found that:

- 1.3% of the samples would be higher than 17.
- 0.2% of the samples would be higher than 20.

On the basis of this, it would be expected that if 17 circuits are provided about 1.3% of calls would be lost, and if 20 are provided about 0.2% of calls would be lost. The number of junctions that must be provided therefore depends on the proportion of calls which it is permissible to allow to fail due to shortage of plant. Having decided what percentage of calls are allowed to fail for this reason, it is then necessary to have tables to determine how many circuits are needed for this performance for a given amount of traffic. The next paragraphs describe the nature of the mathematical model which is used to generate such tables, but as this it not used further in the book the reader may omit it if he wishes.

It has been found that a mathematical model of telephone traffic which has the same statistical characteristics as ordinary telephone traffic can be created by assuming for a group of circuits that:

(1) the probability of a new call arriving in a short time interval δt is equal to $k(1).\ \delta t$.

(2) The probability of a particular existing call being terminated in a short time interval δt is equal to $k(2).\ \delta t$.

These assumptions are intuitively satisfying, as the first is suggested by the expected independence of arriving calls, and the second is a plausible representation of the varying duration of calls.

This model has the advantage that it defines a Markov process which is capable of easy manipulation, and one of the properties of the model is that the expected number of simultaneous calls as a function of time is represented by a Poisson distribution.

The Poisson distribution has the property that it is fully defined by a single parameter; the mean, i.e. the average (or expected) number of simultaneous calls, and for the most telephone traffic this is the only parameter measured and is so closely identified with all traffic engineering practice that instead of being called "the mean value of the telephone traffic", it is universally called "the traffic". It is a dimensionless quantity (a pure number) and the unit is called an Erlang.

It is not possible to provide enough equipment to carry every call when it is attempted and it is usual to design on the basis that during busy periods about 1% to 2% of calls encounter congestion on the first attempt because there is no idle device to carry the call at some point in its path. Since a subsequent attempt, after a delay of a minute or more, is extremely likely to be successful, and since over 10% of calls fail at the first attempt because the called subscriber is busy, this amount of congestion is not unreasonable. Surveys of subscribers reaction show no evidence that this amount of congestion creates any dis-satisfaction. The probability of congestion is often called "grade of service".

TABLE 2-2 — PURE CHANCE TRAFFIC, FULL AVAILABILITY TRUNKS

Number of Trunks	Offered Traffic in Erlangs for the Grades of Service shown			
	0.01	0.005	0.002	0.001
1	0.010	0.005	0.002	0.001
2	0.153	0.105	0.065	0.046
3	0.46	0.35	0.25	0.19
4	0.87	0.70	0.53	0.44
5	1.36	1.13	0.90	0.76
6	1.91	1.62	1.33	1.15
7	2.50	2.16	1.80	1.58
8	3.13	2.73	2.31	2.05
9	3.78	3.33	2.85	2.56
10	4.46	3.96	3.43	3.09
11	5.16	4.61	4.02	3.65
12	5.88	5.28	4.64	4.23
13	6.61	5.96	5.27	4.83
14	7.35	6.66	5.92	5.45
15	8.11	7.38	6.58	6.08
16	8.87	8.10	7.26	6.72
17	9.65	8.83	7.95	7.38
18	10.44	9.58	8.64	8.05
19	11.23	10.33	9.35	8.72
20	12.03	11.10	10.07	9.41
21	12.84	11.87	10.80	10.11
22	13.65	12.64	11.53	10.81
23	14.47	13.42	12.27	11.52
24	15.29	14.20	13.01	12.24
25	16.12	15.00	13.76	12.97
26	17.0	15.8	14.5	13.7
27	17.8	16.6	15.3	14.4
28	18.6	17.4	16.1	15.2
29	19.5	18.2	16.8	15.9
30	20.3	19.0	17.6	16.7

Since a call may encounter congestion at several points, it is necessary to allocate grade of service limits for each stage of the switching that are compatible with the overall objective and values between 0.002 and 0.01 are specified for the probability of congestion for individual parts of the system.

The number of devices required at any part of a telephone system is a function of the traffic offered, the grade of service specified and also of any equipment constraints which may make it impossible to use a particular device, even though idle. A multitude of formulae exist for specific situations, and the more important ones have been computed and tabulated, so that in most cases it is only necessary to refer to the relevant table.

Table 2-2 is an extract from a standard traffic table, and lists the traffic which can be carried by a group of switches or junctions for various grades of service and under conditions where the preceding switching does not restrict access in any way, this condition being known as "full availability". This table will be used to illustrate some aspects of Network Design. It will be noted that large groups of circuits are more efficient than small ones; thus for a grade of service of, say 0.01, five circuits can carry 1.36 Erlangs, but if ten times this traffic (13.6E) is to be carried, only 22 circuits are needed.

NETWORK DESIGN

Network design is concerned with defining the locations of the exchanges forming a telephone network, the form of the junction (or trunk) network linking these exchanges and the nature of the switching facilities needed in the exchanges. The ultimate objective is to manipulate these parameters in such a way as to produce the most economical network, and involves establishing a balance between conflicting considerations, as follows:

- The traffic per junction can be increased by combining traffic to several destinations over part of the route; however, this increased efficiency of junction loading is obtained by forcing the traffic to follow less direct and therefore more costly routings.
- Savings achieved by complex network designs are partly countered by the cost of more complex switching equipment.
- Existing equipment and junction plant is a constraint on freedom of action.

The Australian telephone system is a single network which, under the influence of the above considerations has become a complex mixture of several types of solution. The underlying principles are best understood by examining an actual network at an earlier stage of development.

In 1940 the city and suburbs of Newcastle, out to a radius of 5 miles was a self contained "Unit Fee Network", and was served by 5 manual exchanges as shown in Fig. 2-5. Table 2-3 shows the number of subscribers connected to each exchange, and an estimate of the traffic between them. It will be noted that the table shows a range of traffics from 36 Erlangs between Hamilton and Newcastle to 0.1 Erlangs between New Lambton and Stockton. The network design problem is to provide means of carrying all this traffic in the most economical manner.

Four possible networks are shown in Fig. 2-6. In Fig. 2-6 (a) a separate group of junctions is provided for each parcel of traffic giving 20 distinct groups of junctions and a type of design known as a "mesh network". In Fig. 2-6 (b) only 8 groups of junctions are provided radiating from Newcastle exchange, and a call between any two of the other exchanges must be switched via Newcastle. This type of design is known as a "star network".

These two networks represent extreme positions each with its own advantages and disadvantages. In the mesh network any call is carried over a group of junctions dedicated to that purpose, and provided in the most economical manner. However, where the parcels of traffic are small, the junctions will be lightly loaded. In the star network, each junction route is large and efficient, but this efficiency of usage is achieved by compelling some traffic to follow a longer, and more expensive path, and by providing more versatile and more expensive switching equipment at Newcastle.

These differences can be illustrated by looking at specific cases. From New Lambton to Stockton there is 0.1E of traffic and this would require 2 direct junctions in a mesh network each carrying 0.05E. In the star network this would be carried over a New Lambton to Newcastle route of 8E and a Newcastle to Stockton route of 4E, in each case adding less than a quarter of a circuit to the total requirements. For this traffic, the direct junctions needed for a mesh network would be no shorter than the two junctions needed for a star network. In this case the star network appears to be superior to the mesh. At the other extreme is Hamilton to Waratah, with 6 Erlangs. In the mesh network this would require 13 circuits, each carrying 0.46E. In the star network this traffic would have to be switched via Newcastle, over a distance three times as great. In this case, the cost of the longer junctions would outweigh any increased efficiency of usage of junctions.

From the foregoing, an obvious move is to have a mixture of star and mesh trunking as shown in Fig. 2-6 (c). This is usually described as a star network with super-

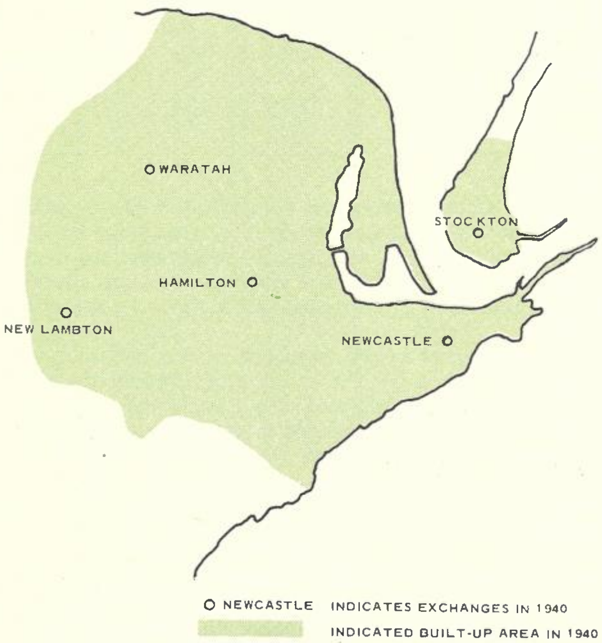

Fig. 2-5 — Newcastle Network in 1940

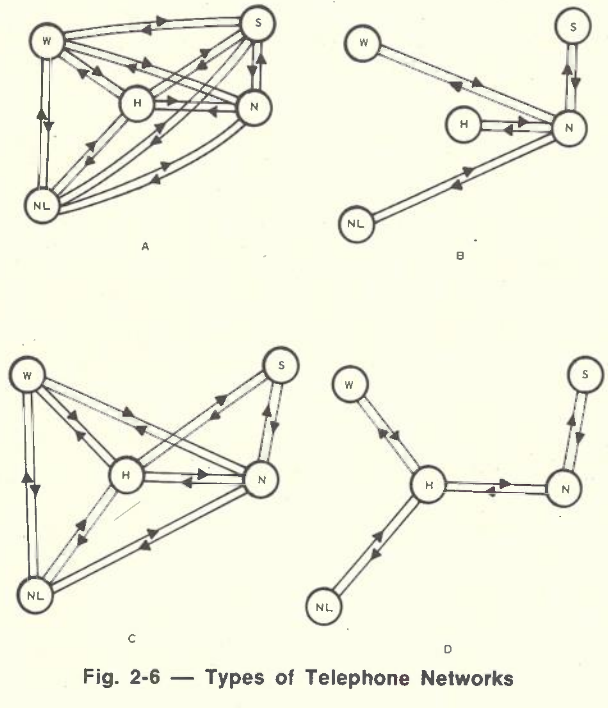

Fig. 2-6 — Types of Telephone Networks

TABLE 2-3

Exchange	Newcastle	Hamilton	Waratah	New Lambton	Stockton
Subscribers in 1940	1978	1424	766	281	132
Traffic in Erlangs to:					
Newcastle	Local	36	15	5	2.5
Hamilton	30	Local	7.5	2	1
Waratah	10	6	Local	0.9	0.4
New Lambton	4	2	1.2	Local	0.1
Stockton	2	1	0.3	0.1	Local

imposed direct routes, particularly since many networks including Newcastle began as stars, and direct routes were added as traffic increased.

In the mesh network all exchanges have identical functions, being required to connect either two subscribers, or a subscriber and a junction, and an exchange with these facilities is called a terminal exchange. In the star network, or the mixed network of Fig 2-6 (c) the exchange at Newcastle has an additional function of connecting two junctions together. This additional function is called "tandem switching" or "transit switching", and an exchange which performs it is called a "tandem" exchange. There are various types of tandem exchanges with special designations and where they handle mainly or only trunk traffic they are usually called "Trunk Switching Centres".

The costs of tandem switching have a substantial effect on network design, in ways which differ for various types of exchange equipment. In 1940 all exchanges in the Newcastle network were manual, and the equipment costs of providing tandem switching were negligible, but it required additional operators and gave slower service. The network is believed to have been in the form of Fig. 2-6 (c) with less than 1% of traffic tandem switched. At that time plans were being prepared for conversion to automatic and the proposed network is shown in Fig. 2-6 (d). This network had two tandem exchanges, Newcastle and Hamilton and a call from New Lambton to Stockton was switched via both tandems, and used three junctions. By providing two tandems a very efficient junction layout was possible and with step-by-step trunking the tandem switching costs were not very great.

There are a number of important variations and extensions of the concepts outlined above. One is that the terminal exchange and tandem functions at a tandem switching centre are often performed by different blocks of equipment, so that there are in fact two separate exchanges in the one building. Even when the two functions are physically combined it is often useful in the design phases to treat them as separate entities.

In a mixed star and mesh network a technique known as alternative routing is often employed to improve the efficiency. The principle is to provide a direct route between two terminal exchanges which has less than the necessary number of junctions to give the design grade of service and to switch calls via the tandem if they arrive when all direct junctions are busy. As an example, the 2 Erlangs of traffic from Waratah to New Lambton require 8 junctions to give 0.002 grade of service. However, if 3 junctions only are provided they will carry 79% of the offered traffic, leaving 21% or 0.42E which must be "overflowed" via the tandem. It is more economical to do this than to provide the additional 5 junctions needed to give 0.002 grade of service on the direct route. Alternative routing is extensively used in modern networks, and gives substantial economies.

So far all junction routes have been assumed to carry traffic for one direction of switching only. It is possible to equip a junction so that it can carry calls originated from either end and it is then called a bothway junction. This gives greater junction efficiency, but requires more expensive exchange equipment. The increase in efficiency is greatest for small traffic routes, so that bothway junctions tend to be confined to such cases.

There are about 6000 exchanges in Australia, all of which must be linked together in a network. There are consequently a large number of tandem exchanges and an elaborate switching pattern, in which occasional calls use 8 junctions and trunk circuits in tandem and are switched at 7 intermediate tandem centres. However, in spite of its complexity is is built up using only the elements and techniques already described.

Chapter 3 – Principles of Trunking and Switching

THE ELEMENTS OF AN EXCHANGE

A terminal exchange is one which has subscribers' lines and junctions connected to it, and is required to establish three kinds of call:

- A call between two subscribers both connected to that exchange (a local, or internal call).
- A call originated by a subscriber connected to this exchange and directed to a subscriber at another exchange and which is therefore connected to a junction to that exchange, or to a tandem exchange (an outgoing call).
- A call originated elsewhere, requiring connection from the junction on which it enters the exchange to the called subscriber (an incoming call).

In most exchanges the path of a local call begins by sharing the same switching equipment as outgoing calls and finishes sharing switching equipment with incoming calls so that it is possible to regard a local call as a combination of an incoming and outgoing call, linked together by a 'local junction'. There is usually some part of the exchange wiring which can be logically defined as the 'local junction', and in some cases there is actually a group of relays (relay set) providing signalling and other facilities at this point. Such a relay set is usually called a 'cord circuit' because it performs analogous functions to a similar group of relays on each pair of cords used to switch calls in a manual exchange.

By adopting this viewpoint it is necessary to consider only two types of call via a terminal exchange; outgoing and incoming.

Nearly all subscribers' lines are required both to make calls and receive them, and are therefore bothway circuits in respect to signalling and switching. Trunk or junction lines on the other hand are not necessarily required to provide for bothway switching, and the junctions between a pair of exchanges may be divided into two groups, one for each direction of switching, or used as a single group of bothway junctions. The choice between these alternatives is a matter of economics, which generally favour bothway junctions if the total number required is small.

Since every connection required in a terminal exchange is between a subscriber at one end and a junction or cord circuit termination at the other, the switching task can be specified in the form shown in Fig. 3-1.

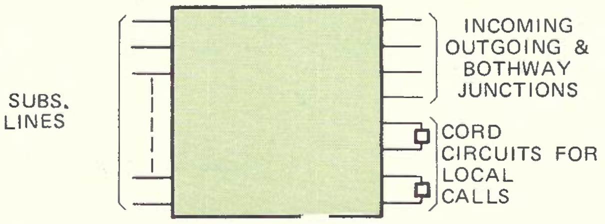

Fig. 3-1 — Block Diagram Small Terminal Exchange

This shows the exchange as a switching unit with two sets of terminations. One set terminates subscribers' lines, while the other terminates junctions and cord circuits, and the machine is required to make connections as desired between a specified subscriber's terminal and a specified junction or cord circuit. The request for switching may arise from either end and the control of the machine must be bidirectional. The illustration says nothing about the internal structure of the machine which, in a large exchange, usually requires the operation of several switches to establish one connection.

The requirement of switching in either direction causes difficulties with some types of switches and, because of this, exchanges are sometimes organised as two more or less independent units as shown in Fig. 3-2.

In this case there are two independent switching units, one for each direction of calling. They are each one way devices, and therefore may be simpler, in addition to which it is possible to take advantage of differences in the nature of the switching task in each direction.

For an incoming call, a specific incoming junction must be connected to a specific subscriber, and no other, so that the input and output points are both defined. For an outgoing call it is sufficient to select any free junction of the group to the desired distant exchange, since they are all capable of being used to complete the call. The process of switching to a specific line is called 'individual' or 'final' selection, while the process of switching to one line out of a group is called 'group' selection. As might be expected, group selection is generally a simpler task than final selection, and therefore the outgoing switching machine in Fig. 3-2 may be less complicated and expensive than the incoming one.

On the other hand, subscribers' lines, and bothway junctions must appear on both machines and be provided with directional switching. In many exchanges there is a mixture of the two techniques of Figs. 3-1 and 3-2 and this will be discussed later when specific types of exchange are described.

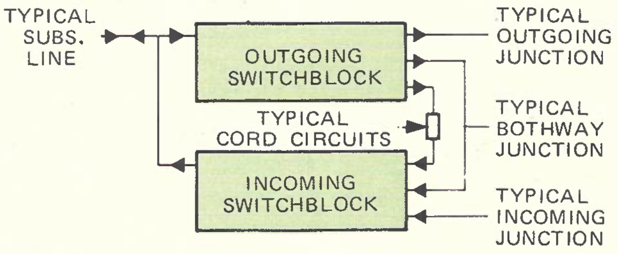

Fig. 3-2 — Block Diagram Large Terminal Exchange

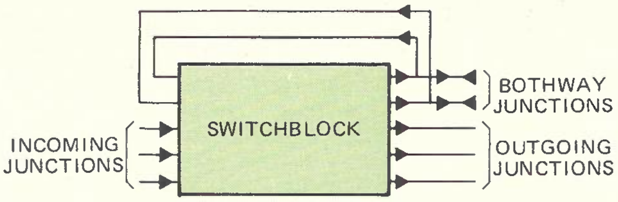

Fig. 3-3 — Block Diagram Tandem Exchange

A tandem exchange is one to which only junctions are connected and there are two basic methods of construction. Fig. 3-3 shows the method used when most trunks are unidirectional and requires a one way switching machine.

If a large proportion of the junctions are bothway, the system shown in Fig. 3-4 is sometimes used. The left hand side of the switching machine provides terminations for junctions, while the right hand side terminations are linked together in pairs — analogous to the cord circuits shown in Figs. 3-1 and 3-2. Any call must be switched from the junction on which it is incoming to one side of a link, and then from the other side of the link back to the junction to which it must be switched. The advantages and disadvantages of the two alternatives depend very much on the details of the various types of switching equipment and control circuits.

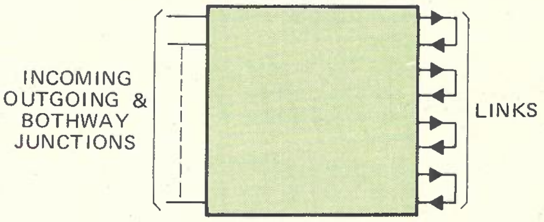

Fig. 3-4 — Block Diagram Tandem Exchange

The size of terminal and tandem exchanges varies over an enormous range; there are terminal exchanges in country areas with fewer than 20 subscribers and two or three junctions, while in the large cities exchanges of 10,000 lines are common, and some are expected to grow to over 40,000 subscribers and 10,000 junctions in the next 20 years. Similarly tandem exchanges range from sizes less than 100 junctions to a few of a planned size of 50,000 junctions. The variety of detailed requirements even between exchanges of similar size is so great that there is no possibility of standardised exchanges except in very small sizes, and the larger ones are custom built from convenient sized switching units used as 'building blocks'.

THE CROSSPOINT CONCEPT IN SWITCHING SYSTEMS

General

A considerable body of theory has been developed in respect of the methods of interconnecting switches to form a telephone exchange. Most of this theory ignores the physical details of the switches and describes them as arrays of crosspoints, and the complete assembly, shown as a block in Figs. 3-1 to 3-4 as a connecting network, or a speech path network.

A crosspoint is a device which will make or break a connection between two sets of wires. One such device is a relay with a number of springsets as shown in Fig. 3-5(a).

This particular crosspoint has 3 wires in each set; and three spring contacts sets, but crosspoints may

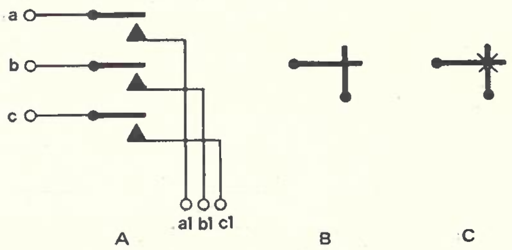

Fig. 3-5 — Crosspoints

have more or fewer wires if required. In fact, some parts of crossbar control systems have crosspoints with over 100 wires.

The usual symbol for a crosspoint is two intersecting lines as shown in Fig. 3-5(b), and if it is necessary to indicate that it is operated a diagonal cross as in Fig. 3-5(c) is used.

Crosspoints are usually assembled to form 'rows', and arrays. Fig. 3-6 shows a row of five crosspoints, in relay contact form and in crosspoint symbols, while Fig. 3-7 shows a 5 x 10 array of crosspoints.

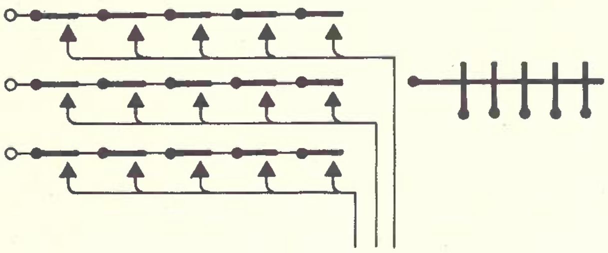

Fig. 3-6 — 1 x 5 Crosspoint Array

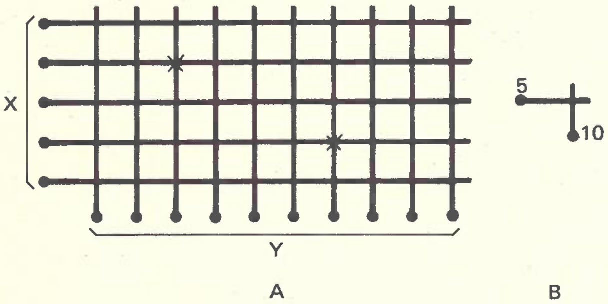

Fig. 3-7 — 5 x 10 Crosspoint Array

This array is made up of 50 crosspoints in a 10 x 5 array linking the 5 terminations marked X to the 10 terminals marked Y. Clearly, by operating the appropriate crosspoint it is possible to connect any particular X side termination to any particular Y side termination, and to set up a maximum of five such connections simultaneously. Crosses on the diagram show two possible connections. The symbol shown in Fig. 3-7(b) is frequently used to show this kind of rectangular array.

A crosspoint array of this kind can be constructed in many different ways, and the various forms can be classified into those using relay like crosspoints (including crossbar switches), those using mechanical switches, and those using active electronic devices.

Mechanical Switches As Crosspoint Arrays

Uniselectors

Mechanical devices are the most easily understood, and Fig. 3-9 is an illustration of one of the most widely used switches in a step-by-step exchange, which is known as a uniselector. Its construction and operation is more clearly shown in the simplified sketch in Fig. 3-9. The three main components are the wipers and wiper carriage, the bank contacts, and the drive mechanism.

The wipers are the movable contacts of the switch, and are mounted on the wiper carriage, forming an assembly which allows the wipers to rotate over the bank contacts. The bank consists of sets of fixed contacts located on a circular arc, so that by suitably positioning the wiper carriage, each wiper will be in contact with one of the bank contacts. In Fig. 3-8 there are four sets of wipers, and the bank contains 25 rows of four contacts, so that the wipers and bank form a 25 position, 4 pole switch. The wipers are stepped sequentially from one bank position to the next by the drive mechanism, consisting of an electro-magnet operating on a ratchet and pawl. Because the bank contacts are located on an arc of 180°, each wiper has two arms, so that as one set of wipers is leaving the 25th contact, the opposite arms are entering the bank at the first contact.

There are several different types of uniselector, operating on this principle in use in the APO with minor variations in detail, and information about them is available in APO engineering instructions. The number of wipers may vary from 3 to 10.

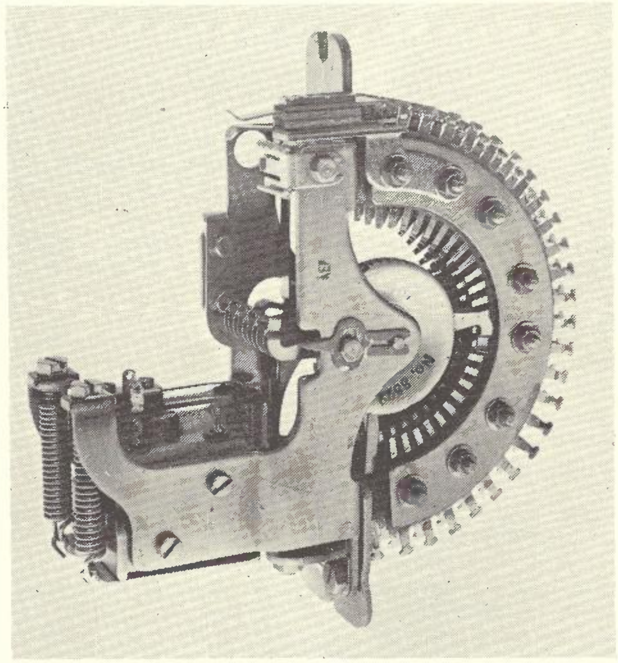

Fig. 3-8 — Uniselector

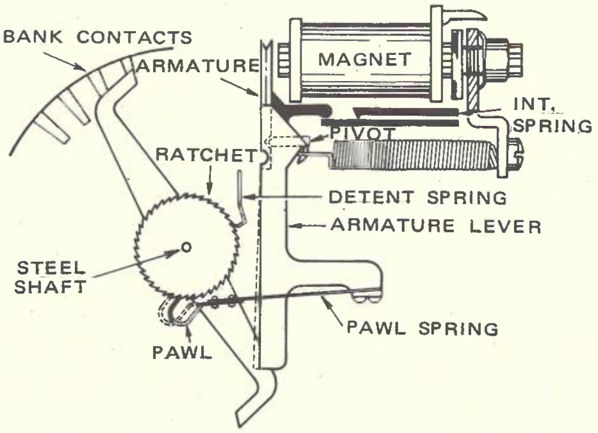

Fig. 3-9 — Uniselector Operation

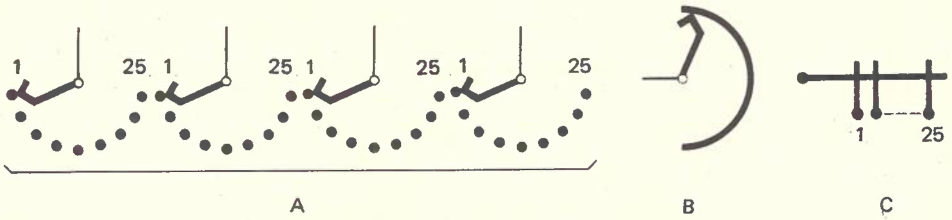

Fig. 3-10 — Uniselector Symbols

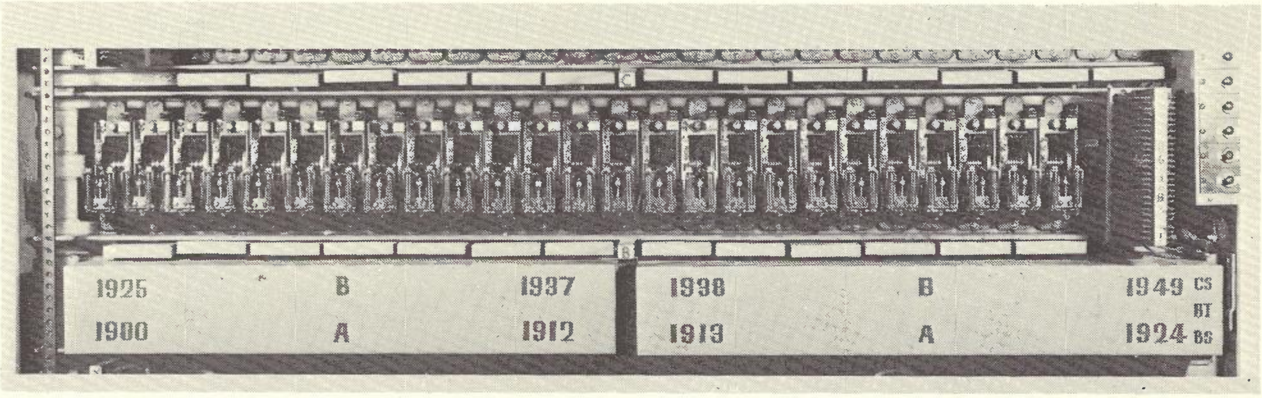

Fig. 3-11 — Shelf of 25 Uniselectors

This switch is usually represented in circuits by the symbol of Fig. 3-10(a), in which every wiper and its corresponding bank contacts are shown, or in circuits where less detail is needed by the symbol of Fig. 3-10(b). The switch performs the function of a row of 25 crosspoints, as described earlier, and can therefore be represented by the symbol of Fig. 3-10(c).

If several switches of this kind have their bank contacts multipled together they then form a crosspoint array of the type shown in Fig. 3-7. For example, Fig. 3-11 is a photograph of a 'shelf' of 25 such switches with their outlets multipled to make a 25 x 25 crosspoint array.

The wiper carriage rotates through 180° to step over 25 positions, and each wiper has two arms 180° apart, so that as one arm leaves the bank at the 25th position, the opposite arm enters it at the 1st position. The switch can also be used as a 1 x 50 crosspoint array by using 'single ended' wipers. These wipers, have only one arm and contact the bank for only 180° of each revolution of the wiper carriage. By having two such wipers 180° apart, moving over 2 different arcs and joined together the switch effectively has 50 positions, as shown in Fig. 3-12.

For the first half revolution wiper 1 contacts outlets 1 to 25 of arc 1, while wiper 2 is free of the bank, while for the second half revolution wiper 2 contacts outlets 26 to 50 on arc 2 so that the pair of wipers can contact 50 outlets. To get 3 wire crosspoints, it would be necessary of course to provide a bank with 6 rows of contacts, and 3 pairs of single ended wipers.

Another way of getting 50 outlets which is of more general application is by means of 'wiper switching', and for this method, double ended wipers are used with an auxiliary 'wiper switching' relay to connect one or the other set of arcs as shown in Fig. 3-13.

This shows 4 arcs being used to provide a 1 x 50 2 wire crosspoints array but in practice 6 to 10 arcs would be used, giving 3, 4 or 5 wire crosspoints. One wiper

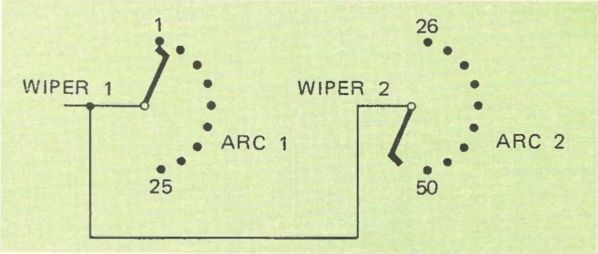

Fig. 3-12 — Single Ended Wipers

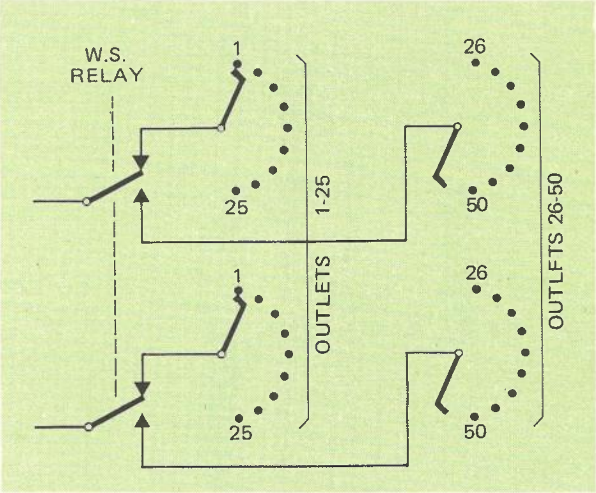

Fig. 3-13 — Wiper Switching

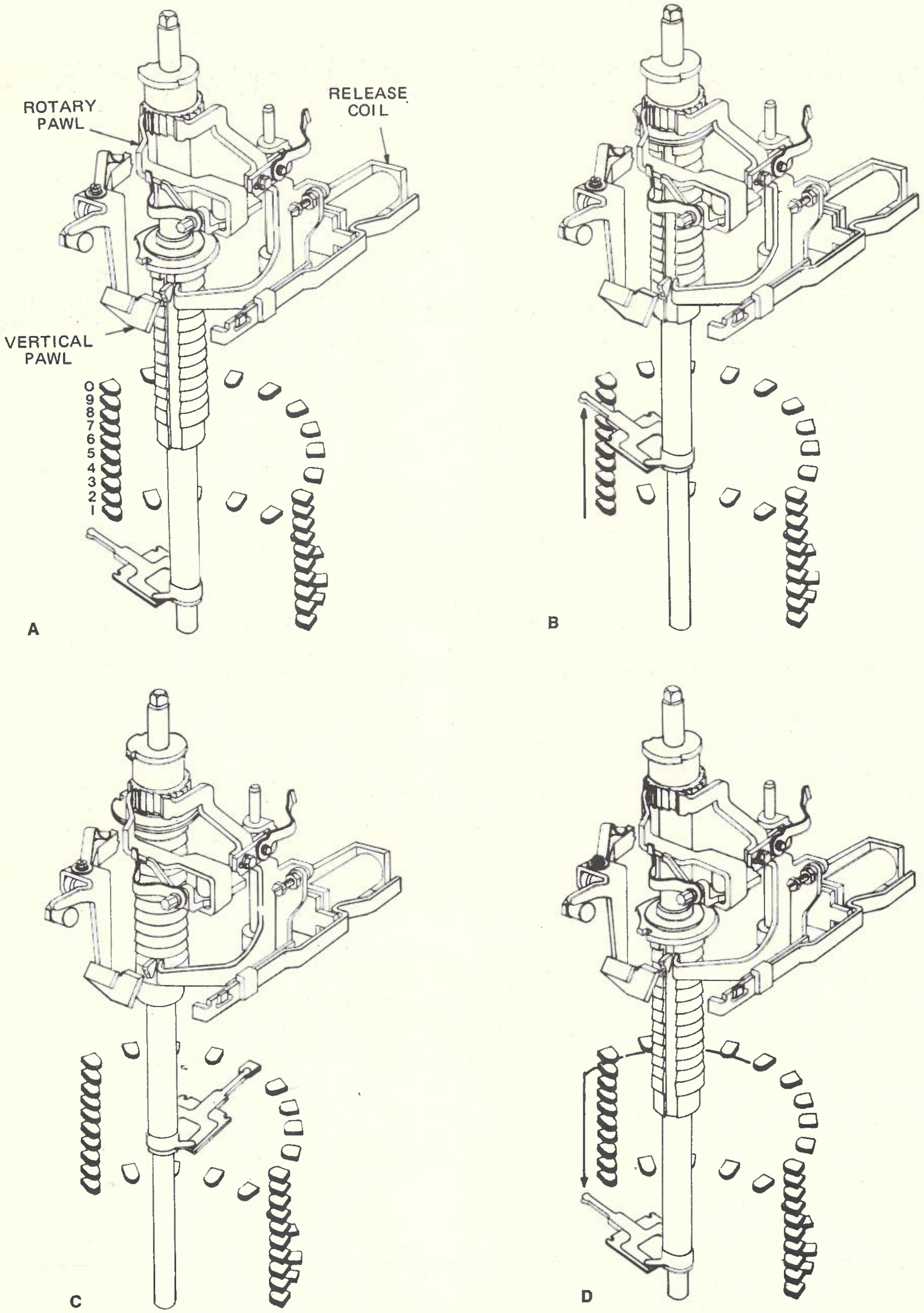

Fig. 3-14 — SE 50 Bi-motional Selector

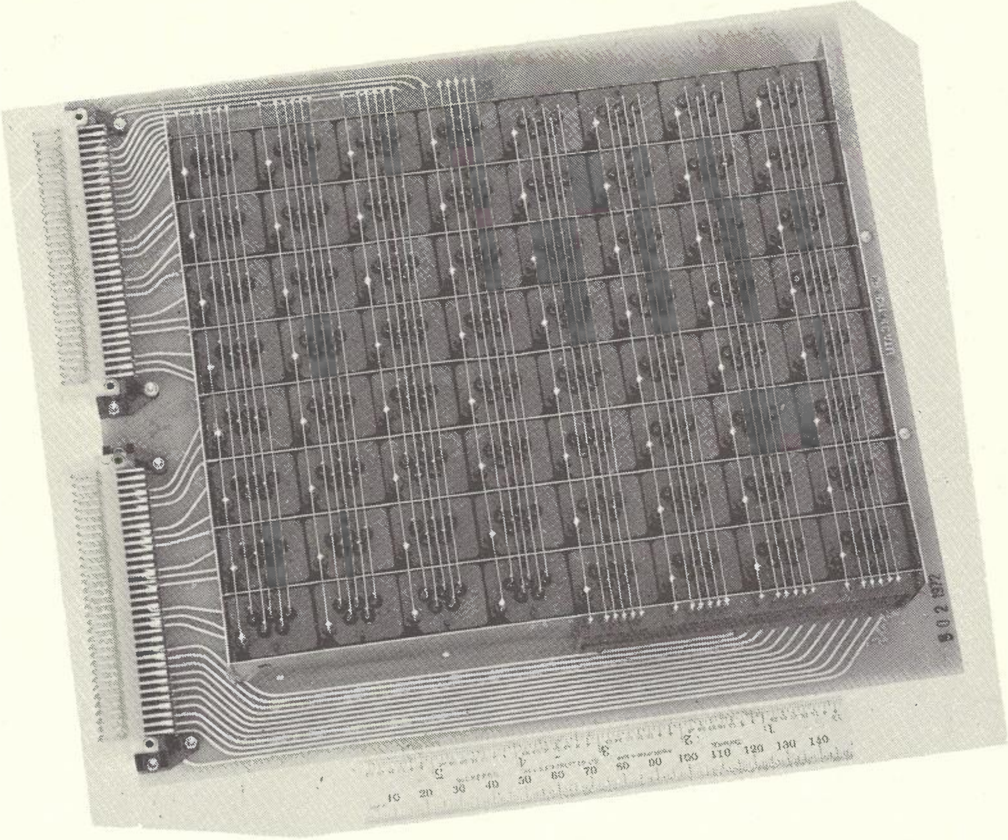

Fig. 3-15 — Reed Relay Crosspoint Array

switching relay is needed to select the desired sub-set of 25 outlets, under control of the logic circuitry of the selector. If enough arcs are available, additional wiper switching relays can be used to give more crosspoints per switch position and in one extreme case a 50 position, 16 arc uniselector has been used to give five, 3 wire crosspoints for each position so that the switch becomes a 1 x 250 crosspoint array.

Bi-motional Selectors

Another very important mechanical switch, and the mainstay of step by step automatic telephony is the bi-motional selector. It is essentially a 100 position switch and as its name implies, the process of stepping to a particular position involves two separate actions. The wipers are carried on a shaft, which can move vertically to one of 10 positions, usually called levels and then rotate in a horizontal arc to one of 10 rotary positions at each level. Thus the 100 positions of the wiper tips are located on the inside surface of a sector of a cylinder. Figs. 3-14 (a), (b), (c) and (d), which are simplified drawings of part of one type of selector, show how this action allows each wiper to contact any one of 100 bank contacts. The stepping of the wiper carriage is achieved by two separate magnets operating ratchet and pawl drive mechanism. The magnets are known naturally as Vertical and Rotary Magnets while a third 'Release' magnet is used to release the switch.* The mechanisms are best understood by actually manipulating a switch, as it is very difficult to show the operation clearly in drawings; however, APO Engineering Instructions, and Training documents give adequate details of the operation and adjustment of the three main types of bi-motional selector in use in Australia.

The mechanism is also made to operate a variety of auxiliary springsets which provide indications to the switching circuit controlling the selector of the actions taking place. Typical springsets indicate that the switch has lifted vertically from its rest position (off normal springs), has stepped past the initial rotary position (rotary off normal), etc. In some circuits as much as half of the circuit logic is provided in this way.

In most modern bi-motional selectors wiper switching is used to make the 100 position switch provide 200 crosspoints. The mechanism compels these crosspoints to be treated as 10 sub-sets each of 20, and the switches are organised in stages corresponding closely to the numbering of the subscribers as will be shown later. A bi-motional selector is thus a highly specialised device which because it is designed to do one specific task is very efficient and economical for that task.

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* Not all bi-motional switches have a separate release magnet, and one in particular (2000 type equipment) uses the rotary magnet for release.

Relay Type Crosspoint Arrays

Relays

Relays can obviously be used to provide crosspoint arrays, simply by suitably connecting their contacts. Fig. 3-6, for example showed the contacts of 5 relays used to provide a 1 x 5 crosspoint array.

To perform as a selector, it is merely necessary to arrange to operate the relay corresponding to the desired crosspoint. A 4 x 5 crosspoint array could be constructed by multipling the outlets of four such arrays. It would then be necessary to provide control circuits to ensure that the desired relays are operated and these could not include more than one in any horizontal row, nor more than one in any vertical row. When relays are used in this way, because the interconnections are systematic it is sometimes possible to adopt constructional techniques which reduce the labor involved in wiring.

Fig. 3-15 shows one view of an 8 x 8 crosspoint array made up of 64 reed relays, as used in the 10C processor controlled exchange. The relay coils, and one side of each reed insert are mounted on a printed circuit board which provides part of the wiring. The other ends of the reed inserts are wired together with a bare wire multiple.

Another construction of more conventional form is the RAM series of multicoil relays used extensively in LME crossbar control circuits and one such unit is illustrated in Fig. 3-16. It is made up of 10 relays mounted side by side on one mounting, with the fixed contacts of the relay springsets taking the form of contact strips so that the multipling needed for a 1 x 10 crosspoint array is inherent in the construction. Several (say 5) such multicoil relays may be wired together to give a 5 x 10 array. Each crosspoint of an array using RAM relays can have up to 12 wires.

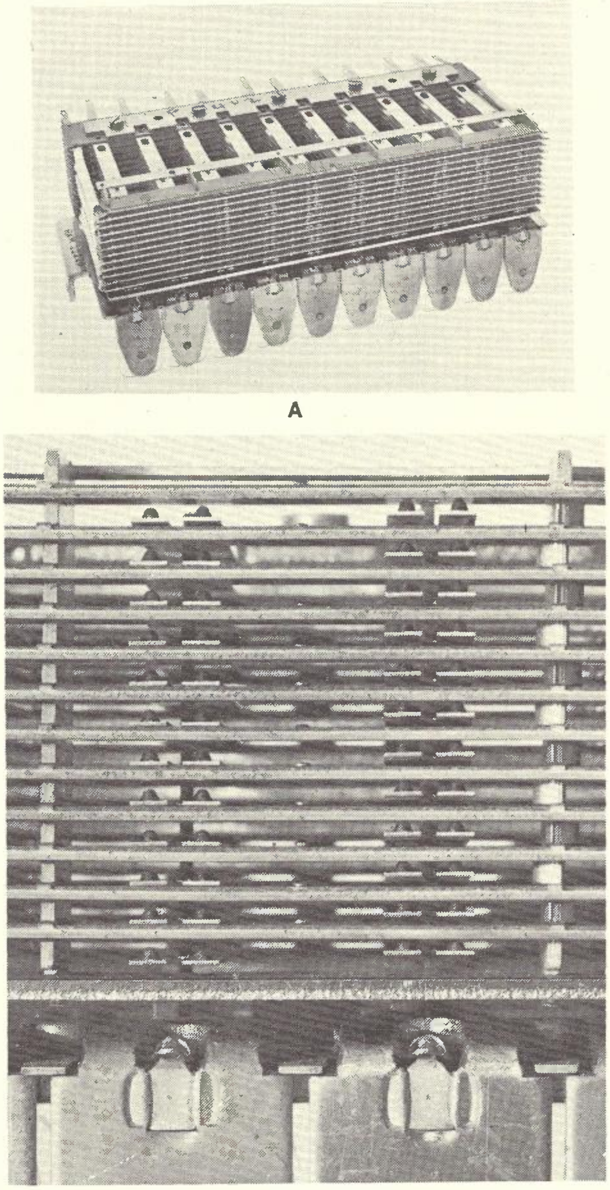
The above forms of crosspoint array require one relay per crosspoint, but if a small number of wires per crosspoint is needed a technique analogous to wiper switching can be used to reduce the number of relay coils required. Fig. 3-17 illustrates the method, with 7 relays used to provide a 1 x 10 crosspoint array with 3 wires per crosspoint. The 5 relays R1 to R5 each have 6 springsets, corresponding to 2 crosspoints, while the two remaining relays A and B have 3 springsets each. By simultaneously operating one of the relays A and B and one of the relays R1 to R5, the three inlet wires can be entered to any of the 10 sets of 3 wire outlets, numbered 1A, 1B etc to 5A, 5B. This technique appears in many disguises, and is given various names, but generally the relays corresponding to A and B are described as 'outlet switching' relays. The switching is usually but not necessarily restricted to doubling the number of crosspoints, and if enough contacts are available on the main relays three and four fold multiplication is possible.

Several such arrays can be multipled together, to provide for example a 10 x 10 array. In such an array, only one out of relays A and B, and one out of relays R1 to 5 in one row must be operated at a time, and once such a pair is operated to close a crosspoint the other relays in that set will not be called on to operate until after the operated relays have released to break that connection.

Crossbar Switches

A crossbar switch is a relay contact type of crosspoint array in which advantage is taken of the fact that only a limited number of states and of changes of states are allowed in the array

This limitation allows the number of relay coils needed to control the contact sets to be greatly reduced.


A

B

Fig. 3-16 — (a) RAM Multicoil Relay
(b) Close up of RAM Relay

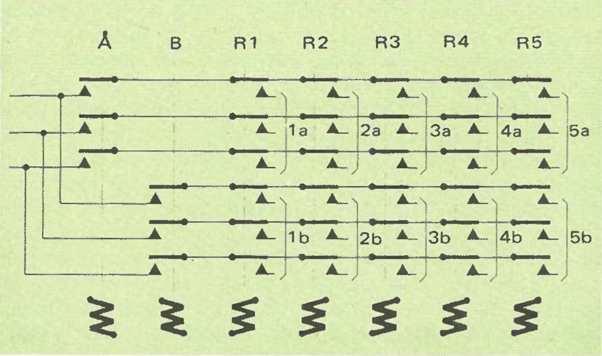


Fig. 3-17 — Use of Outlet Switching Relays

One form of the LME crossbar switch has 100 contact sets in a 10 x 10 array, and 20 operating magnets, one for each horizontal row and one for each vertical column, as shown diagramatically in Fig. 3-18(b). Each contact set can be defined by the horizontal and vertical magnets corresponding to the row and column, and thus the marked contact set is described as H3, V5.

The operation of the contact sets obeys the following rules:

- If a vertical magnet is not operated, all of the contact sets in that vertical row are open.
- When a vertical magnet operates, any contact set(s) in that vertical row for which at that time the appropriate horizontal magnet is operated will be closed.
- Once a vertical magnet has operated, the springsets which it closed when operating, remain closed for as long as the vertical magnet remains operated, regardless of the subsequent state of the horizontal magnets.
- Likewise, springsets in that vertical row which were not operated will remain un-operated regardless of the subsequent state of the horizontal magnets.

It can be seen that these rules allow each vertical column of the switch to be used as a 1 x 10 crosspoint array, independently of any other vertical. A crosspoint is closed by pre-operating the horizontal magnet and then operating the vertical magnet. Having done so, the state of that vertical set of crosspoints will remain unaltered as long as the vertical magnet is operated. Consequently the horizontal magnet can be released, and the switch is then ready to operate a crosspoint on any other vertical, (including those on this horizontal row). Thus each vertical, with the assistance of the horizontal magnets (which it shares with 9 other verticals) performs the same functions as 10 complete relays wired as a 1 x 10 crosspoint array.

Most LME crossbar switches have 120 spring contact sets, in 10 vertical columns of 12, with the two additional contact sets in each vertical row used for outlet doubling, so that it is necessary to operate two horizontal magnets to set a crosspoint, and each vertical becomes a 1 x 20 crosspoint array with a maximum of five wires per crosspoint.

Some of the important characteristics of a crossbar switch are as follows:

- The cost per crosspoint is greater than for rotating switches, but the electrical quality of the crosspoints is much higher and maintenance costs are extremely low. This applies to all crosspoint arrays using relay type contacts.
- It takes only about 50 ms to operate a crosspoint, compared with a second or more for mechanical selectors. However, only one crosspoint can be set at a time, because the one setting mechanism is shared by all ten verticals.
- The switch cannot easily be built with a large number of crosspoints. The largest switch in general use is the Pentaconta selector, with 28 horizontal magnets, giving 52 crosspoints per vertical.
- In common with all relay contact type crosspoint arrays, there is no built in mechanical logic of the type incorporated in step by step selectors.

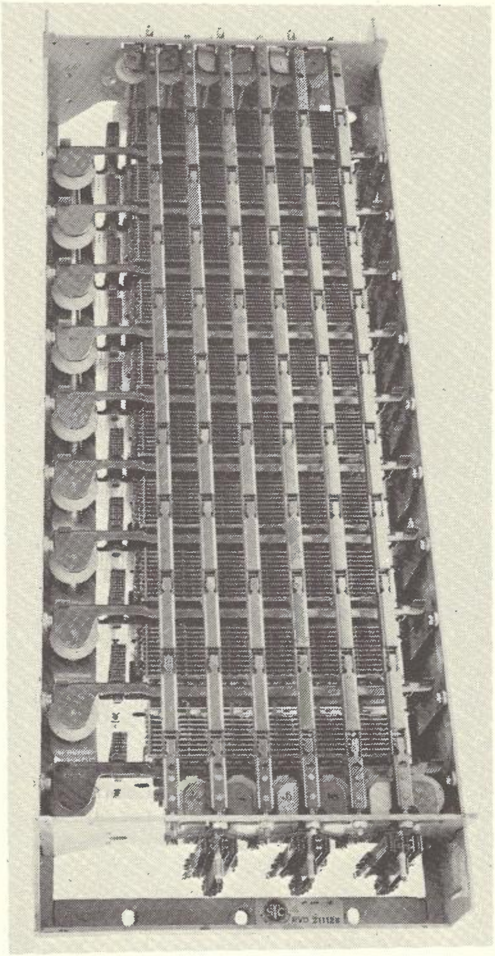
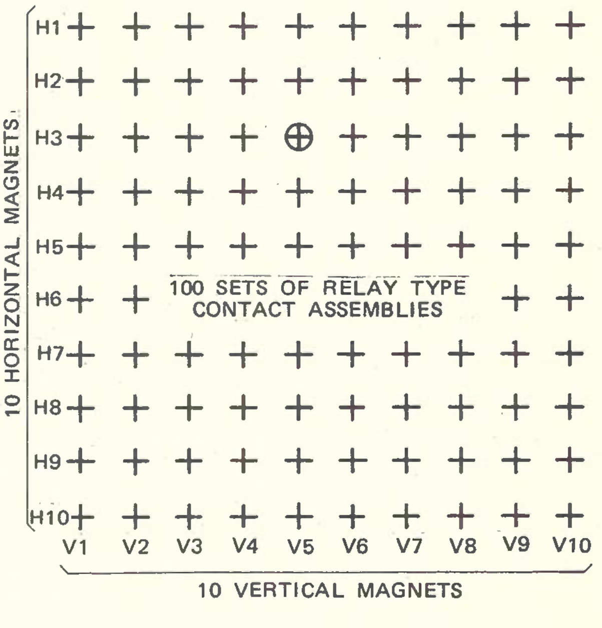


Fig. 3-18 — (a) Crossbar Switch



\+ REPRESENTS LOCATION OF A SET OF RELAY LIKE SPRING CONTACT ASSEMBLIES

⊕ CONTACT ASSEMBLY DEFINED BY H3 & V5

(b) Principle of Crossbar Switch

Electronic Switches As Crosspoint Arrays

The development of crosspoints using active electronic devices has been the subject of lengthy and very extensive investigations. Such devices as transistor switches are inherently capable of being used, but so far all attempts have either been inferior in performance to mechanical contacts, or so expensive as to be impracticable except in situations where they have some particular advantage. Some, for example have been used in warships, where extreme reliability under severe conditions of mechanical shock is imperative. They have potential applications in IST (Integrated Switching and Transmission) exchanges in which speech is switched in pulse code modulated form, and very wide frequency ranges are involved. Devices of this kind may well be part of the switching systems of the future.

THE EXCHANGE AS A COLLECTION OF CROSSPOINT ARRAYS

Small Exchanges

A large part of the cost of an exchange is made up of the cost of crosspoints and the mechanisms directly associated with them; therefore switching configurations which minimise the number of crosspoints are likely to lead to economical exchanges. However, the cost of controlling the complex switching configurations which are necessary to get an absolute minimum number of crosspoints is also an important factor.

The simple array of Fig. 3-7 can be used for a telephone exchange and is used for small terminal exchanges. Fig. 3-19 shows the switching stage of a 30 line ARK511 exchange.

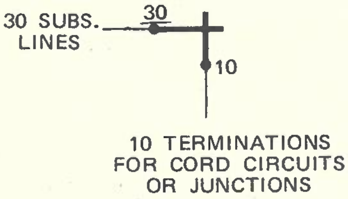


Fig. 3-19 — Crosspoint Diagram 30 Line Exchange

This exchange is of the form shown in Fig. 3-1, and requires both way control of switching, but as it uses crossbar switches with marker control this is not very difficult. Moreover for exchanges of such small size most junctions are bothway. The ARK511 series of exchanges is built in sizes up to 90 lines, requiring a 90 x 15 crosspoint array; but it will be realised that the number of crosspoints is roughly proportional to the square of the number of lines and so it is necessary to use a different technique for larger exchanges.

A fairly simple exchange using two stages of switching is the 100 line ARK521 exchange, and Fig. 3-20 shows a method of interconnection which is only slightly different from that exchange and caters for 90 subscribers.

In this scheme there are 4 arrays of crosspoints arranged in two stages designated SLA and SLB. There are 3 SLA arrays each with 30 terminations for subscribers and 6 or 7 terminations which are connected to the SLB stage. The SLB stage array is of 20 x 20 crosspoints with one side connected to SLA switches and the other side to junctions or cord circuits.

An outgoing or incoming call between any subscriber and any junction can be established by operating one crosspoint in the appropriate SLA array, and one in the SLB array. Similarly a call between two subscribers via a cord circuit requires the operation of 4 crosspoints. This exchange has a total of 20 terminations for junctions or cord circuits and requires 1000 crosspoints, compared with 90 x 20 or 1800 required with a single array.

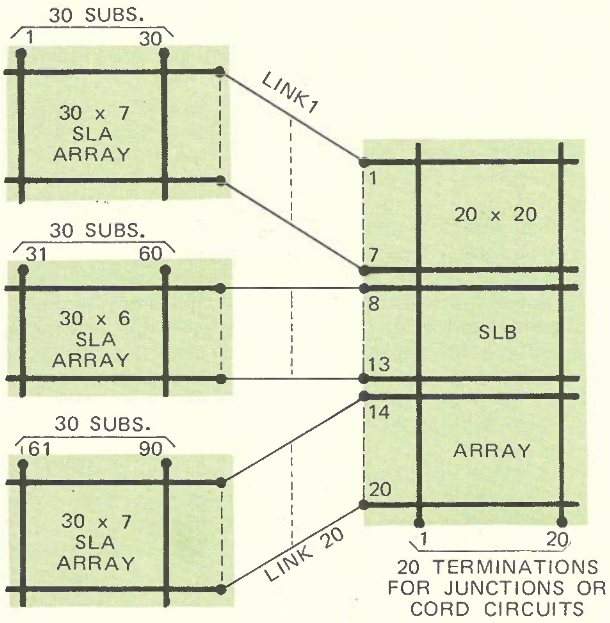


Fig. 3-20 — Crosspoint Diagram 90 Line Exchange

It has one limitation which does not apply to a single stage array in that only 6 or 7 simultaneous calls are possible within any group of 30 subscribers; but subject to that limitation any idle subscriber can be connected to any idle junction or cord circuit. It is, of course, a more complex system to control than a single stage array, and the saving in number of crosspoints is gained at the cost of a more expensive control system.

One important feature of this particular pattern of interconnection is that the individual arrays can be controlled independently. For example, a call from a particular junction to a subscriber in the 1-30 group can be connected over any of the links 1-7, and any idle link in that set can be chosen, without needing to consider the next step in switching the call.

On an outgoing call or the outgoing section of a local call the SLA stage is used to switch the subscriber to one of the links to the SLB, and the SLB stage switches that link to a specific outgoing junction or cord circuit. On an incoming call the SLB stage switches the incoming junction to one of the links to the desired SLA stage, and the SLA stage switches the link to the called subscriber's line. In this system three different kinds of switching function can be identified.

On an outgoing call, the SLA stage is a traffic concentrating device, or 'preselector'. In this application all the outlets are identical, and the function is to switch to **any** free outlet.

Secondly, on outgoing calls the SLB stage outlets form a number of different sets or groups, i.e., cord circuit inlets, and one or more sets of junctions, and this stage is required to switch to a free outlet within a specified group. This type of switching is called 'group selection'. Similarly on incoming calls the SLB stage has to select a link in the group of links giving access to a particular SLA array, and is again a group selector, but with inlets and outlets transposed.

The third type of selection operates in the SLA stage on incoming calls. In this case switching is required to a specific outlet and this is 'individual' or 'final selection'.

Large Exchanges

Preselection

In larger exchanges these different functions are performed in individual specialised units of equipment with more than one crosspoint array for each function and different sizes of crosspoint arrays and interconnection methods are needed for each purpose.

The simplest switching requirement is preselection for which the most important application is in connecting subscribers to group selectors in order to reduce the numbers of selectors required. This is only worth while if the saving in selectors is greater than the cost of preselection, and the objective is an optimum design in respect of the combined cost of pre-selection and group selectors. Three basic arrangements have been used, known as full availability, graded access, and link trunking. These three alternatives will be examined with specific application to a group of 1000 subscribers originating 40E of traffic.

Full availability: In a full availability system a single crosspoint array is used to give each subscriber access to every group selector, and with full availability 57 selectors are required to give a grade of service of .002 or one lost call in 500. The interconnection would require a 57 x 1000 crosspoint array which might take the form of 1000 switches of 57 outlets each and is shown in Fig. 3-21(a).

Alternatively as in Fig. 3-21(b) the 1000 subscribers could be treated as four separate blocks of 250 each with full availability access to a separate block of group selectors. Each block would then require 20 group selectors for the same grade of service, or a total of 80, but the number of crosspoints is reduced to 4 x 20 x 250 or 20,000. Therefore, 23 extra selectors are needed, as the price of saving 37,000 preselector crosspoints. Given the cost of the selectors, and of the various alternative crosspoint arrays, a choice between them can be made on economic grounds.

Graded Access: In a graded access system, also known as an interconnected system, (*) the subscribers are again divided into a number of separate units, each having access to some of the group selectors but not as isolated blocks. For example, as in Fig. 3-21(c) the subscribers could be divided into 8 units of 125, each unit having access to 20 of the selectors via a 125 x 20 crosspoint array, or 125 twenty position switches, but with some, or all of the selectors connected to more than one array. If an efficient method of connecting the switch outlets to group selectors is used, 68 selectors will be required for .002 grade of service. In this case the number of crosspoints in the preselector array is again 20,000 as in the second full availability case but the number of group selectors has been reduced from 80 to 68.

Two main types of interconnection are in common use, depending on whether the switches test selectors in sequence or at random, both giving similar efficiency.

Fig. 3-22 shows an interconnection scheme for sequential testing, connecting 22 switches to the outlets of 4 arrays with 10 outlets each and the principle is that the earlier choices are accessible to only one group of subscribers, while the later choices are progressively shared by larger numbers of subscribers with the last choices accessible from all subscribers. The theoretical basis for this can be found in any text on telephone traffic engineering.

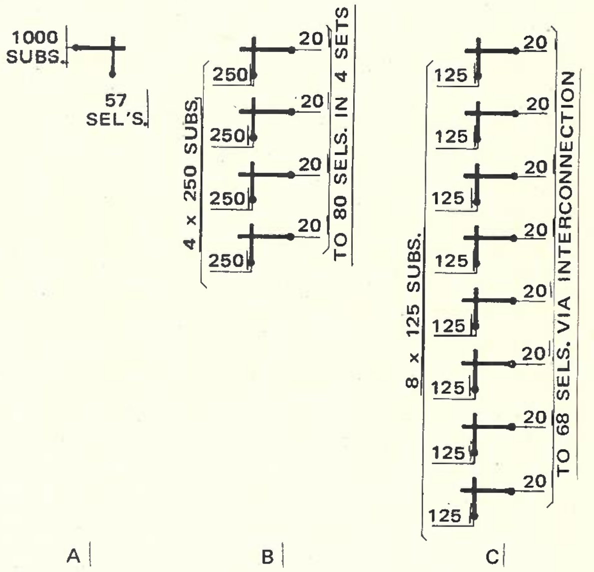


Fig. 3-21 — Single Stage Pre Selection

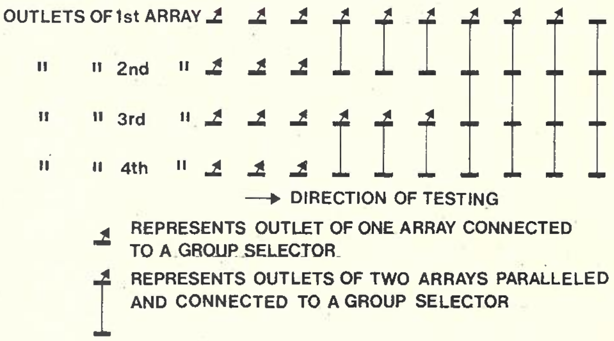


Fig. 3-22 — Homing Type Grading

The method of interconnection used for switches with random selection is based on an entirely different principle. The grading is arranged so that, as far as possible every selector is reached from the same number of sources, and that the number of selectors shared by two groups should be the same for any pair of groups. These principles are illustrated by the small grading shown in Fig. 3-23.

In this example there are 4 groups of switches, each with 6 outlets, and with the outlets interconnected to 12 1st selectors. It can be determined by examination that each selector is reached from two groups of switches, and that every pair of groups shares access to 2 selectors. In this case the requirements are fully met, but in many practical cases it is only possible to partly satisfy them. This type of interconnection is known as a homogeneous interconnection if this requirement is fully satisfied.

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* The expressions "grading" and "interconnection" are interchangeable, but it is more usual to call a sequential testing system a grading, and a random testing system interconnection.

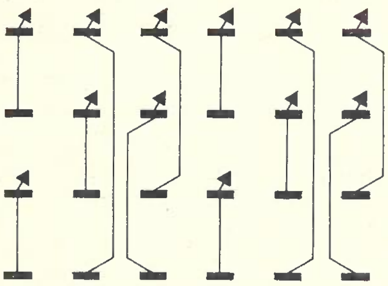


Fig. 3-23 — Non Homing Type Interconnection

More details on the method of computing the traffic capacity of gradings and of the design rules and procedures will be found in standard texts on traffic engineering. Fig. 3-24 shows the traffic capacity of a range of gradings, from which it can be seen that efficiency rises with availability, and an availability of at least 10 is needed for reasonable efficiency, while on the other hand the rate of increase of efficiency beyond an availability of 20 or 30 is relatively small.

(Note: In the following discussion the term 'stage' is used to describe both a complete switching stage (e.g. 1GV) comprising a number of 'partial stages' and these 'partial stages' themselves (e.g. GVA, GVB). The precise meaning will be obvious from the context in which it is used and 'partial stage' will be used only where essential to conform with accepted APO practice).

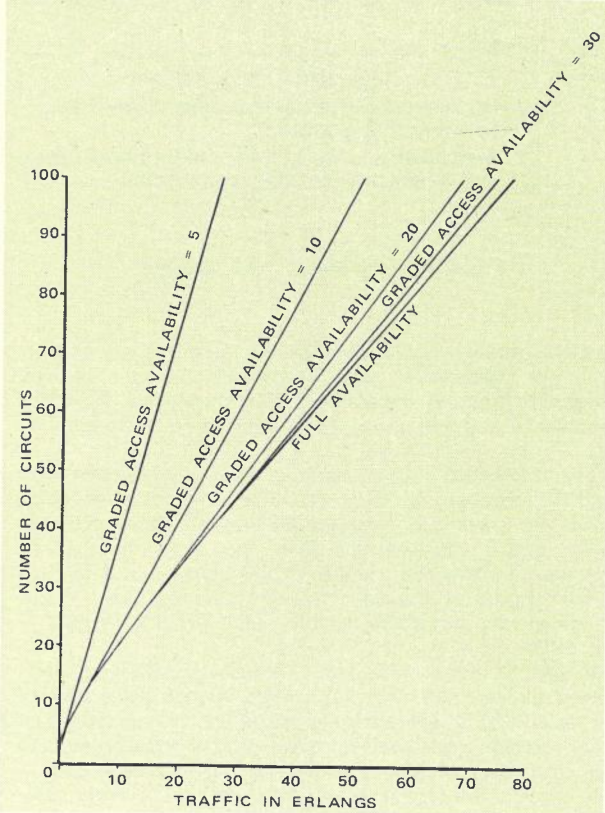


Fig. 3-24 — Traffic Capacity of Gradings

Link trunking: Link trunking makes use of a different principle and requires at least two stages (in this case 'partial stages') of switching, and a typical configuration is shown in Fig. 3-25, where because of the number of interconnections between the two stages, only sufficient have been shown to indicate the pattern.

The subscribers have been divided into sets of 50, and the access for the first set of 50 is shown in full detail. They are connected to a 50 x 10 crosspoint array or selection stage giving full availability access to 10 'links'. Each link connects one outlet to an inlet of a second crosspoint array each of which gives access to 6 1st selectors. Because each link is connected to a different secondary array, access is available to a total of 60 1st selectors.

However, although all selectors can be reached by any subscriber the system is not equivalent to a full availability system due to a phenomenon known as 'internal blocking'. In this particular configuration there is only one link from a particular primary array to a particular secondary array, and if this is in use for one call, any idle group selectors connected to that secondary array are inaccessible from that primary array. Consequently, congestion may occur even though there are idle selectors and the number of group selectors must therefore be increased to compensate. The calculation of the traffic capacity of link trunking systems is complicated and involves consideration of the state of the links and the outlets of the preselectors. However, a useful approximation of the performance of the system can be obtained by the following procedure:

If the first stage arrays have n(1) outlets and the second stage arrays have n(2) outlets, then the total number of outlets available from one inlet is n(1) x n(2). However, a proportion of the

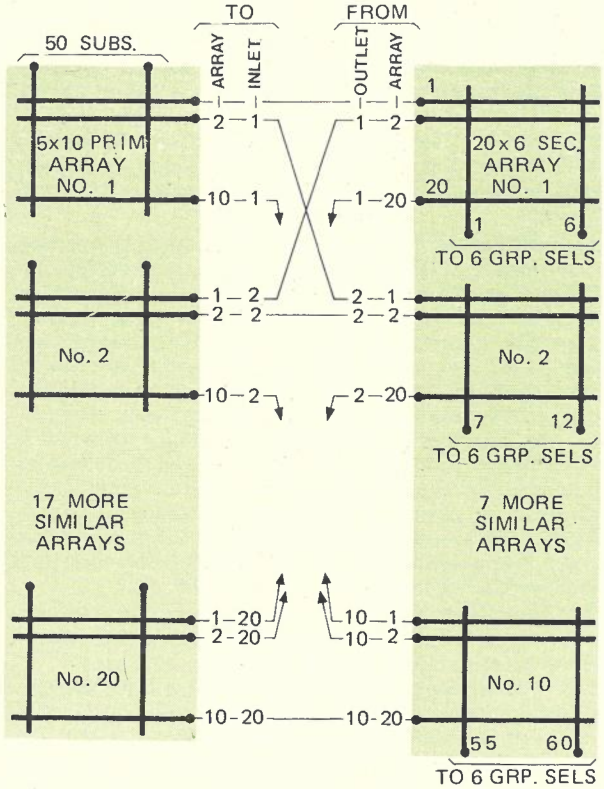


Fig. 3-25 — Link Trunked Pre Selector

$n(1)$ outlets will be occupied and if the traffic per link is 'a' erlangs, then the average number of occupied links is $n(1) \times a$, and an average of $a \times n(1) \times n(2)$ secondary stage outlets will be inaccessible due to internal blocking. Therefore the system may be expected to behave like a grading with availability $(1-a) \times n(1) \times n(2)$: This approximation method is described as 'effective availability', and comparison with exact calculations shows that it is usually fairly close.

In the case under discussion, there is 2E of traffic from each primary group, and the traffic per link is 0.2E. Therefore the 'effective availability' is $0.8 \times 10 \times 6 = 48$. This linked trunk system with 11,200 crosspoints is therefore as good as a single stage interconnected system with an availability of 48, which would require 48,000 crosspoints, more than 4 times as many.

In terms of crosspoint economy link trunking is the most powerful technique known, but it involves a more complex control problem. The choice of a path through the system involves examination of both the stages at once, and an outlet from the first stage must be chosen which is not only free, but which also leads to a secondary group which contains at least one idle outlet. This requirement of selecting a link satisfying two (or even more) conditions simultaneously is known as 'conditional selection'. If instead of this selection process, any free link is selected, the call effectively tests only the outlets of one secondary stage (6 in this case) and the efficiency is no higher than for a grading of this availability.

Link trunking and grading may be combined if desired, and in the case under consideration this would permit either a reduction in crosspoints to give an effective availability of as low as 20 or 30, or the interconnection of the outlets of a number of 1000 line blocks in a larger exchange.

Group Selection

Two Stages: In Group Selection it is necessary to divide the outlets into a number of groups or routes, and with a single stage array this requires a rather large number of crosspoints per inlet. One common group selector formation in step-by-step systems uses the previously described 200 outlet switch, with the outlets divided into 10 'levels', or routes of 20 outlets each.

The outlets for each route can be graded precisely as described for a pre-selector, giving satisfactory efficiency on the outgoing routes. In order to produce a switch with 200 outlets or crosspoints a fairly complex mechanical structure is required, but is is possible to incorporate into this structure a large amount of 'electromechanical logic', which helps to keep down the total cost of the step-by-step system.

For group selection the use of link trunking gives an even greater reduction of crosspoints than in the case of preselection. A widely used link trunked group selector is the GV stage of LME crossbar, illustrated in Fig. 3-26.

There are two stages in this selector with 13 x 20 and 14 x 20 arrays in the first (GVA) stage and 6 x 20 arrays in the second (GVB) stage, giving access to 400 outlets. However, because of internal congestion, the effective availability is a better guide to its capabilities. With typical traffic each inlet carries 0.6E and the average traffic per link is then $(0.6 \times 13\text{-}1/3)/20$ or 0.4E, giving, an effective availability of $400 \times (1-0.4)$ or 240. The total number of crosspoints is 4000 for 80 inlets or 50 crosspoints per inlet which is about one fifth of the crosspoints needed in an equivalent single stage array. With an effective availability of 240 this configuration is roughly equivalent to a 10 x 20 outlet bi-motional group selector, and can be used as a group selector by suitably arranging the outlets into routes. The method of allotting outlets to routes is an important factor in minimising internal congestion, and this is best explained by considering how to allot 20 outlets to one route. The 20 outlets could be chosen all from one GVB array, or 10 from each of two GVB arrays, 5 from each of 4, 4 from each of 5, 2 from each of 10 or one from each of 20 GVB arrays. In each case the numbers of outlets accessible at a particular time will range between 20 and 0, depending on the state of the links, and in each case the long term average number of accessible outlets will be 12. However, the time distribution of the number of accessible links will be different for each case. The different cases are illustrated in Table 1. In case 1 with all outlets in the same array, for 60% of the time the only suitable link will be idle and all outlets accessible, but for the remaining 40% of the time this link will be in use and access to all outlets blocked, so that the grade of service cannot be better than 0.4. In case 2, access to all outlets will be blocked for only 16% of the time, and for a further 48% of the time only one link will be idle and access will be available to only 10 of the 20 outlets. This clearly gives a better chance of reaching an idle outlet and it would appear that case 6, where each link is capable of being used, and would only block one outlet of the route if it is busy, is likely to give least congestion. This can be proved rigorously, and a general rule for link trunked systems is that as far as possible, traffic 'streams' should be spread over as many links, and link combinations as possible.

In the same way if it is desired to allot 10 outlets to a route, they should be chosen from 10 GVB arrays, while if it is desired to allot 40, or 60, or 80, they should be chosen 2, 3 or 4 from each of the arrays.

The control of a link trunked group selector is a fairly complex problem, as it is necessary to find an idle outlet which can be reached via an idle link. This cannot be done without examining simultaneously and in a co-ordinated manner the outlets from both the first and second

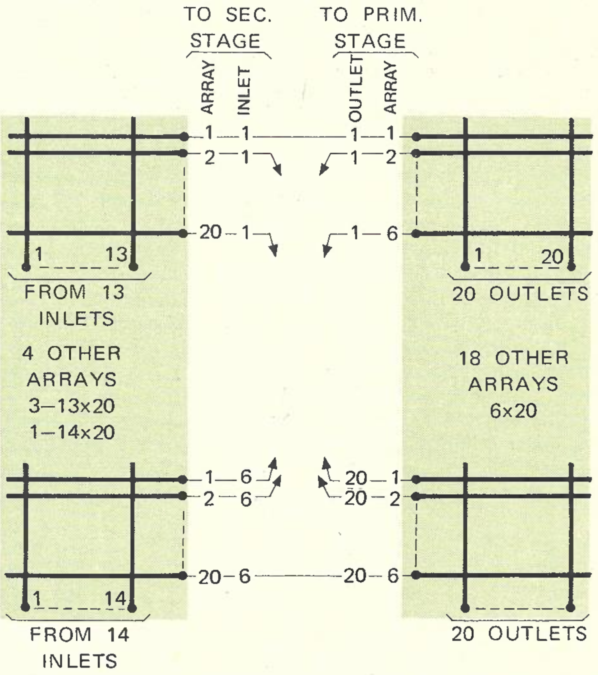


Fig. 3-26 — Link Trunked Group Selector

TABLE 3-1

Allocation Method	No. of Circuits Blocked by Link Congestion	Probability
Case 1. All outlets on One GVB Array	0	0.6
	20	0.4
Case 2. Outlets spread Over two GVB Arrays	0	0.36
	10	0.48
	20	0.16
Case 3. Outlets spread Over four GVB Arrays	0	0.1296
	5	0.3456
	10	0.3456
	15	0.1536
	20	0.0256
Case 4. Outlets spread Over five GVB Arrays	0	0.0778
	4	0.2592
	8	0.3456
	12	0.2304
	16	0.0768
	20	0.0102
Case 5. Outlets spread Over ten GVB Arrays	0	0.0060
	2	0.0403
	4	0.1209
	6	0.2149
	8	0.2508
	10	0.2006
	12	0.1115
	14	0.0424
	16	0.0106
	18	0.0016
	20	0.0001
Case 6. Outlets spread Over 20 GVB Arrays	<11	0.8722
	11	0.0710
	12	0.0355
	13	0.0145
	14	0.0049
	15	0.0013
	>15	0.00031

stage. It is **not** possible to select any idle outlet from the first stage blindly, without looking ahead to see what the consequence is of selecting that particular outlet. This is both the inevitable penalty of adopting link trunking and the source of its strength. The question of control will be elaborated further in discussing detail design of exchanges, but it can be seen that the control cannot be vested in individual switches and that there is no such thing as a step-by-step linked trunked system.

The method of drawing out the interconnections of two stages in a link trunked system in detail is useful for illustrating the principles, but is too elaborate for most applications and impractical for showing more complex systems. The interconnection between stages of any link trunked system is always systematic, to give a maximum degree of uniformity, and therefore it need not be shown in detail. A very condensed method which is generally used is shown in Fig. 3-27.

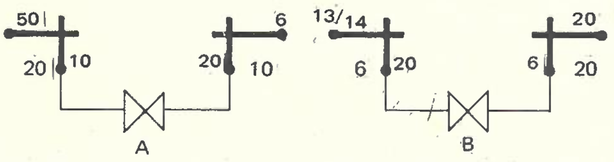


Fig. 3-27 — Method of Showing Link Trunking

This shows both of the link trunked schemes so far discussed in skeleton form. The diagonal cross symbol indicates an interconnection between the two arrays of the form which has previously been shown in detail, while the two sets of arrays are each shown by a single symbol. The numbers indicate the size of the array, and the number of similar arrays. For example, in Fig. 3-27(a), the first stage is made up of 20 arrays, each 50 x 10, so that there are 1000 subscribers and 200 links and the second stage is made of 10 arrays, of 20 x 6 which connect the 200 links to 6 outlets. Fig. 3-27(b), likewise shows the make up of the group selector shown in more detail in Fig. 3-26.

The systems shown so far have only one link from each first stage array to each second stage array. In some circumstances it is possible, and desirable, to provide two or more links between each combination of arrays. For example, if a group selector required only 200 trunks to be terminated on its outlets, the selector shown in Fig. 3-26 would have half its outlets idle. If the spare outlets could be multipled with working outlets, in such a way that two different links could be used to reach each outlet, internal congestion would obviously be reduced. One systematic way to do this would be to parallel the outlets of the first and second GVB arrays and likewise the third and fourth, fifth and sixth, etc. The effect of this is to make the first two 6 x 20 GVB arrays into a single 12 x 20 array, with 2 links from every GVA array and similarly, with the remaining arrays There are now 200 outlets, instead of 400, but the internal congestion is lower. If each link carries 0.4E then the probability that both links are occupied, and that the relevant outlets are inaccessible is only $(0.4)^2$ or 0.16.

This particular configuration can be represented by Fig. 3-28. The fact that 2 links are provided between every pair of arrays can be deduced by calculation, or may be specified in the way shown.

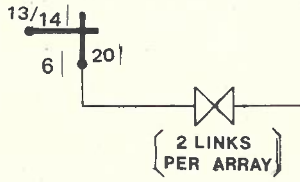


Fig. 3-28 — Multiple Links

Three or More Stages: In a 2 stage system there are two methods of controlling internal congestion. In the GV stage under discussion the number of links from each GVA array is greater that the number of inlets, thereby reducing the traffic per link and reducing internal congestion by expansion. The other technique is the use of multiple links, but can only be used where the number of outlets needed is small enough to allow it to be done. Expansion causes the number of second stage crosspoints to be increased in proportion and thus the GV stage has 50% expansion, and the total crosspoints in GVB are 50% greater than in GVA. Multipled links on the other hand cause a reduction in the total outlets, which cannot often be tolerated. There is therefore a practical limit to what can be achieved with only two link trunked stages and beyond this point it is necessary to use three stage systems.

A first attempt at a three stage system is shown in Fig. 3-29, based on 20 outlet switches. The first two stages can be thought of as a conventional 2 stage system with 400 inlets and 400 outlets. The third stage is made up of 400 arrays each 1 x 20, giving access to 8000 outlets. Naturally, 400 inlets will not fully load 8000 outlets, and a number of similar units would have their outlets multipled.

Any inlet can reach any of the 400 links to the third stage, via one specific path, and therefore any one of the 8000 outlets. However, to reach a specified outlet it is necessary for a specific link between the first and second stages, and another specific link between the second and third stages, to be idle. There is no expansion in the stages so the traffic per link is the same as the traffic per inlet, and as before this will be assumed to be 0.6E per circuit. The probability that the two links required to reach a specific outlet from a specific inlet are both idle will then be $(1\text{-}0.6)^2$ or 0.16, and the probability of blocking is 0.84, which is inconveniently large.

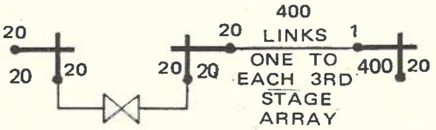


Fig. 3-29 — Principle of 3 Stage System

At the same time the number of outlets is too large for most applications, so the technique of multipled links can be used to create a more useful design. By multipling the outlets in five, the total number of outlets will be reduced to 1600, each of which is accessible from a specified inlet over 5 different paths. The probability of blocking is now $(0.84)^5$ or 0.42 similar to that of the two stage selector previously described. The effective availability is 1600 (1-0.42) = 928, and is achieved with 60 crosspoints per inlet, compared with the 50 crosspoints per inlet of the two stage. As in this example, three stage link trunked systems are often more economical in crosspoint usage for a given performance than two stage systems.

By selecting different combinations of expansion, and multipling of paths, it is possible to get a wide variety of different three stage systems, with differing degrees of internal blocking, and a probability of blocking between specified inlets and outlets as low as 0.1 can be achieved.

Fig. 3-30 shows the formation of the 400 inlet, 1600 outlet, 3 stage system being discussed. It is not possible to show in detail the method of interconnecting links as there are far too many. The principle, as usual, is to keep the maximum possible degree of independence between paths, and as there are 20 second stage arrays the 20 links from each first stage will be allotted one per second stage, thus ensuring that every second stage outlet is equally accessible from every inlet. The 400 second stage outlets must be divided into sets of 5, each to one of the 80 third stage arrays and each set of 5 inlets must be reached from 5 different links, which requires them to be fed from different second stage arrays. Again, in allotting outlets to routes, this must be done in such a way that the paths used for each outlet are different. In a practical system outlet allocation rules are specified in a manner which achieves the necessary result without requiring examination of the internal structure, and reduces this work to a routine.

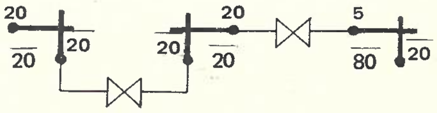


Fig. 3-30 — 1600 Outlet Three Stage System

It hardly needs pointing out that the control of a 3 stage link system is considerably more complex than a 2 stage system, and the adoption of a 3 stage system is never lightly undertaken. However, for some applications the cost of the control circuitry is recovered many times over in the resulting economics in the total system.

It is also possible to go beyond three stages, and crossbar systems with a 4 stage group selector system are in use, particularly for large trunk exchanges. Four stages is the practical limit with relay logic in the control circuits, and even this is only achieved by permitting some compromise with the ideal interconnection of stages. However with computer techniques for the control circuits it is possible to control link systems with a large number of stages and such systems are coming into use. The extension beyond 3 stages follows the same basic principle, but there is a wider variety of possible configurations. In such a system the designer has under his control a number of parameters, the most important being:

- size(s)
- traffic per link
- number of stages
- degree of multipling of paths.

Entraide: A more elaborate configuration which is sometimes used for group selectors is known as 'entraide' and is characterised by links from one stage to an earlier one, used on an overflow basis to carry traffic which encounters internal congestion on the normal path. Fig 3-31 shows the interconnection of the 'entraide' selector stage used in the Pentaconta system; and it can be seen that it includes a normal 2 stage link trunking configuration with 2 links from the first stage to every second stage. In this form it would give access to 1000 outlets, with about 25% probability of any second stage array being unavailable due to internal congestion. In addition to this there is an 'entraide' route of 10 outlets from the first stage, each of which connects to an inlet of a differentent first stage array, and therefore has further opportunities for reaching the desired outlet. The system can also be drawn in the form shown in Fig. 3-32, and in this form it is seen to be a combination of a 2 stage and a 3 stage system. The 3 stage system is only used if the links needed for 2 stage switching are occupied and therefore only a small amount of traffic is switched via 3 partial stages.

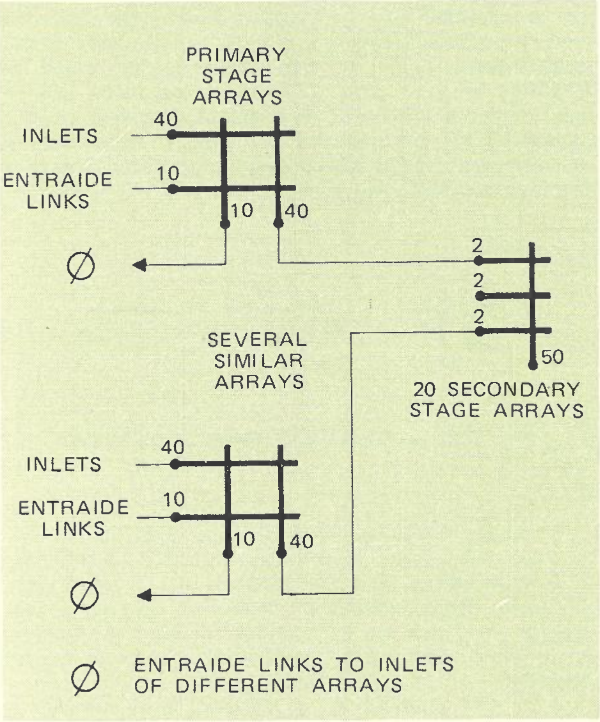


Fig. 3-31 — Selector with Entraide

The main application of 'entraide' is to bridge the gap between the capacity of a 2 stage and a 3 stage system, and although it could also be used with a larger system, these have so much more flexibility in adjusting capacity and blocking by variation in link loading that there is no actual case where entraide is used with 3 stages in the basic system.

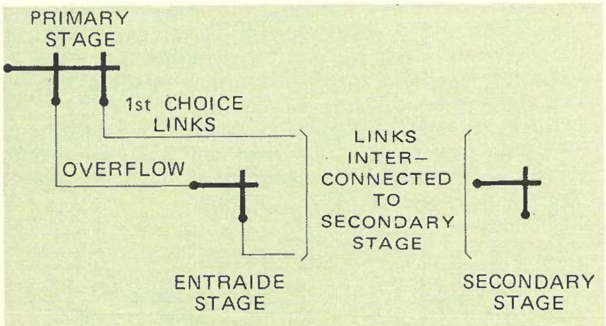


Fig. 3-32 — Alternative Entraide System

Final Selection

Final selection requires access to every outlet, and this is not possible with the large values of internal congestion usually found in link trunked systems. If a large enough number of multiple paths is provided the internal congestion of a 3 or more stage system on a call to any specific outlet can be made low enough (say 0.002) to allow the system to be used as a final selector. However, if such a system is examined it will be found that the links to the last array in the system act as independent groups and the system can be treated as a combination of a group selector and final selectors. This can be seen from Fig. 3-33 which shows the arrangement of the combined final selector/preselector stage used in ARB Telex exchanges.

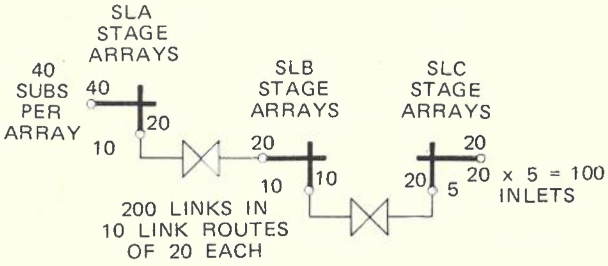


Fig. 3-33 — Link Trunked Final Selector

There are 3 stages in the system designated SLA, SLB and SLC. The subscribers' lines are connected to 10 separate SLA arrays of 40 x 20, and since every call to a particular subscriber must use the array to which it is connected, the SLB and SLC stages can be regarded as a 2 stage group selector with access to 10 routes, each of 20 outlets. The control of this system is in fact divided into two stages, one of group selection using SLC and SLB, and an independent step of final selection using SLA. It can be appreciated that a link trunked final selection system must have at least 3 stages.

Optimum Size of Crosspoint Arrays

Economical use of crosspoints is the basic reason for using any link trunked system and there is therefore a need to compare the effectiveness of different configurations, and in particular to decide on an optimum size of crosspoint array. This can seldom be done by direct comparison as two configurations based on different sized arrays will seldom give identical facilities.

A method which is of more general application, although at the same time rather less specific, can be derived by considering the multiplication of the number of effective paths achieved by a specific array.

In an $n \times n$ array, with traffic per inlet and per outlet of 'a' erlangs, the average number of effective outlets, i.e., those not blocked by internal congestion, is $n(l-a)$, and the array, if used as an intermediate switching stage therefore multiplies the number of paths through the system by $n(l-a)$, at a cost of (n/a) crosspoints per erlang. Now in comparing arrays, since the arrays act to multiply the paths, two arrays will give a multiplication of $(n(l-a))^2$ for twice as many crosspoints, and a reasonable figure of merit (FOM) could be created by dividing the logarithm of the multiplying factor by the crosspoints per erlang, i.e., $\text{FOM} = (a/n) \log (n(l-a))$.

It can be shown that this is a maximum for $n = 2e$ and $a = 0.5$ and its value is $1/4e$.

Therefore a normalised figure of merit, having a maximum value of 1 is:

$\text{FOM} = 4ea/n \log (n(l-a))$.

There are more rigorous proofs that this does in fact represent the efficiency of crosspoint utilisation in the central stages of the type of multi-stage systems under consideration. However, its applicability is confined to such situations.

Fig. 3-34 is a plot of contours of this figure of merit, against circuit loading and array size, and it can be seen that the peak at $n = 5.44$ and $a = 0.5$ is extremely broad. Crosspoint efficiency is only one aspect of switching system design and the equally important one of control circuit complexity tends to favour systems with fewer stages obtained by selecting larger values of n and lower values of a.

The earliest switching systems were developed before link trunking was a practical tool, and were confined to stage by stage control. For this type of interconnection, switches of at least 100 outlets are needed, and this requirement led to the development of designs in which the crosspoints were relatively inexpensive, and were positioned in a two co-ordinate structure. Much of the control logic took the form of mechanical devices, incorporated in the switch; for example, a vertical magnet which would respond directly to dialled impulses, and select a level. The crosspoint efficiency of a 100 outlet switch with 0.6E loading is seen from Fig. 3-34 to be about 25%; but nevertheless the low cost construction of the crosspoints themselves and the economy of single stage control enabled such systems to compete with crossbar for a long time.

The crossbar switch was invented in 1913 and its main characteristics are that the crosspoints are in the form of relay contacts, operated by a relay like mechanism. Originally it was envisaged that each switch would be used as a single selector of 100 outlets, replacing a Strowger group selector. It was demonstrated to be a more reliable mechanism, and to have superior crosspoints, but it was so costly in this form that it languished for some 25 years.

The development around 1940 of practical systems of link trunking, making efficient use of switches of smaller capacity, was necessary before crossbar could compete economically with systems using mechanically operated switches; but from this point crossbar fairly rapidly took over almost the whole field of automatic switching. In Australia the LME system was adopted as standard, using a switch which provides a 10 x 20 crosspoint array. It can be seen from Fig. 3-34 that the crosspoint efficency of systems using this selector is very high, but in practice, to reduce the number of stages of selection a link loading around 0.4 which is lower than optimum is used, and occasionally switches are parelleled to give an availability of 40 while for CAX's a variant giving 30 outlets per vertical has been developed.

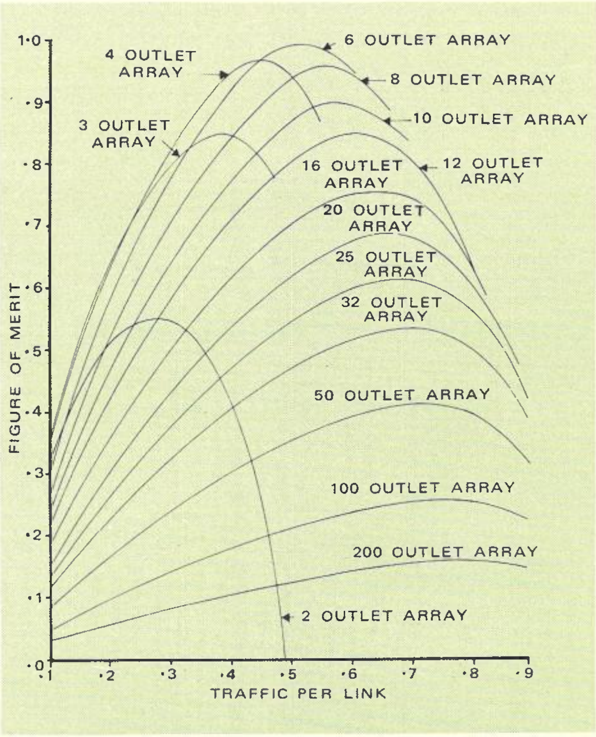


Fig. 3-34 — Figure of Merit for Link Trunking

A number of other switches are in use in Australia for PABX's, including the Pentconta switch of 52 outlets. This switch is the largest size crossbar switch regularly used for link trunking systems, and permits some very useful configurations, particulary in large exchanges, and at the same time is just enough for stage by stage control. As a point of fact, most Pentaconta PABX's use stage by stage trunking, which is more flexible in PABX applications in sizes up to about 1000 lines. Most other crossbar switches are of 10 or 20 outlets, but when 10 outlet switches are used they are frequently combined to give a 20 outlet or larger unit. Two extreme cases are a 5 outlet unit (which is always multipled to give a larger size), and a 100 outlet switch developed by Bell, Antwerp, which is hardly ever used in a link trunked system.

Stored program control (SPC) exchanges, usually called 'electronic exchanges' which are only in service in a few countries, but seem likely to take their place as the major type in a few years, use an array of reed relay crosspoints. In these systems there is less difficulty in controlling a link trunk system with a large number of stages, and there is a greater emphasis on efficiency of crosspoint usage. The most frequently used array is an 8 x 8, which is very close to optimum, and is convenient for control by a computor using binary arithmetic.

However, because there is no common mechanism to impose constraints, it is possible to build the arrays from almost any convenient sub. units, and 4 x 4 sub. units are often used giving the possibility of assembling, such size arrays as 8 x 8, 12 x 12, or 16 x 8, as required. This also allows an array to be increased during the life of an exchange from 4 x 4 to 8 x 8, or from 8 x 8 to 16 x 16, and in a large exchange this procedure can give a much more orderly method of extension than is possible with crossbar switches of fixed size.

Chapter 4 – Principles of Common Control

INTRODUCTION

THE NEED FOR COMMON CONTROL

CONTROL SYSTEM TRAFFIC

QUEUEING OF MARKERS

REGISTERS AS BUFFER STORES

CONTROL SYSTEM (INFORMATION) SIGNALLING

DEVELOPMENT OF COMMON CONTROL SYSTEMS

INTRODUCTION

Chapter 3 showed how switching units with the functions of pre-selection, group selection, or final selection can be constructed by using either mechanical switches with a large number of crosspoints, or crossbar switches or other devices with a limited number of crosspoints in a link trunked configuration. A crosspoint diagram of a relatively small exchange, in which all three types of selection were required, was also presented.

Larger exchanges are built up of a number of the above types of unit to provide the necessary interconnection of its terminations, together with a suitable means of controlling them to set up connections as ordered by the subscriber. These two parts are called the speech path network and the control equipment respectively, and both parts take quite different forms in step by step and crossbar networks.

In a step by step exchange or network, each selector function is performed in a single stage switch, and the necessary control equipment is permanently associated with each switch. This is illustrated in Fig. 4-1(a), which shows how a step by step exchange of 1000 lines could be constructed, if the requirement was limited to connecting these lines together, with no access to telephones in other exchanges.

Every subscriber's line is connected firstly to a uniselector, used for originating calls, and secondly to the bank contacts of a group of final selectors, used for terminating calls to all subscribers having the same hundreds digit in their number. When a call is originated, the uniselector belonging to the calling line searches for and switches to a free group selector. The first digit dialled (hundreds) steps the group selector wipers to the corresponding level, and the selector searches over that level to one of the free final selectors serving that hundreds group. The second (tens) digit steps the final selector to the "tens" level, while the third (units) digit steps it around to the position corresponding to the called subscriber's line. Figs. 4-1(b) and 4-1(c) show progressively in less detail the configuration of the same exchange. The form shown in Fig. 4-1(c) is known as a trunking diagram and is used extensively to represent the main features of an exchange.

The trunking diagram of a 2000 line step by step exchange is shown in Fig. 4-2 and it can be seen that there are two stages of group selection. The first stage is operated by the thousands digit and selects a free second selector of those serving the required thousands group. Subsequent digits operate the second and final selectors as before. In large step by step exchanges and networks, each digit of the subscriber's number has to operate a separate selector stage and this characteristic is the reason for the designation "step by step".

In a crossbar system all the switching logic is external to the actual switches, in common control devices whose use is shared by many switches; the dialled digits do not directly control switching stages. One result of this is that the switching configuration is usually not a direct representation of the numbering of the network. Fig. 4-3(a) shows, without any details of the control mechanism, the speech path network of a 1000 line crossbar exchange located in a multi-exchange network.

There are two separately controlled link trunked stages. One is a combined pre-selector/final selector unit known as a subscribers (SL) stage which serves 1000 subscribers and can make two kinds of connection. On outgoing calls it connects the calling line to a group selector inlet using two partial stages as a pre-selector, while on incoming calls it connects a junction to the subscriber using all four partial stages. (For a larger exchange each 1000 subscribers has a separate SL unit). The other is a group selector (GV) stage, with two partial stages.

An outgoing call is connected via SLA and SLB preselection stages to a free group selector inlet where a "register" is temporarily connected to record the number dialled. After the full number of the called subscriber is dialled the register directs the group selector to select either a suitable outgoing junction or a link to the final selector. If a junction has been selected (because it is a call for another exchange) the next selector stage in the distant exchange or tandem can still request any or all digits of the called number from the register if necessary to control further switching. If it is a local call, a link to the SL stage is selected and only the three last digits are forwarded to the SL stage to allow it to switch to the called subscriber. The number of switching stages is independent of the number length since 3 or 4 digits may be used to switch the group selector on a local call, while on a tandem switched call several tandem stages may be positioned by the same number of digits.

A large exchange usually has two, or more group selector stages and Fig. 4-3(b) shows a 5000 line exchange, with an originating (1GV) stage and an incoming (GIV) stage.

It can be appreciated that in a crossbar system the

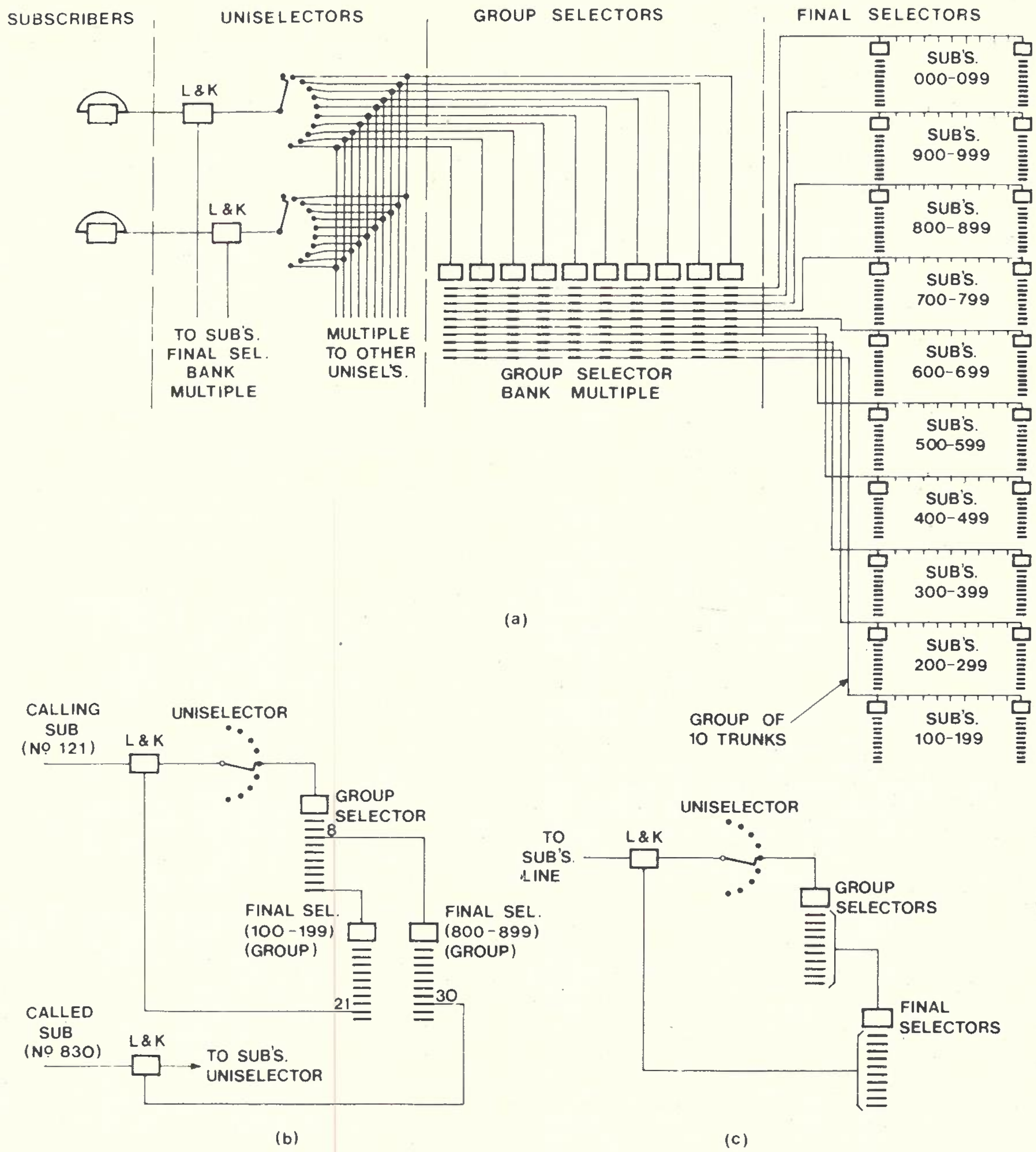


Fig. 4-1 — Principle of 1000 Line Exchange.

speech path switches are almost devoid of switching logic and are basically "slaves" of the other parts of the exchange where the "intelligence" is concentrated in a relatively small number of devices. These devices, of which the most important are registers and markers, interwork on an exchange or network scale, so that to describe the control mechanism of a crossbar exchange or network requires a "system" rather than a "component" oriented approach.

The rest of this chapter will therefore be devoted to consideration of the system design of crossbar signalling and control. In order to do so it will be necessary to make some unsupported statements about the properties of the various elements of the system which cannot be fully demonstrated until later when detailed descriptions of these elements will be given. However, without taking these liberties it is almost impossible to show how crossbar has evolved into its present form.

THE NEED FOR COMMON CONTROL

The first crossbar switch was invented in 1912 but proved to be ahead of its time, because the only trunking configurations known required one crossbar switch to be used as a single 100 (or 200) outlet selector by paralleling the inlets to the 10 verticals. In this form it was so much more expensive than a step by step group selector that its other advantages of reliability and easy maintenance were completely outweighed, except for a few obscure applications. Thus for 25 years the only applications of crossbar were in very small rural exchanges, which were so reliable that they could be installed in remote villages which might be snow bound for weeks in the winter, and for register finder circuits in a system based on rotating switches, where it was chosen because of its high speed of operation.

In the late 1930s the possibility of crosspoint economy by the use of link trunking was realised, and for the first time it became conceivable that a crossbar exchange of large size could be built at a cost competitive with other systems, and with the inherent advantages of reliability and fast switching. At the same time, the complexity of the process of choosing an outlet and a path through a link trunked selector stage is much greater than that of single stage selection, and some form of common control was an essential complement to the use of link trunking.

The idea of common control is simply this: "Because the process of selecting a path through a selector stage and operating the necessary crosspoints can be completed in less than a second, while the path so set up will be used for a conversation lasting several minutes, a few sets of control equipment can be used to control the setting up of calls for a large number of selector stage inlets." Just how many controls are required and how they are associated with selector stage inlets is a traffic engineering problem.

CONTROL SYSTEM TRAFFIC

Every time a switch inlet is seized, it must seize a control, and hold it for the period needed to complete its switching process. This procedure can be described as a "call" to the control from the switch inlet, of duration equal to the time required to control the switching — this duration being called "service time." It is not difficult to see that if a group of inlets carries speech calls of average holding time "T" (seconds) and the associated controls require "t" (seconds) to switch the call, then

$$\text{Control Traffic} = \text{Speech Traffic } x(t/T)$$

This relationship is of considerable importance in control system design, being the most convenient means of estimating the control traffic.

The control circuits used to control switching stages are usually called markers, and one of the significant features of markers is that the total marker traffic of even a large exchange is extremely small. For example consider the 1st Selector (1GV) stage in an exchange with 5000 subscribers and a calling rate of .04 Erlangs per line. This is typical of a medium sized suburban exchange, and the 1GV speech path traffic is 200E. Assuming a call holding time (T) of 100 seconds, and a marker holding time (t) of 0.5 seconds, there will be a marker traffic of 1E, and it is necessary to provide sufficient markers and a suitable marker coupling facility to carry this traffic.

One possibility is to have the markers in a full availability group, so that any inlet can use any marker as shown schematically in Fig. 4-4(a). If not more than 1 call in 500 is allowed to fail because of all markers being busy 6 markers are necessary, so that the average traffic per marker is 1/6E, i.e. each marker is idle five sixths of the time. As a typical marker is a very large item of equipment which can cost several thousand dollars, this very light usage is a costly matter.

QUEUEING OF MARKERS

The only way to increase the traffic efficiency for such small quantities of traffic is by queueing. In a queueing or delay access system a call which arrives when there is no free device available to serve it is not rejected, but instead is allowed to wait in a "queue" until a serving device is available. In such a system no call need be lost provided a long enough queue can be accommodated and the queueing delays are acceptable. The design criterion for such a system is therefore not lost calls, but the distribution of waiting times for delayed calls. Usually only one or two points on the distribution are specified, and for markers the APO has specified that less than 1% of calls are delayed by one second or more in reaching a marker. Such delays

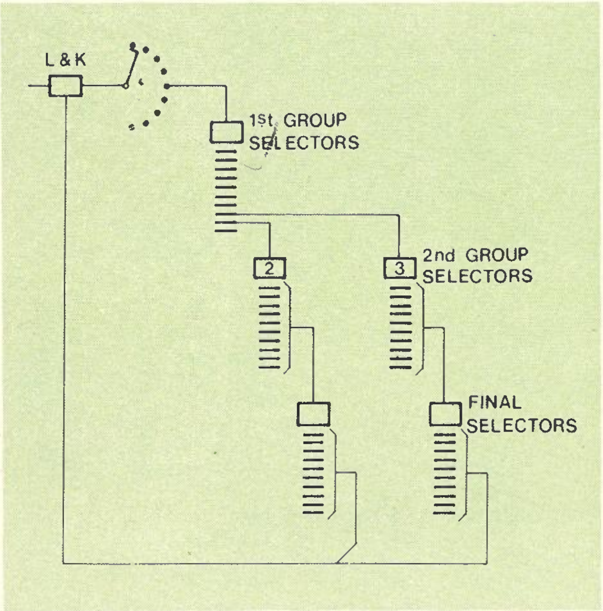
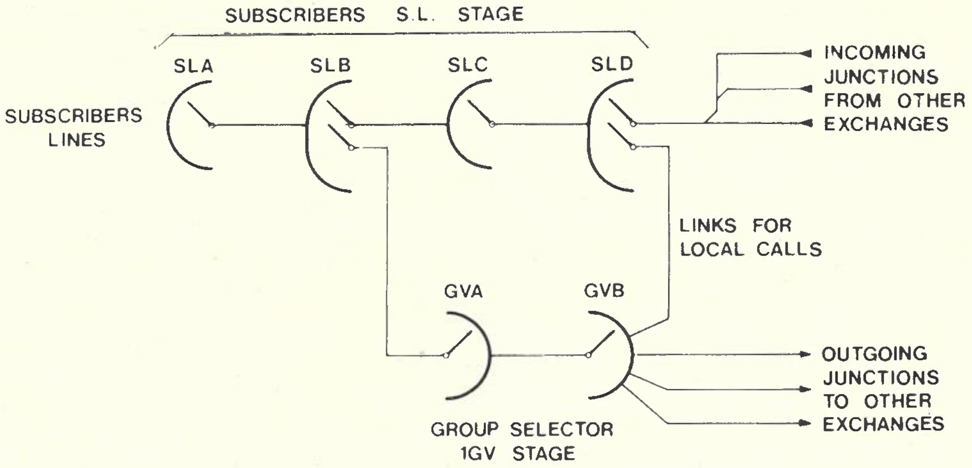


Fig. 4-2 — 2000 Line Step-by-Step Exchange.

are barely noticeable to the customer, so the resulting service impairment is unimportant.

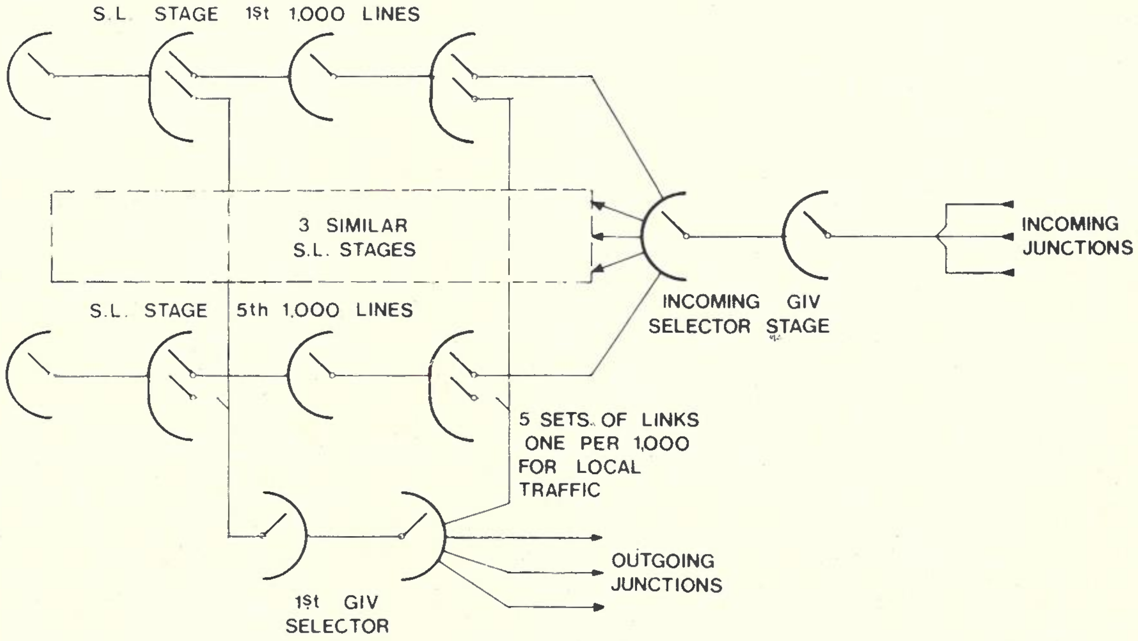
Calculating the delay distribution in a queueing system is a far more complex traffic engineering problem than calculating the probability of loss in a lost calls system, and exact solutions are available only for a limited number of very simple cases. One such case is where there is only a single server (marker), with constant holding time for each call, and Fig. 4-5 gives the delay distribution for this case for a number of values of marker traffic. The time scale in this figure is in units of holding time, which is a standard procedure to normalise the presentation.

Assuming a marker holding time of 0.5 seconds the delay criterion is that less than .01 of calls are delayed by more than 2 holding times and it can be seen that this is met with a traffic of 0.28E on the marker, which is greater than the traffic carried by each marker in the full availability no delay group of 6 markers discussed earlier and performance meeting the standard can be achieved with 4 markers. Fig. 4-4(b) shows schematically the arrangement for 4 markers and 320 inlets.



1,000 LINE CROSSBAR EXCHANGE

(a)



5,000 LINE CROSSBAR EXCHANGE

(b)

Fig. 4-3 — Crossbar Exchanges.

Obviously, at the traffic levels, and for the operating times applicable to crossbar markers, delay access is a very powerful method of increasing marker loading; so powerful in fact that it permits markers to operate as independent units with satisfactory efficiency. This method of working means that the switching stage inlets are divided into blocks with each block being controlled by a single marker. The coupling arrangements between inlets and markers are much simpler for this configuration than when each inlet has access to a group of markers, and this configuration is used wherever possible. Typically, one marker will serve between 40 and 160 inlets depending on the traffic, and the marker holding time.

REGISTERS AS BUFFER STORES.

The use of delay access has a number of subsidiary requirements which tend to offset the economies. Firstly, the marker must receive routing information to control the switching and with delay access this must be available *at the precise time the marker is ready* — no earlier, or the information would be lost and as far as possible no later, or the marker holding time will be unnecessarily increased. Since the time at which the marker is connected is unpredictable this means that the marker has to ask for routing information when it is ready and two way information transfer between the marker and the source of information is essential. A corollary of this is that the source cannot be a subscribers dial and that a buffer store must be inserted between the subscriber and the markers. This buffer store is usually called a register, and is also a piece of common equipment. As the register must always have the necessary information to reply to any request from a marker, it must not start to set up the call until the full wanted number is stored, so that post dialling delay is inevitable and usually long enough to be noticeable. These various requirements and conditions are interdependent, so that there is in effect a package deal involved; marker costs can be reduced by using delay access, which permits increased loading and if desired less complex marker coupling arrangements, provided all the following conditions are accepted:

- Registers are provided to receive the subscriber's dialling and act as a buffer store.
- A bothway information signalling system is provided between registers and markers.
- The resulting post dialling delays are acceptable.

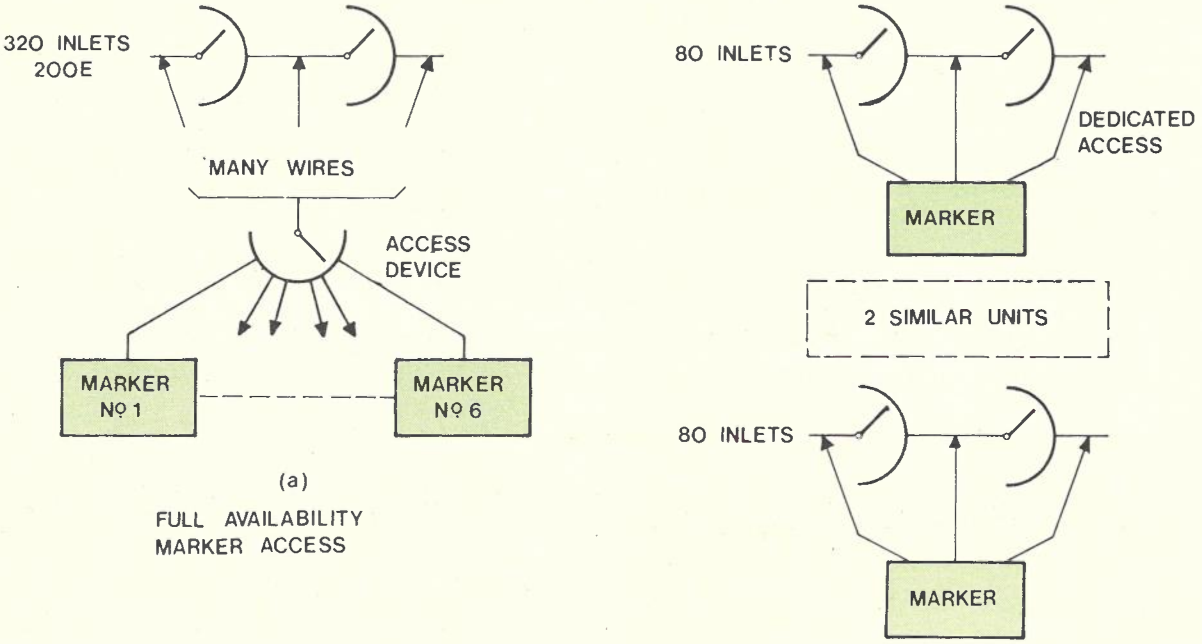
In the crossbar system this package is the only method which produces a control system capable of competing economically with the other types of system.

CONTROL SYSTEM (INFORMATION) SIGNALLING

The choice of a signalling system between markers and registers is an important factor in producing a satisfactory crossbar system. The marker service time per call includes the time needed to signal between register and marker and therefore if the signalling time can be reduced, there is a corresponding reduction in marker traffic, and each marker can control more inlets. Assuming 100 seconds holding time per call, the speech path traffic which one marker can control for three different marker holding times is given in Table 4-1.

It can be seen that halving the marker holding time allows a marker to control considerably more than twice as much speech path traffic, and that therefore there is an economic incentive to reduce marker holding time and a high speed signalling system between marker and register can be good sense economically apart from any other advantages.

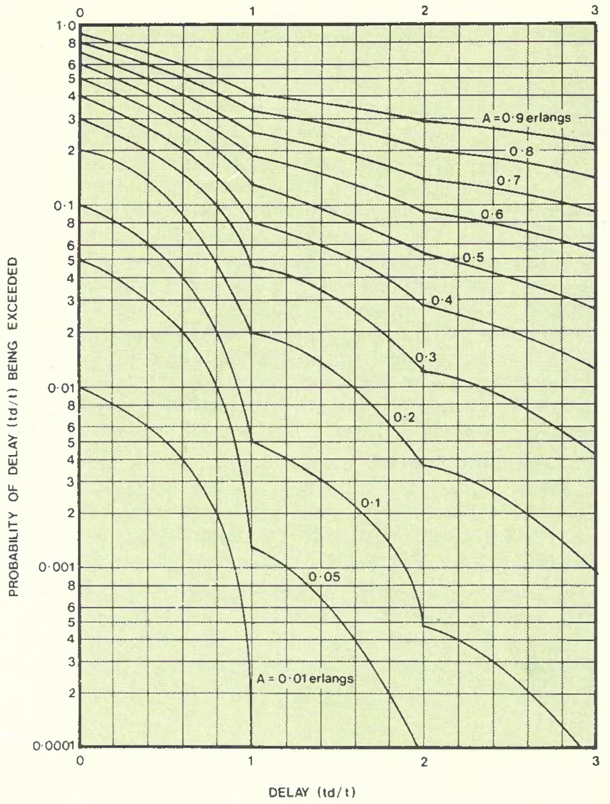
Multifrequency Code (MFC) signalling as used in



(a)
FULL AVAILABILITY
MARKER ACCESS

(b)
1 : 80 MARKER ACCESS
(WITH QUEUEING)

Fig. 4-4 — Marker Access.



DELAY CURVES FOR CONSTANT SERVICE TIME WITH ONE MARKER AND CALLS SERVICED IN RANDOM SEQUENCE

t MARKER HOLDING TIME
td DELAY DUE TO QUEUING
A MARKER TRAFFIC

Fig. 4-5 — Delay Distribution.

TABLE 4-1

Marker Holding Time	Traffic Per Marker	Corresponding Speech Path Traffic
1 Sec.	.15E	15E
0.5 Sec.	.28E	56E
0.33 Sec.	.38E	114E
0.25 Sec.	.48E	192E

LME crossbar is an important element in reducing marker holding times sufficiently to allow them to be organised as single independent markers controlling a discrete part of the exchange.

This of course requires the exchange to be designed so that it is built up of appropriately sized modules and in the original form these modules were 1000 line subscriber (SL) stages, and group selectors of 2 partial stages with 80 inlets and 400 outlets. Since then it has been possible to design a 3 partial stage group selector with single marker control, giving more efficient use of junctions. The limitations of single marker working prove too restrictive for trunk exchanges where the external circuits are more expensive and therefore the ARM trunk exchange has a configuration in which up to 20 markers may simultaneously control the one large block of switches over four partial stages, but this is the only significant use of multiple markers in LME crossbar.

The registers are both a buffer store and signalling conversion device, and for each call a register is held from the time the subscriber signals that he is about to call (by removing the handset) until the connection to the called number is complete, so that typical holding time is 15 seconds giving register traffic of the order of 15% of speech path traffic or 30 Erlangs for the 5000 line exchange being used as an example. Because the register traffic is much larger than marker traffic, reasonable efficiency can be obtained without queueing, and at the same time the holding time is so great that queueing could only give a great increase in efficiency if very long delays were permitted. For these reasons, access to registers is via "register finders" operating as a lost call system and with availabilities of about 20.

The signalling and switching sequence of a call in a crossbar network, and the devices that are involved are as follows:

(1) Subscriber commences call (i.e. removes handset).
(2) Subscriber is connected to register (and receives dial tone).
(3) Subscriber dials into register.
(4) When register has stored a complete number it calls the first marker.
(5) Marker and register interchange signals, marker switches call through its stage, causing next marker to be called and then drops off.
(6) Second and subsequent markers repeat step 5. Last marker signals "connection complete" or "end of selection" to register.
(7) Register drops off.
(8) Called party's bell rings.
(9) Called party answers and conversation takes place.
(10) Call is metered.
(11) Call is cleared.

The signals involved in the above steps are grouped into two categories. "Line Signals" are those which must be received and acted on by equipment permanently associated with the speech path, and "Information Signals" are those which are received and acted on by markers or registers.

Line Signals include all signals above except those in steps 3, 5 and 6. Since they must be transmitted, identified and acted on by equipment permanently associated with the speech path, a fairly simple and economical system is desirable. Meeting these requirements is helped by the relatively low information transfer rate needed, and the small number of distinct signals that need to be recognised. Within a small network with physical junctions they are carried by DC signals over the speech pairs, while carrier systems are provided with low speed binary signalling channels for the same purpose. Signalling conversion and repetition relay sets are needed at various points in the system and these are called line relay sets. The signal "call marker" is also transmitted via the line signalling system and is classified as a line signal.

Information signals are present only at defined times at the beginning of a call, and the start of a sequence of information signals is announced by a line signal, i.e., "Subscriber calls" or "call marker". Because these signals are received, and (except the subscribers original dialling), sent by items of common equipment shared by many inlets, it is possible to use more versatile signalling systems. The structure of the exchange is such that the speech path which will later be used for conversation is available between the register and the marker, permitting a fast high-speed tone signalling system to be employed.

Fig. 4-6 shows the devices concerned with signalling and control added to the speech path trunking of Fig. 4-3. These devices are as follows:

- The cord circuit (SR) relay set which is placed at the 1GV inlet, and which handles most of the line signals to or from the two telephones in a call. The signalling currents are also used to provide power for the microphones in the two telephones.
- A supplementary switching stage known as a register finder (RS) associated with the SR relay set, which provides a connection to a register when required.
- Registers (Reg-L) reached via the RS stage.
- Markers (GVM) associated with the 1GV and GIV selector stages, with one marker per 80 or 160 selector inlets.
- Markers (SLM) associated with the SL stage with one marker to each 1000 line group. This marker will connect a calling subscriber to an SR relay set for outgoing traffic and an SLD inlet to the called subscriber on an incoming call.
- Line relays (LR/BR), one pair for each subscriber, whose main function is to recognise an outgoing call and provide a busy test.
- Junction relay sets (FIR and FUR) to provide an interface between the signalling conditions on the line and those within the exchange and to transfer signals across the interface.

DEVELOPMENT OF COMMON CONTROL SYSTEMS

Some readers may be intrigued that a control mechanism so devious and at the same time so powerful ever came into existence, and a short digression into history may be of interest.

The system naturally was not invented from scratch in the 1930s, when the need arose, but depended on earlier developments, going back almost to the beginning of automatic telephony. The first element to be developed was the buffer store, with two way signalling between the switch and the buffer store. In its first form the buffer store was not a common control unit but was the subscriber's calling device. It had 3, and later 4 slide switches on which the desired number was set up *before* the subscriber pressed a call button. The first selector then began stepping, sending back an impulse on one leg of the subscriber's line for each step. These impulses stepped a rotary switch until it was on the position marked on the calling device for the first digit. A "stop" signal was then sent to the selector on the other leg of the line, the selector searched and reached a free second selector and the same procedure was repeated. Fig 4-7 shows the circuit principles involved.

The motives for this bizarre system were twofold. Firstly, this system did not require the switches to be in step with a dial and allowed the use of robust switches driven from a rotating shaft via clutches. It was claimed, and with justice, that this kind of switch

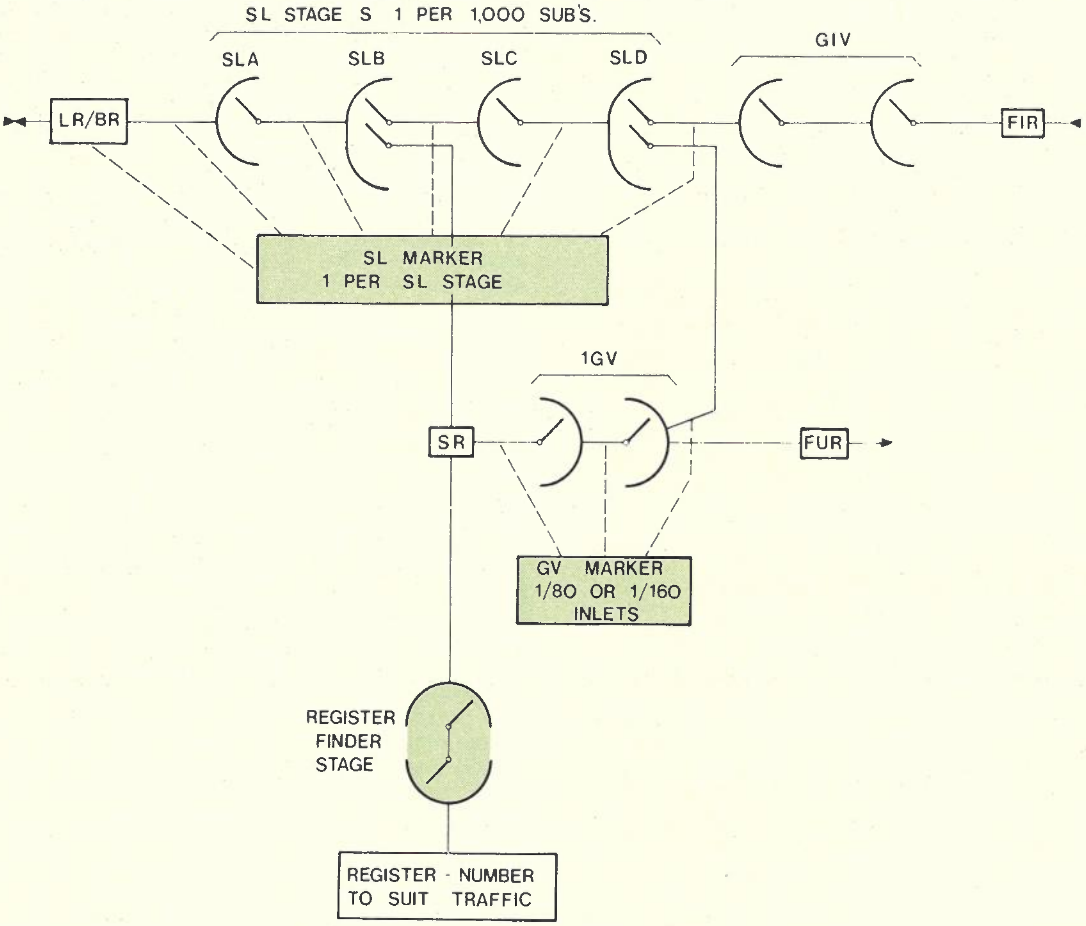


Fig. 4-6 — Control Equipment in ARF Exchanges.

could be made more robust than a ratchet and pawl drive switch. (The rotating drive shaft was driven from a single motor of about one horsepower to serve all switches in the exchange.) Secondly, since the telephone dial was already patented by the most successful competitor, some clearly different calling device was needed.

This system was able to compete with Strowger step by step equipment and was in service as early as 1906, while by 1910 it had inspired the development by Western Electric of the "Rotary" system. In this system a true register was provided, coupled to the line via a register coupler. The subscriber had an ordinary dial which set switches in the register that corresponded to the slide switches on the subscriber's calling device of the earliest system. The same type of two way signalling was used and it had now received the name of "revertive signalling". The Rotary system proved to be very satisfactory and was used extensively in France and Belgium in particular, including the Paris telephone system. With further developments it continued to be manufactured until after 1950. Two other systems, the Western Electric Panel System and the LME 500 outlet switch system employed virtually the same technique and design details, but with different switch mechanisms and both were very widely used.

This line of development produced the register as a buffer store, and the idea of two way signalling as a means of ensuring that the signalling timing suited the switch. In fact, the switch controlled the timing and the register waited till the switch condescended to send back its revertive pulses. The selector switches used mechanical logic for most of their functions, and control circuits were simple and individual to each switch. As far as possible in these early systems any complex intelligence needed to create complex network configurations was concentrated in the register.

The use of common controls for switches was extensively pursued in the 1930s with the development of a variety of competing systems using simple switches (usually uniselectors) with relay logic replacing mechanical logic. Most of these systems failed to dislodge the established step by step and machine drive systems, one notable exception being the Siemens motor uniselector. However, in this period many common control configurations were tried, and it was realised that the machine drive systems using revertive signalling could use common controls for the switches on a delay access system to add new facilities, such as those needed for automatic trunk switching.

Thus it was that by the mid 1930s when link trunking was being developed for crossbar switches in Sweden all the necessary control techniques were already in existence in the 500 point switch system, and there was a large body of engineering experience to guide the designers in the direction they followed.

At that time the best that could be done in respect of register to marker signalling was a high speed dc signalling system about three times as fast as loop disconnect dialling. This was a reasonable compromise between speed and economy and for local networks the post dialling delay was acceptably short, indeed much less than any other system suitable for large cities. The system, known as ARF101 was one of the first successful crossbar systems for large networks, and many parts of the ARF 102 system used by the APO are almost unchanged from that design. The development of transistors and more economical tuned circuits made it possible by about 1955 to introduce MFC signalling with even higher signalling speed and the potential of providing numerous special facilities that could not be given with the simpler dc signalling scheme.

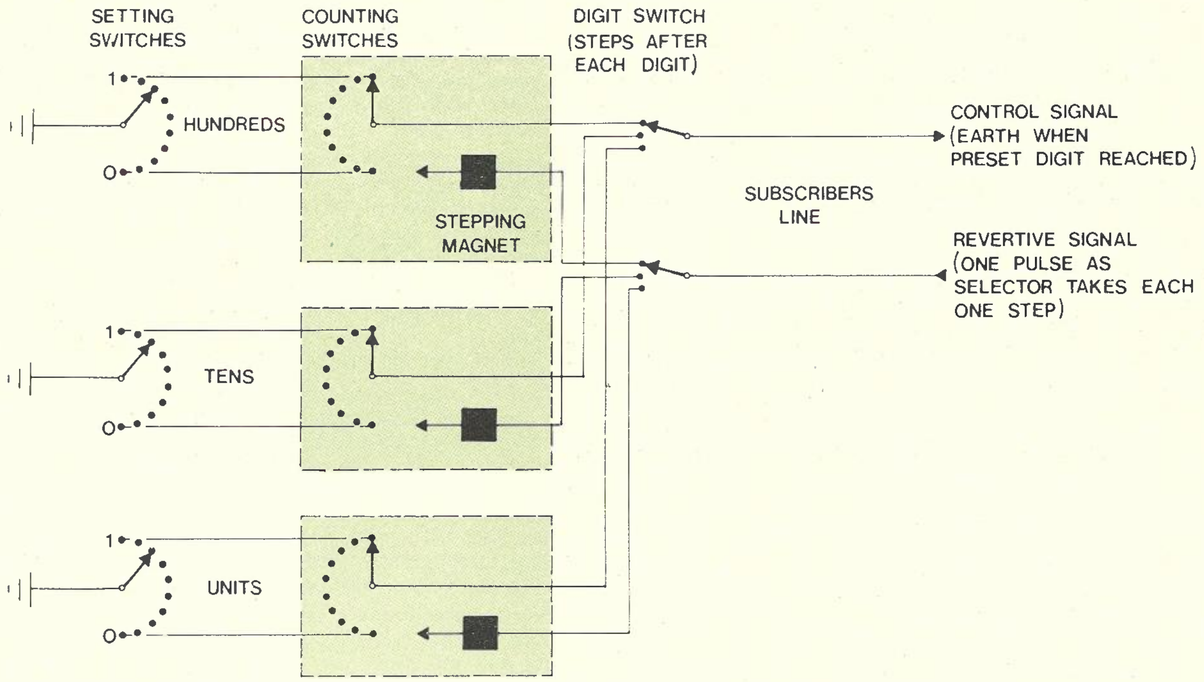


Fig 4-7 — Principle of Revertive Signalling.

Chapter 5 – Line Signalling

INTRODUCTION

In a large telephone network a few comparatively simple signals from a telephone may result in the execution of complex switching operations in several widely spaced telephone exchanges in order to set up the desired connection, and all of these actions must subsequently be cancelled at the end of a call. This requires a signalling (i.e. data transmission) network covering the full extent of the switching system, and in all but the most recent developments, this takes the form of a signalling path associated with each transmission path and switching device so that, simultaneously with the building up of a speech path from the originating point, a signalling path is built up linking every component of the speech path.

For the reasons given in the previous Chapter on control system design, the signalling in the crossbar system is divided into two components known as line signalling and information signalling. The line signalling component requires a relatively low signalling speed and the facilities are usually provided as a by-product of the speech path, in one of the three following forms:

- A speech path in the form of a pair of wires, either for a subscriber's line or for a junction is capable of carrying signals down to zero frequency, and the band below about 200 Hz which is not required for speech transmission is available for signalling. In addition, the whole bandwidth is available (subject to some constraints) during part of the setting up process.
- Within an exchange a supplementary wire or wires for signalling may be provided in parallel with the speech wires. There is usually at least one such extra wire used for holding the connection through the exchange, and ARF crossbar has two signalling wires, to provide for a variety of internal signalling needs.
- Junctions provided by carrier systems are usually unable to transmit low frequencies but a separate signalling path is provided in all modern systems. In Frequency Division Multiplex (F.D.M.) systems use is made of frequencies between channels, which are combined with the speech path at the first modulation point, and remain associated with it until the final demodulation.

In order that this signalling network can perform its functions, every exchange in the telephone network must be provided with the facilities to:

- Recognise and act on signals received over lines (either subscribers or junctions) connected to it;
- Transmit or repeat signals over these lines for action at the exchange, or telephone connected at the other end;
- Interchange signals between parts of the exchange.

This is usually done by providing a 'line relay set' at the exchange termination of every line, with facilities for sending and receiving signals on both the exchange and line side of the relay set, and to perform, or control the performance of switching actions needed in the exchange as a response to the signals. Fig. 5-1 shows a connection set up in an exchange using this line signalling configuration, and a number of important terms can be defined on the basis of this diagram.

Any telephone call is set up from one end, so that in the completed connection one subscriber is the calling party and the other the called party. By a long established convention these are known respectively as the 'A' party and the 'B' party and Fig. 5-1 has been drawn with the calling or 'A' party on the left and the called or 'B' party on the right. Therefore the line shown on the left hand side is either the 'A' party's telephone line, or a junction to which the 'A' party's line has been connected via another exchange (or exchanges). Likewise, the line on the right hand side is either the 'B' party's telephone line, or a junction that is, or will be in due course, connected to the 'B' party's telephone line.

The side of the exchange nearest to the 'A' party is called the incoming side, and the relay set at that point is called an 'incoming' relay set, while the other side of the exchange is the outgoing side, and the relay set is called an 'outgoing' relay set.

It will be realised that the designations 'A' and 'B' party are appropriate for the duration of a particular call only, because a normal telephone can both originate and receive calls, and can therefore be the 'A' party for one call and the 'B' party for the next. A subscriber's line must therefore be terminated on both the incoming and outgoing sides of its exchange, with a line relay set capable of handling calls both incoming and outgoing from the exchange. Such a relay set is called a 'bothway line relay set', but for any one call will be in use as either incoming (to the exchange), if the telephone is the 'A' party, or outgoing if the telephone is the 'B' party. Bothway trunks and junctions also exist, and some exchanges are so designed that the one line termination can be used both for incoming and outgoing traffic. In any of these cases, the designation incoming and outgoing can still be applied for the duration of a particular call.

In Fig. 5-1 both relay sets are required to receive line signals from either side and repeat them, and the two relay sets working together must arrange for the line signals to be acted on in the exchange. This latter function is usually vested in one only of the two relay sets, which then becomes the more complex of the two. If a relay set is required to repeat line signals either with or without changing the form of the signals the relay set is often called a repeater or a signalling repeater.

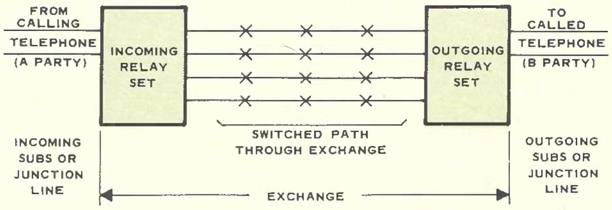


Fig. 5-1 — Line Relay Sets.

Automatic Telephones

The signalling facilities of an automatic telephone have been standardised for over fifty years, and have exercised a dominant influence on the design of automatic equipment and the associated signalling facilities. Fig. 5-2 is a simplified representation of the signalling facilities of a subscriber's telephone.

There are four separate devices, each providing a different signal as follows:

- A bell, responding to 16 Hz ac power from the exchange to indicate an incoming call.
- Switchhook contacts, which are controlled by the handpiece, giving two conditions known as 'on hook' and 'off hook'. The on hook condition applies when the handpiece is in place, and the contacts place the bell in series with a capacitor across the line. In this condition the bell can be rung by ac power from the exchange but no direct current can flow through the telephone. The off hook condition applies when the handpiece is removed and the contacts place the telephone in the speaking condition. In this condition the dc resistance of the instrument is about 100 ohms. Equipment at the exchange determines the state of the switchhook by observing the change in dc resistance.

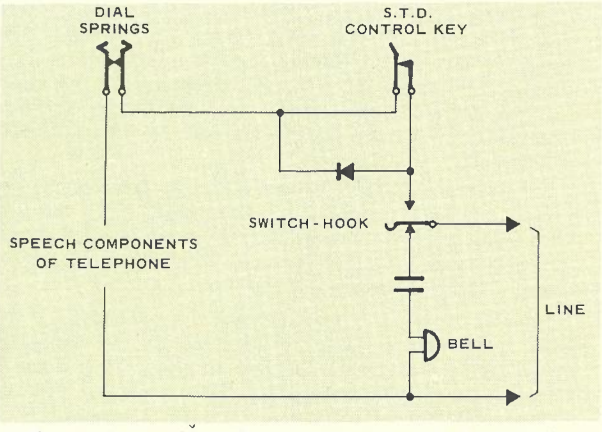


Fig. 5-2 — Signalling Elements of Automatic Telephone.

- Dial interrupter springs in series with the line which, when the dial is returning to normal, open the circuit in a series of short breaks, the number of which is equal to the digit dialled. The standard timing is 66ms breaks, with 34ms intervals, giving 10 impulses per second, as shown in Fig. 5-3.
- A recent addition is a series diode, which can be shorted out by a control key. When the exchange equipment detects the presence of a diode it will not permit certain types of call (STD for example) and such calls can therefore only be made by persons in possession of a key. This control lock and key is provided only as an optional extra.

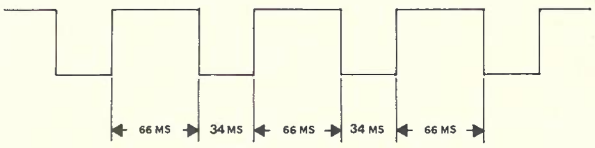


Fig. 5-3 — Detail of Dial Pulses

It will be noted that in the speaking condition, the speech components of the telephone are in series with the line. The exchange equipment is so designed that a current of about 50mA is present on the line at these times and this current is used both as an indication of the state of the switchhook and also to provide the power needed by the telephone transmitter.

The two states of the switchhook are known as 'switchhook signals', but the word 'signal' in this context carries three overlapping meanings.

- Firstly there is what may be called the 'message' contained in the signal. When the subscriber lifts off the handset it means 'I want to make a call', or 'I am answering this call', depending on whether or not the bells are ringing. Thus the same action has a different 'message' depending on the context.

- Secondly there is the circuit change arising from removing or replacing the handset, or at least that part of the circuit change which is related to signalling. In this case it is the change from an open circuit between the wires of the line in the on hook condition to a low resistance path in the off hook condition.
- Thirdly there is the change which is detected at the exchange end of the line, from which it is inferred that the telephone is in the 'on hook' or 'off hook' condition. In this case it is the absence, or presence, respectively of current in the line.

The use of the one word 'signal' for all three of the above meanings is deeply ingrained in the technical literature, and usually the context in which it is used is relied on to avoid ambiguity. This practice will be followed here, except that where it is desirable to emphasise that the second or third meaning applies, the term 'electrical condition' will be used.

The switchhook and bell are used respectively to generate and receive line signals, while the dial, and the diode, where fitted, generate information signals. In the subscriber's line these two types of signal use the one signalling path, and in step-by-step automatic switching systems they continue to share the same path in virtually the same form right through the network. This type of information signalling is known variously as 'loop', 'loop disconnect', 'dial pulse' and 'decadic' signalling.

In most crossbar systems the register separates line signals and information signals and transmits the two categories by different techniques. However, because of the need for interworking between crossbar and step by step exchanges, many crossbar line relay sets are required to transmit decadic information signals.

The line signals which are transmitted from the subscriber's telephone and the electrical conditions used for them are listed in Table 5-1.

TABLE 5-1 — LINE SIGNALS AND ELECTRICAL CONDITIONS

When Used to Call (i.e. A Party)		When Used to Answer (i.e. B Party)	
Signal	**Electrical Condition**	**Signal**	**Electrical Condition**
Call	DC Loop	Answer	DC Loop
Release	DC Open Circuit	Clear	DC Open Circuit
		Reanswer	DC Loop

The functions of these signals have already been described, except for 'B' party 'clear' and 're-answer'. In the telephone network release of the call normally takes places when the 'A' party restores his telephone and therefore the 'B' party switchhook condition subsequent to answering is unimportant. This allows the 'B' party to temporarily restore the handset, or leave the dc loop temporarily open circuit to transfer the call to another telephone and this is sometimes a very useful facility. The 'clear' and 're-answer' signals correspond to 'on hook' and 'off hook' conditions subsequent to answer, and may be repeated without limit. This system where the establishment and release of a call is controlled by the calling party only is called 'calling party release'.

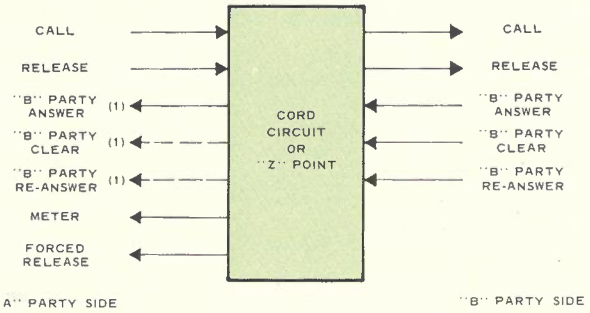
In most modern systems this method of controlling the release of a call is modified to provide that release will also occur if the 'B' party has cleared for a specified period — typically 90 to 180 seconds — even if the 'A' party has not released. This system, known as 'modified calling party release' prevents the 'B' party's telephone being kept out of service if the 'A' party fails to release, due, for example, to incorrectly replacing the handset. It also releases any junctions which would otherwise be held on such calls.

One further release condition which has advantages in special cases is 'last party release'*, where the call is not released until both parties clear. This is necessary on certain types of test calls and in crossbar exchanges a facility exists for temporarily marking a particular subscriber's line for last party release on incoming calls, so that malicious calls can be held and their origin traced.

Cord Circuit Point

In order to provide these more complex release conditions the control of release must be performed by a decision circuit which is provided with information about the state of both switchhooks. This decision circuit forms part of a relay set located somewhere in the completed connection, most frequently in the terminal exchange to which the 'A' party is connected, but sometimes at a tandem exchange through which the call is switched. By analogy with manual switchboards this point is often called the cord circuit point.

There should be only one such point in a call, and it must transmit the release instruction towards both the 'A' party and the 'B' party (but only as far as the subscribers line circuit, since no electrical signal can replace the handset). The release signal towards the 'B' party need not be distinguishable from 'A' party release but a new signal is needed in the direction of the 'A' party and is called 'forced release'. These signals are illustrated in Fig. 5-4.



NOTE (1) THESE ARE OPTIONAL SIGNALS

Fig. 5-4 — Signals at Cord Circuit Point.

Metering

One further signal is required to allow the charges for a subscriber to be recorded. The charge for any call dialled by a subscriber is a multiple of a 'unit fee charge'. For calls to a defined 'local area', usually about 20 miles radius, a charge of one unit fee is made, regardless of the call duration while calls outside this area are classified as trunk calls and the charge depends on the distance, and on the duration of the call. (For further details see the previous chapter).

Call charges are recorded on an electro mechanical counter (subscribers meter) associated with each sub-

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* The APO uses a variant of this known as 'B party control'.

scriber's line, and the method employed by the APO for trunk calls requires that the meter be stepped at regular intervals during the call. The cord circuit point is the most logical location for determining the timing of these charges, and a signal is therefore required from the cord circuit point to operate the subscriber's meter. This signal, unlike the preceding ones, is transmitted while conversation is proceeding.

When a cord circuit point is able to apply metering signals for trunk calls it is usually called a 'charge point'.

The signals so far described have to be transmitted over all, or a substantial part of a complete connection and require responses at various points along the connection. These two requirements of end to end transmission and action at intermediate points are fully satisfied by the exchange configuration of Fig. 5-1 in which line signalling relay sets are provided at the exchange termination of each internal circuit.

A line signal from the 'A' party side will be identified at the incoming relay set, which will then retransmit or repeat it over the exchange path to the outgoing relay set, which in turn identifies and repeats it to the outgoing line. Either or both relay sets, as well as repeating the signal, can cause action within the exchange in response. Line signals in the B to A direction are handled in a similar manner. As signalling repeaters these relay sets can use different types of electrical conditions for signalling on their two sides, so that there is a considerable degree of freedom in types of line signalling.

In addition to the above signals, there is a wide variety of line signals needed within a single exchange, or from end to end of a particular junction, and even within a single switching stage of an exchange. Every part of the telephone system therefore has its own particular requirements of line signalling, and its own schedule of electrical conditions to represent the signals needed at that stage.

There is, of course, a large degree of standardisation, particularly of the end to end signals and nearly all line signalling conditions used on trunks and junctions in Australia can be regarded as variations and extensions of four basic schemes, as follows:

- Loop Signalling.
- Separate Path Pulse Signalling.
- Separate Path Continuous Signalling.
- Rural Carrier.

In addition there is a signalling scheme developed for use with PCM carrier systems, and which will become important if PCM systems are used more extensively. A number of older systems are in use but they are all obsolescent, and are being replaced fairly rapidly.

LOOP DISCONNECT SIGNALLING

Transmission Bridges

Loop signalling is undoubtedly the dominant form of line signalling (and will retain this dominance for many years) being used on subscribers' lines, and nearly all junctions provided by physical conductors, as well as being the basis of signalling within most types of exchanges. The principles and techniques of loop signalling are best illustrated by examination of a specific case, and the configuration of Fig. 5-5 in which there are three signalling relay sets, two subscribers lines (A and B) and two junctions will be used.

Because loop signalling uses the speech path for signalling it is necessary to separate signalling and speech at the relay sets and prevent signalling currents from passing through the relay sets. This is done by using one of the two types of circuit shown in Fig. 5-6.

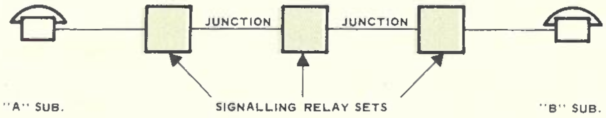


Fig. 5-5 — Typical Connection.

In Fig. 5-6(a) there is a series capacitor in each conductor of the line, and the signalling relays and contacts are connected across the line on either side. Since the relay coils appear as a large inductance at speech frequencies, the relay coils and the capacitors form a rudimentary high and low pass filter set, allowing speech to be transmitted with little attenuation, while confining the signalling currents to their own side of the relay set. If the relay impedance is too low for satisfactory speech transmission, series inductors, as shown on the left hand side may be included to increase the shunt impedance.

In Fig. 5-6(b) a transformer is used to isolate the two sides of the relay set for signalling, and the signalling conditions are applied and recognised across capacitors in the centre points of the primary and secondary. In this case, the transformer inductances and the centre point capacitors form the necessary filters to separate speech and signalling.

Either combination of circuit elements is known as a 'signalling bridge', 'transmission bridge' or 'supervisory bridge'. Fig. 5-6(a) is known as a condenser bridge or a 'Stone bridge' while Fig. 5-6(b) is known as a transformer bridge or 'Hayes bridge', in each case recalling the name of the inventor.

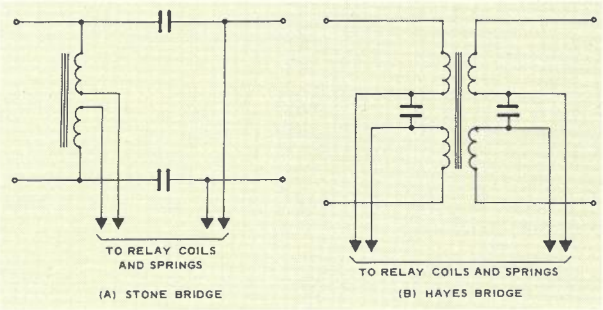


Fig. 5-6 — Transmission Bridges.

Electrical States

By means of transmission bridges at the two ends of a junction, the two wires of the junction are made available for signalling. These two wires are used to connect signalling equipment at each end in the form of a single series path (or loop), usually containing the elements shown in Fig. 5-7. At one end of the junction, sometimes called the battery feed end, dc potentials are fed in series with a relay while at the other end relays and rectifiers are connected between the two wires. At each end relay contacts can alter the magnitude and/or direction of the current in order to transmit signals.

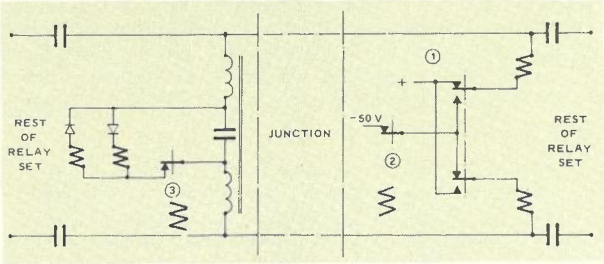
There are three possible conditions which can represent signals:

- Current in normal direction
- Current in reverse direction
- No current.

TABLE 5-2

Relay States			Line Current	Ability to Identify State at Opposite End	
Battery Feed End		Other End Relay 3		Battery Feed End	Other End
Relay 1	Relay 2				
Released	Released	Operated	Normal	Yes	Yes
Operated	Released	Operated	Reversed	Yes	Yes
Either (1)	Operated	Operated	Zero	No	Yes (2)
Released	Released	Released	Zero	Yes (2)	No
Operated	Released	Released	Zero	Yes (2)	No
Either (1)	Operated	Released	Zero	No	No

Notes: (1) Since relay 2 is operated to give zero current, the state of relay 1 is important.
(2) If zero current is not caused by local relay it must be due to relay at distant end.



RELAY ① CONTACTS TO SIGNAL BY REVERSED POLARITY
RELAY ② CONTACTS TO SIGNAL BY OPEN CIRCUIT
RELAY ③ CONTACTS TO SIGNAL BY OPEN CIRCUIT

Fig. 5-7 — Loop Signalling Principles.

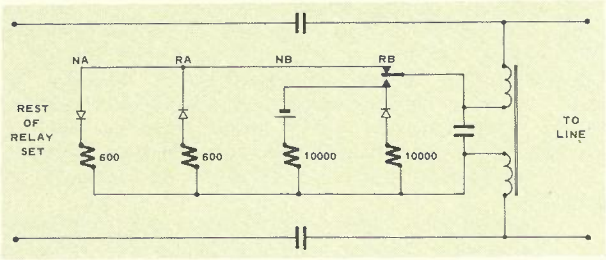


Fig. 5-8 — Additional Signals with High Resistance Relays.

Because the signalling relay contacts at each end of the junction are in series, there is considerable interference between the two signalling directions. This is illustrated by Table 5-2, which shows that there is considerable ambiguity in the zero current state.

The meanings given to these states must be such that the interference does not affect the performance of the system, and this is not unduly difficult. However, in some cases the interference is minimised by adding two new states of 'low current normal polarity' and 'low current reversed polarity', and using the circuit of Fig. 5-8, at the end remote from the battery feed. At the battery feed end the relays are designed so as not to operate on 'low current', which at that end is therefore interpreted as 'zero current'. At the other end, a more sensitive relay is switched into circuit, which operates on the low current. There are now five electrical states of line current, and the only interference remaining is that with zero current (due to relay 2 operating), the battery feed end cannot determine the signalling condition at the other end (Fig. 5-7).

This circuit can often be simplified if some signalling combinations are not used, and in particular, in the high resistance case it is usually only necessary to detect the presence or absence of battery and not its polarity, so that one relay can be used without diodes.

Signalling Schedules without Multimetering

In a simple network such as the APO step-by-step system prior to about 1955 the only signals needed were seize and release, originating at the A party's telephone and requiring to be transmitted progressively to every relay set in turn, and B party answer requiring to be transmitted backwards as far as the point where metering is determined. Design of a line signalling system to provide these facilities can be considered as a matter of defining an electrical state to specify each of these signals.

In doing so there are already some constraints in respect of the subscribers line sections of the connection, since the signalling facilities of the telephone are defined and there is a further requirement that the exchange supplies a source of dc power to the transmitter. Consequently, for the A party's line the relay set must be at the telephone battery feed end of the signalling circuit, and loop and open circuit at the telephone as previously specified will correspond to call and release. Again, for the B party's line the relay set must be at the battery feed end of the signalling circuit. Provision must also be made to transmit a 16Hz ringing current for the call signal.

For the other two links there is no inherent reason for the battery feed end to be at one position or the other, but the most satisfactory signalling schedule is obtained by placing it always at the B party, or incoming end of the junction. The call and release conditions are then loop and open circuit as for the A party's telephone. In the B to A direction normal polarity is made to correspond to the 'on hook' condition of the B party and reverse polarity to 'off hook.' These signalling schedules are listed in Table 5-3.

This signalling schedule allows for B party switch-hook conditions to be repeated to the A party telephone, and this makes signalling identical on junctions and on the A party's line, and allows some simplification of exchange circuits. The only use made of them, on the A party's line, is that the B party's first answer is used in public telephones to facilitate coin collection.

Signalling Schedules with Multimetering

With the introduction of STD and of more complex release conditions, as described earlier, a greater number of signals are needed in the B to A direction, and the simple signalling system used for step-by-step needs to be expanded. As discussed earlier, the B to A signals needed are:

- B party answer
- B party clear
- B party re-answer
- Forced release
- Meter

As there are only three electrical conditions available to represent all these signals, the effective capacity of the signalling system must be expanded in some way. This has been done by adopting two different schedules, for junctions on the A party and the B party side of the cord circuit point.

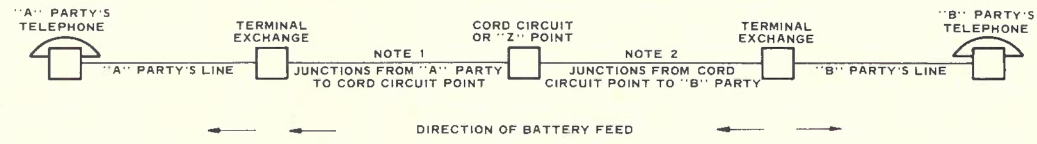
On the B party side the signals needed are the same as the simple step-by-step network and the same signalling schedule is used. On the A party side, it has been decided that B party switch-hook signals subsequent to the first answer will not be transmitted, as they are not used. This limits the signals needed to B party answer, metering, and forced release. Metering is signalled by a 150 ms transition from reversed polarity to normal and back again, while forced release uses the remaining condition of open circuit at the battery end.

TABLE 5-3 — SIGNALLING IN S x S NETWORK

Signal	Electrical Condition		
	A Party's Line	Junction	B Party's Line
Battery at	Exchange End	B Party (Incoming) End	Exchange End
A-B Signals			
Call	Loop	Loop	16Hz Ring
Release	Open Circuit	Open Circuit	No Signal
B-A Signals			
B Party on Hook	Normal Polarity	Normal Polarity	Open Circuit
B Party off Hook	Reverse Polarity	Reverse Polarity	Loop

The metering signals used on junctions on the A party side of the cord circuit point cannot be used on subscribers' lines, because the loop current is used to power the carbon microphone and the polarity changes used for metering would cause audible interference as the current passed through zero. Moreover, the use of diodes in the telephone for access barring prohibits the use of polarity reversal even as an answer signal. Therefore it is now APO standard practice to normally provide no B-A direction signalling on the A subscriber's line. On public telephones, where B party answer is needed, and diode

TABLE 5-4



SIGNAL	ELECTRICAL CONDITION FOR SECTIONS			
"A" TO "B" DIRECTION				
CALL	LOOP	LOOP	LOOP	16 Hz POWER (RING)
RELEASE	O/C	O/C	O/C	NO SIGNAL
"B" TO "A" DIRECTION				
CALL NOT YET ANSWERED	NORMAL POLARITY	NORMAL POLARITY	NORMAL POLARITY	O/C
"B" PARTY ANSWER	NOTE 3 & 4	REVERSAL POLARITY	REVERSAL POLARITY	LOOP
"B" PARTY CLEAR	NOT USUALLY PROVIDED (NOTE 4)	NOT USUALLY PROVIDED (NOTE 4)	NORMAL POLARITY	O/C
"B" PARTY REANSWER	NOT USUALLY PROVIDED (NOTE 2)	NOT USUALLY PROVIDED (NOTE 4)	REVERSAL POLARITY	LOOP
FORCED RELEASE	NOT POSSIBLE	O/C BATTERY FEED	NOT NEEDED	NOT NEEDED
METERING	NOTE 5	NORMAL POLARITY FOR 150 M.S.	NOT NEEDED	NOT NEEDED

NOTE 1 THE CORD CIRCUIT POINT IS FREQUENTLY IN THE TERMINAL EXCHANGE ESPECIALLY FOR UNIT FEE TRAFFIC IN WHICH CASE THIS SECTION IS NOT PRESENT. SOMETIMES THIS SECTION INCLUDES AN INTERMEDIATE EXCHANGE.

NOTE 2 THIS SECTION IS NOT PRESENT IN ALL CASES. WHEN IT IS, IT MAY INCLUDE ONE OR MORE INTERMEDIATE EXCHANGES.

NOTE 3 "B" PARTY ANSWER MAY BE SIGNALLED BY REVERSE POLARITY IN CERTAIN CASES.

NOTE 4 FOR UNIT FEE CALLS FROM STEP BY STEP EXCHANGES, ALL "B" PARTY SWITCHHOOK CONDITIONS ARE REPEATED TO THE "A" PARTY TELEPHONE. IN THIS CASE, THE CORD CIRCUIT POINT IS IN THE "A" PARTY'S TERMINAL EXCHANGE.

NOTE 5 WHEN THE SUBSCRIBER'S EQUIPMENT REQUIRES THIS (IN PARTICULAR S.T.D. COIN TELEPHONES) A 50 Hz SIGNAL OVER THE CAILHO IS PROVIDED BY A SPECIAL RELAY SET.

access barring is not required, a special signalling unit (called an MR relay set) repeats B party answer as a polarity reversal. On STD public telephones, and some other lines there is also a requirement for the transmission of metering signals to the subscriber's instrument. These are transmitted as 50Hz pulses over a centre point earth return (cailho) circuit which does not interfere with speech. As with the answer signal, a special signalling unit is fitted to each line requiring this facility.

This method of providing for multimetering requires the use of four different signalling schedules all designated by the general title 'loop signalling.' When it is essential to distinguish between them the following designations are often used:

- 'A' party subscriber signals — on the calling subscriber's line.
- Silent reversal signals — on junctions on the 'A' party side of the cord circuit point.
- 'B' party switch-hook signals — on junctions on the 'B' party side of the cord circuit point.
- 'B' party subscriber signals — on the called subscriber's line.

The signalling schedule for each of these segments is given in Table 5-4.

One disadvantage of the above system of signalling is that a variety of signalling relay sets is needed, depending on the particular signalling schedules on the A and B sides of the relay sets.

Another technique which was investigated at the time multimetering was being developed by the APO involved adding a new signal for metering, (in fact the 50Hz cailho signal used on subscribers' lines in the present scheme) so that polarity reversals invariably represented B party switch-hook signals. The result would have been some reduction of relay set varieties, but the savings were judged to be less than the extra cost of the additional signalling facilities required to provide the 50Hz cailho signals.

With the exception of metering, line signals occur at times when conversation is not possible and therefore some incidental noises in the speech path associated with their transmission can be tolerated. Therefore, the filtering provided to separate speech and line signals need not be of a very high standard, provided it prevents line signals in one section of the complete speech path from spilling over into adjacent sections and has a sufficiently low attenuation to speech frequencies. In the design of these elements signalling requirements are more stringent than speech transmission, and the relays are designed with emphasis on their signalling performance rather than transmission efficiency, which of course must not be impaired by the arrangement adopted.

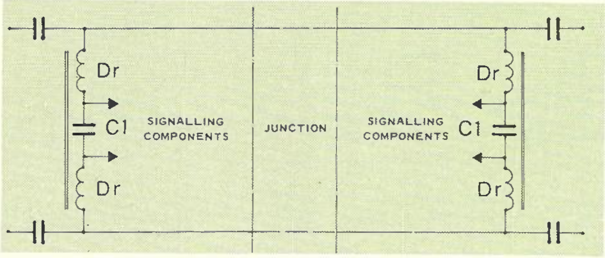


Fig. 5-9 — Filtering for Metering Signals.

The application of metering signals differs from that of other line signals because they are required during conversation and must be inaudible. Where they are transmitted by polarity reversals the signals are filtered by networks of inductance and capacitance and no reliance is placed on relay coils to provide inductance. Fig 5-9 shows the circuit elements normally used at each end. At the battery feed end, where the polarity reversals are generated, the filter made up of the inductor Dr and capacitor C1 reduces the amplitude of high frequency components associated with the signals until they are inaudible. A filter is also needed at the receiving end, because noise is generated in the relay coils as a result of changes of inductance with current and induction effects from relay armature movement.

Decadic Information Signals

If decadic information signals are transmitted over the same line, it is necessary to distinguish them from the line signal for release. Both are generated by interrupting the line current at the end remote from the battery feed but each interruption forming part of a decadic signal is approximately 66 ms, whereas the release signal is of much longer duration, so that time can be and is used as a distinguishing criterion. There is no clearly defined duration of open circuit which a relay set must identify as release, and as it usually depends on the design of slow releasing relays which are not always maintained to close tolerances, it ranges from 200 ms to nearly 1 second for different situations. This can be a source of some operational difficulties and is being given more attention now than in the past.

The requirements to be met for transmission of line signals are considerably different from those to be met for transmission of decadic information, the latter having timing tolerances one or two orders more stringent. High speed of response brings with it a greater sensitivity to operation from transient interference, so that a system optimised for line signals only would have different timing to one optimised for transmission of decadic information signals. The first would have response times of about 50 ms, while the second would have response times of 1 or 2 ms.

The need for these compromises makes relay set design difficult, and in a large heterogeneous network, with equipment designed at different times, and to different specifications there are some extremely difficult maintenance problems caused by these variations. Network changes made possible by the introduction of cross bar systems should eventually minimise the importance of these problems, but at the present stage (1973) the introduction of crossbar into metropolitan networks has made the situation more, rather than less, complex and there is a need for very careful oversight.

One aspect of the use of decadic signalling is that the filters used for multimetering signals cause intolerable impulse distortion and must be switched in and out of circuit, depending on whether decadic information signalling is needed at the particular time.

Intermediate Signals

In addition to the basic line signals, from end to end, there are numerous intermediate signals required between the two ends of a junction or within a telephone exchange, or even a specific switching stage of an exchange. These signals are superimposed on the basic pattern already developed. There is an almost unlimited range of such special signals, both for lines and exchanges, and they need to be studied in detail for each specific application. Exchanges in particular have a very large number of special variations. For junctions there is a group of extra signals in extensive use, known under the names of 'back busy', 'blocking' and 'release guard.' These are signals which indicate that, due to some condition existing at the incoming end, the junction is unavailable. The reason may be, for example, that the line has been taken out of service for technical reasons ('Blocking' or 'Back Busy'), or has not yet completed its release sequence ('Release Guard'). The condition is usually indicated by the same electrical condition as is used for forced release, the signal being distinguished by its context since one signal can only be present if the junction is idle and the other is only present if the junction is engaged. (Actually, forced release and release guard can be consecutive, without any interval between them, or any definite point which can be called the end of the forced release and start of the back busy).

The 'Blocking' signal must be recognised in the idle state, and the use of a sensitive, high resistance relay whose current is not sufficient to be interpreted as a loop condition is necessary, as shown in Fig. 5-8.

Some junctions are designed for both way operation and these must transmit all the necessary line signals in either direction. To do this, each end is equipped with the elements of both an outgoing and an incoming relay set, with provision for switching from one to the other. A problem with both way circuits is that they may be seized at both ends simultaneously, and 'call collisions' which result must be suitably dealt with in the circuit design. Since it must take a finite time for a seizure at one end to be transmitted and recognised at the other, there is always a 'risk time' during which collisions are possible. The only way of completely overcoming problems arising from this is to make the seizure a sequential process; in which the initial action is a 'seizure request', which may be responded to by 'seizure accepted', or 'seizure refused'. In the latter case either the call is allowed to fail, and the subscriber receives busy tone, or a second trunk or junction selected. The choice depends on the probability of the 'seizure refused' condition and the ability of the equipment to make a re-selection.

To fully implement this technique, electrical conditions are needed from both ends to signal:

- Seizure request to other end.
- Seizure from other end accepted.
- Seizure from other end refused.
- Circuit blocked at this end.
- Circuit available for seizure.

Furthermore, the completion of the seizure sequence must see the two relay sets in the correct condition for the direction of the call, i.e. normal battery at the incoming end and loop at the outgoing end, and the sequence must be completed before the next digit is dialled, if decadic information signalling is used.

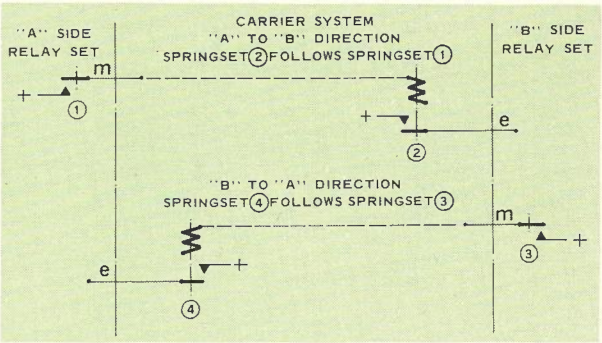


Fig. 5-10 — Signalling on Carrier Channels

No really trouble-free both way relay set for loop conditions has yet been developed, and it is obvious that it would be rather complex and the seizure release sequences would take a fairly long time. Fortunately, the cases where both way signalling on loop circuits are most important are low traffic cases such as from a small exchange and the probability of call collisions is low and can be reduced by various tricks. Quite a big improvement for example can be made simply by sequential searching over a group of junctions in opposite directions from each end, so that as long as two trunks are idle no collision can occur. On a group of 7 trunks this gives nearly a 100 to 1 reduction in call collisions.

SIGNALLING OVER CARRIER CHANNELS

Compelled Sequence Signalling

Modern carrier equipment is provided with signalling facilities, which allow a two-state signal to be transmitted in each direction as shown in Fig. 5-10.

It was originally intended that these two conditions would correspond to loop and open circuit in one direction and normal and reverse polarity in the other. This left no condition to correspond to open circuit battery feed — i.e. forced release and blocking. A system of compelled sequence signalling was therefore developed in which the seizure and release required a sequence of signals in both directions, and provided blocking and release guard facilities. The signalling schedule for this type of signalling is shown in Fig. 5-11.

An unforseen problem with the above arrangement and with any scheme which involved the presence of signalling tone on a large number of channels simultaneously is that the various signalling tones are coherent, and can combine in an unfavourable way to cause severe power over-loading of the carrier system line amplifiers. Because of this, techniques using short pulses in place of continuous tones are now standard.

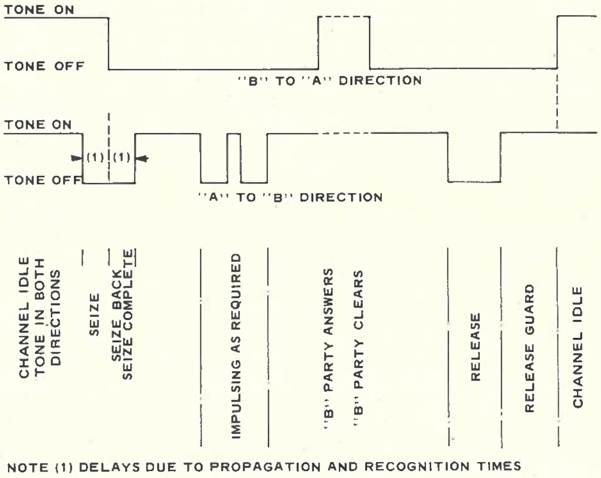


Fig. 5-11 — Compelled Sequence Signalling

LME Pulse Signalling

With pulse signalling, the only way to provide a variety of signals is to control the pulse duration. The APO has adopted, with some variations, the L. M. Ericsson pulse system which uses two pulse lengths; a short pulse of 150 ms nominal, and a long pulse of 600 ms nominal. The short pulse is the shortest which can be reliably transmitted over the carrier signalling path, while the ratio of 4 : 1 is adopted to allow relay timing circuits to be used to distinguish between them.

With only two electrical conditions available, some additional coding is needed to provide for the full range of line signals needed. The method used relies on the fact that line signals must of necessity follow a known sequence, and the schedule of main signals is given in Table 5-5.

TABLE 5-5 — SIGNAL SCHEDULE

Signal	Electrical Condition	
Call	**Short Pulse**	
Release	**Long Pulse**	
Answer	Short Pulse	From 'B' party to Cord Circuit Point
Clear	Long Pulse	
Re-answer	Short Pulse	
Answer	First Short Pulse	From Cord Circuit Point to 'A' party
Meter	Subsequent Short Pulses	
Forced Release	Long Pulse	

Bothway use of trunks is rather easier with this type of signalling because the two signalling paths are symmetrical and independent. The usual arrangement to guard against call collisions is that if signalling is received from the opposite end while the seize pulse is being transmitted, the seize pulse is extended to become a release signal, and busy tone is returned to the caller.

This signalling system is designated 'T' type and was developed by L. M. Ericsson for a register controlled environment. It is not suitable for step-by-step networks, because the pick-up is too long to be accommodated in the interval between dialled digits. A modified system has therefore, been developed in which the decadic information signals are stored at the originating end until the incoming circuit at the far end has been seized and is ready to receive digits. This is indicated by a 'proceed to send' signal which is a short pulse. This means that the first short pulse is proceed to send, the second is 'B' party answer, and the third and subsequent ones are metering. This kind of sequential coding is the only method possible with carrier signalling and has definite limitations, and with the essential differences in technique between carrier and loop signalling techniques, each imposing constraints, it seems to be impossible to add new major line signals within the established format. Indeed, one of the most recent line signalling requirements is for control of echo suppressors on calls used for data transmission and the signal will use a voice frequency tone, transmitted over the speech path in order to avoid the complexity of adding it to existing line signalling circuitry.

Rural Carrier Signalling

A special type of carrier system, known as Rural Carrier, has been adapted to provide junctions to small terminal exchanges using existing aerial wires. This application called for a low cost design and uses transmitted carrier, so that a simple signalling facility can be provided by switching the carrier on and off. This is adequate for signalling in unit fee networks, but because the carrier cannot be interrupted during conversation it cannot be used for transmission of multimetering signals. Therefore, a subsidiary signalling channel, of a very limited signalling speed is added when this is needed. This channel is also used to improve the protection against call collisions. The signalling schedule used for these systems is designated T1.

Pulse Code Modulation Signalling

Pulse code modulation (PCM) carrier systems are a comparatively new development, which by coding speech signals into trains of pulses allows carrier systems to be provided economically over distances of 15 to 50 km without the need for special carrier cables. The nature of the design makes it relatively easy to provide more elaborate signalling and it is usual to have two signalling channels in each direction instead of the one channel provided on standard carrier. Moreover, the restriction on system loading which applies on standard carrier and requires the use of pulsed signals does not apply to PCM. Consequently, a signalling schedule has been developed and designated T5, which makes use of the PCM signalling facilities and allows great simplification of the signalling relay sets.

Very little PCM carrier is in use in the APO, mainly because the development in the largest cities of an extensive co-axial cable network, with standard carrier systems, has already satisfied demands in the field of the greatest advantage of PCM. However, the future extensive use of PCM is highly probable.

Intra Exchange Signalling

Within an exchange, at least three, and usually four wires are available for line signalling, two of these wires being the speech transmission path, and the other wire(s) being used purely for internal signalling. The arrangements vary from one type of exchange to another, but in most exchanges the two speech wires carry line signals corresponding to the external circuits connected to the exchange as this allows a great simplification of either the incoming or outgoing relay set. The two possible situations are shown in Figs. 5-12 (a) and 5-12 (b).

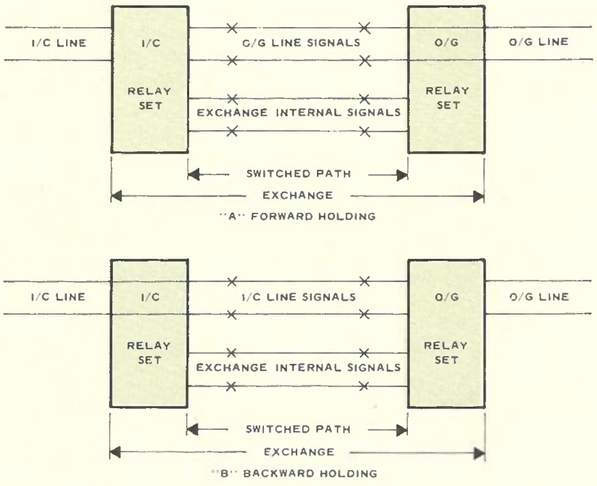


Fig. 5-12 — Intra-Exchange Signalling.

In Fig. 5-12(a) the line signals on the speech pair within the exchange are those needed by an outgoing line, with all line signalling within the exchange controlled from the incoming relay set over other wires. Consequently the speech path wires can be connected straight through the outgoing relay set, as indicated. That is, the outgoing relay set does not have a transmission bridge, and signalling to it is carried over the other exchange wires. The incoming relay set provides a transmission bridge and has the functions of sending, receiving and acting on line signals across three interfaces, one on the 'A' side to the incoming line, one on the 'B' side to the outgoing line, and a further one on the 'B' side to the exchange equipment. The outgoing relay set is considerably reduced in complexity and indeed in some cases is non-existent.

There is, however, one line signal over the outgoing circuit which cannot conveniently be recognised by the incoming relay set over the exchange switching path. This is 'back busy', and if this facility is needed, the outgoing relay set must provide it. This facility can be provided without a transmission bridge, so that even if it is needed, there are still substantial cost savings possible because of the simplicity of the design.

This configuration is known as 'Forward Holding' since one of the more important internal signals is the one which holds the switched path in service and it is sent from the incoming relay set.

In Fig. 5-12(b), the speech pair carries the line signals needed by an incoming line, and the outgoing relay set is the one with a transmission bridge and from which all control is exercised. In this case the only line signal which the incoming relay set must recognise is the pick-up or seizing signal. This configuration is known as 'backward holding'.

All ARF exchanges are designed as forward holding systems, except for the portion of the call from the calling subscriber to the cord circuit relay set, which is backward holding. The direction of holding is shown in detail in Fig. 5-13, which shows the main classes of line relay set which are required. These are the subscribers line relays usually designated as the LR/BR relays, the cord circuit relay set (SR), which is used on all calls outgoing from subscribers in the exchange, outgoing relay sets (FUR) for calls to other exchanges, and incoming relay sets (FIR) for calls from other exchanges.

On a local call, the 'A' side of the cord circuit provides the line conditions needed by the calling subscriber, and the 'B' side provides the conditions needed by the called subscriber, so that, once a connection has been established the subscribers' line relays do not have to recognise any signals over the subscribers' line. The SR holds both backwards to the 'A' party and forwards to the 'B' party.

On outgoing calls, the conditions from the 'A' party to the SR relay set are the same, while on the 'B' side, the SR relay set provides the line signals needed by the outgoing junction. The outgoing relay set (FUR) is therefore a simple relay set without a transmission bridge.

On incoming calls, control and holding are performed in the incoming relay set (FIR) which provides the signalling needed by the 'B' party, as well as holding forward, and includes a transmission bridge.

'd' Wire Signals

The signalling within the exchange is carried on two wires designated 'c' and 'd', which extend through all switching stages, and a third wire designated 'r' which is only provided between the subscribers line relays and the 'A' side of the SR relay sets.

The 'd' wire carries a fairly simple and limited series of signals needed to set up the switching stages which are listed in Table 5-6.

The significance, and the method of using these signals is shown in Fig. 5-14, which is part of the circuit of a crossbar selector (GV or SL stage). In the idle state, the incoming 'd' wire is connected to a call detector circuit, in the portion of the marker known as the code receiver (abbreviated to KMR). The selector is seized by applying ground potential to the 'd' wire at the preceding switch, which initiates action in the marker, as a result of which an outlet is selected, and the necessary horizontal magnets and vertical magnets in the selector rack are operated. Operation of the vertical magnet (GVA or SLD) associated with the selector inlet causes the 'd' wire to be switched, so that the ground from the preceding device is holding the vertical magnet. Another contact operated by the vertical magnet causes earth potential to be extended to the other vertical magnets of the selector stage and to the 'd' wire of the next selected switch, when the same sequence is followed. At the end of the call, the

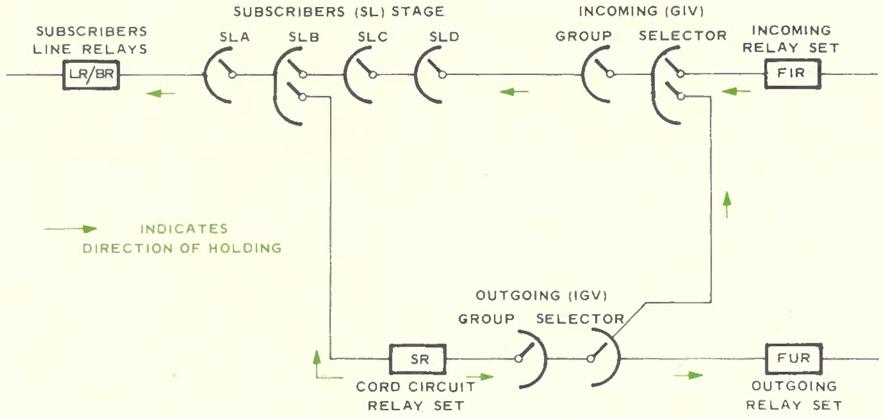


Fig. 5-13 — Holding Conditions ARF Exchanges.

TABLE 5-6 — 'd' WIRE SIGNALS

Signal	Direction	Electrical Condition
Seize, call, call marker, call KMR*	Forward	Ground from Preceding Equipment
Hold	Forward	Ground from Preceding Equipment
Release	Forward	Removal of Ground
Idle	Back	-50V potential in series with 1000 ohms
Busy	Back	Earth Potential

* Different names used for the one signal

ground is removed by the first device in the connection, usually an FIR or SR relay set causing the vertical magnets to release in succession. The only other function of the 'd' wire is to provide a busy test for a marker in a preceding stage when it is selecting an idle inlet in this stage. Examination of Fig. 5-14 will show that the conditions on the 'd' wire are as shown in the last two entries in Table 5-6 for the two states of an idle and a busy inlet.

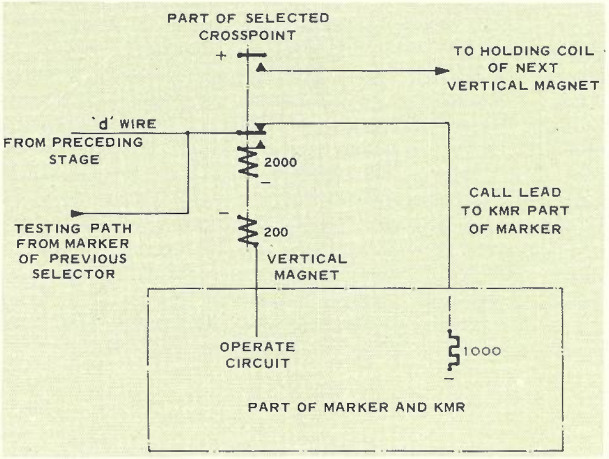


Fig. 5-14 — Use of 'd' Wire.

'c' and 'r' Wire Signals

It will be noted that the 'd' wire is not continuous through the exchange, but that the signals are repeated at every switching stage. The 'c' wire, on the other hand, is continuous between any two line relay sets and carries a variety of signals between them. In a local call, the 'c' wire is used to seize and hold the subs line LR/BR relay set, and to provide a busy test for the subs line. The seize and hold signal is earth potential from the SR relay set, as in the case of the 'd' wire. The busy test is rather more complex, for reasons which will be obvious later.

Between the 'A' party's line and the SR relay set there are five wires, a, b, c, d, and r, as shown in Fig. 5-15, and of these, a, b, c and d have the same functions and signalling as on the 'B' side of the SR relay set, while the 'r' wire is connected to the subscriber's meter (formerly called 'register', hence 'r') and provides metering signals and an answer signal, the latter being needed only for public telephones.

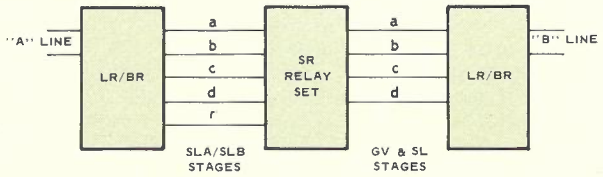


Fig. 5-15 — Signalling Wires in Local ARF Call.

ARF RELAY SETS

The significance of these signalling schedules and the method employed can best be appreciated by a more detailed examination of the circuits of some ARF crossbar relay sets in typical switching configurations.

In a local call there are three line signalling relay sets: two LR/BR relay sets, one for the incoming ('A') side of the connection and one for the outgoing ('B') side, and an SR relay set. The two LR/BR relay sets are, of course, identical, as every subscriber's line is a bothway circuit, used for incoming and outgoing calls.

LR/BR Circuit Operation

On an incoming call, the LR/BR relay set must:

- Recognise a call signal from the telephone and initiate marker operation to connect the line to an SR relay set.
- When switching to the SR relay set is completed, change to a state in which the speech pair is carried through the LR/BR relay set without any series or shunt impedances, to allow battery feed from and signalling to and from the SR relay set.
- Return to normal on a signal from the SR relay set at the end of the call.
- Accept metering signals.
- Protect the line from intrusion by attempted calls incoming to the line.

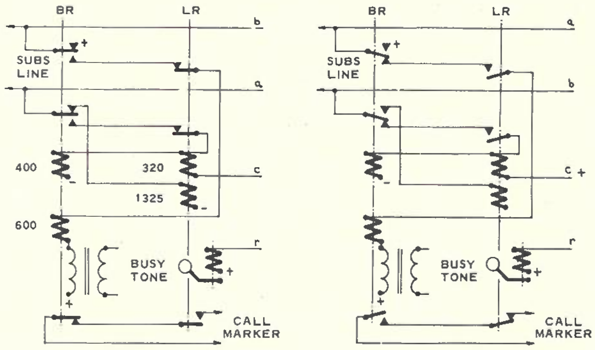
On an outgoing call, the LR/BR must:

- On a signal from the SR relay set switch to the same state as (2) above.
- Return to normal at the end of the call.
- Protect the line from intrusion by further attempted calls incoming to the line.

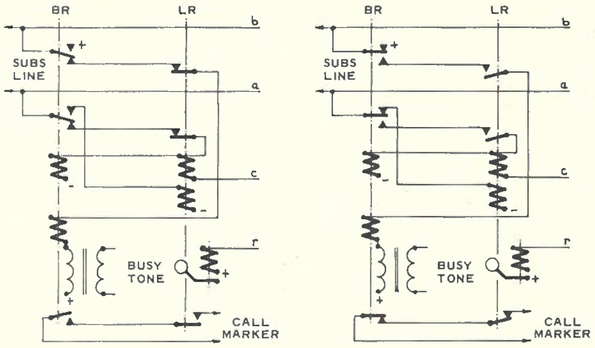
In addition, these relays provide an extra function whereby busy tone can be returned to the subscriber's line from the line relay set without requiring any other equipment to be held. This state is generally called 'line lockout'.

Fig. 5-16(a) is a circuit of the LR/BR relays with both relays shown in the idle condition, which is the state when no call is in progress. It will be noted that relay LR has one winding connected to line to detect calls, outgoing from the subscriber.

When the line is seized for a call incoming to the subscriber, earth is applied to the 'c' wire from the SR relay set, operating the two relays LR and BR in series, giving the situation in Fig. 5-16(b), and it will be seen that there is now no equipment across the line wires 'a' and 'b', which pass straight through. In this direction of switching there is no connection to the 'r' wire.



(A) IDLE STATE (B) SWITCHED FOR O/G OR I/C CALL



(C) LINE LOCKOUT (D) ORIGINATING A CALL

Fig. 5-16 — LR/BR Relay Set.

At the end of the call, the earth is removed from the 'c' wire, and relays LR and BR are no longer held over this path. The relays are so designed that LR releases first, so that if the telephone has not been restored, relay BR remains operated over the line, giving the circuit condition of Fig. 5-16(c). It will be noted that busy tone is fed in series with the BR relay to the subscriber's line. This situation, known as line lockout, continues until the subscriber hangs up.

If the subscriber originates a call, placing a loop across wires 'a' and 'b', the relay LR operates, giving the condition of Fig. 5-16(d), in which there is a circuit between the two 'call marker' wires. This causes the marker to establish a connection to the 'A' side of an idle SR relay set, from which a ground on the 'c' wire operates relay BR and holds relay LR, giving again the condition of Fig. 5-16(b). At this stage the 'r' wire is extended to the SR relay set but is open circuit there. If this call is ultimately successful, the 'r' wire will be earthed in the SR relay set when the called number answers and at the end of the call the wire will be connected for a short period to -ve 50V to operate the meter. The 'r' wire thus provides an answer signal (which is only used if the line is a public telephone, in which case there is a different relay set (MR relay set) which repeats this answer signal to the telephone for control of coin collection and metering.

The release of the call, including if necessary a 'line lockout' sequence, is precisely as for a call outgoing to the subscriber.

The line lockout condition performs another useful function in regard to line faults. The most common line fault is a permanent loop (or call) condition and the exchange is designed so that if a call is present for more than about 45 seconds without dialling, the line is placed on line lockout, so that no exchange equipment

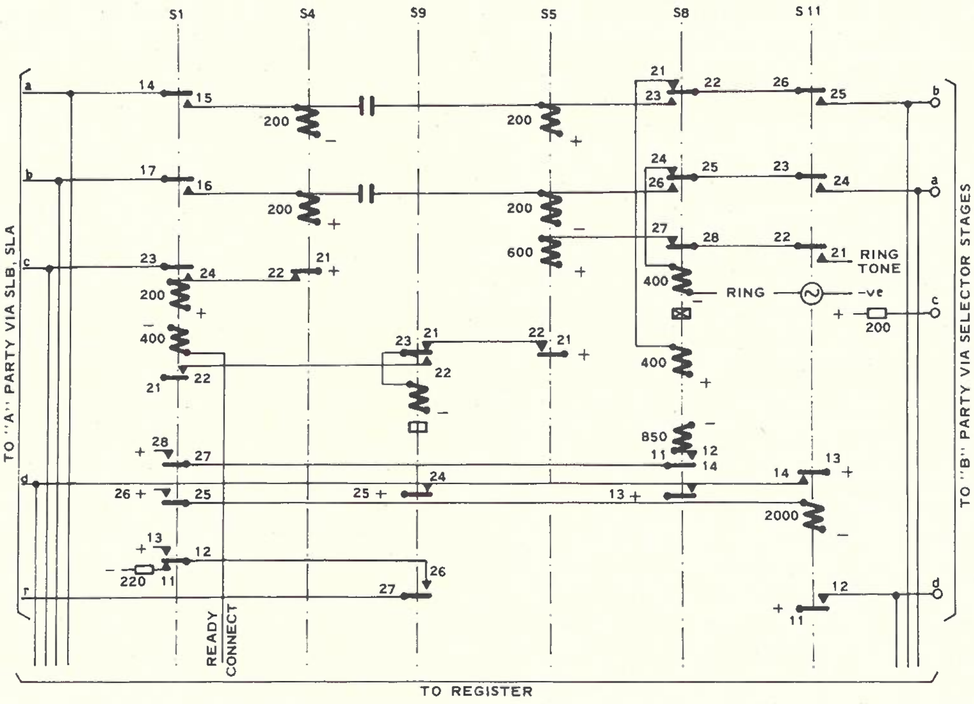


Fig. 5-17 — Simplified SR Relay Set.

other than the LR/BR relays of the faulty subscriber's line is held up. This is the function from which the facility derives its name.

The busy test for a subscriber's line uses the 'c' wire, and it is possible to distinguish between 'sub idle', 'sub busy normal' and 'sub busy line lockout'. This allows some special facilities to be provided, the most useful being to allow test positions to get access to lines on lockout.

SR Circuit Operation — Local Calls

The SR relay set, which provides signalling over the external lines to the two subscribers, and controls the call is a much more complex device. Fig. 5-17 shows a considerably simplified circuit, in which some features have been omitted. This relay set is associated with a register until the call is set up, and during the setting-up period the register performs any necessary line signalling functions. For this reason the 'a', 'b', 'c' and 'd' wires on the 'A' party side, and the 'a', 'b' and 'd' wires on the 'B' party side are extended to the register via the register finder stage, as indicated in the diagram. When the 'A' party calls as described, the call marker signal causes the common control equipment to set up a call to an idle SR and connect it to an idle register which holds the switching stages on the 'd' wire and switches the LR/BR relays into the through condition over the 'c' wire. The register also sets up the call towards the 'B' party, using the 'a', 'b' and 'd' wires for this purpose.

When the connection is established to the 'B' party's line the +ve potential on the 'c' wire via a 200 ohm resistor operates the LR and BR relays, so switching them into the speaking condition. At about the same instant the register operates relay S1 in the SR relay set over the wire designated 'ready connect'. Relay S1 operates relay S11 and the contacts of the two relays connect both sides of the SR relay set to the exchange equipment. Relay S4 also operates from the calling subscriber's line.

With S1, S11 and S4 all operated, the following conditions are applied to the relay terminals:

- Speaking battery is fed to the 'A' subscriber via relay S4.
- Earth (+ve) potential via the 200 ohm winding of S1 is applied to the 'c' wire on the 'A' side. This holds S1 in series with LR and BR in the line circuit.
- The 'A' side 'd' wire is connected to earth (+ve) via a contact of relay S11, holding the 'A' side switches.
- The 'B' side 'd' wire is earthed by a contact of S4, holding the 'B' side switches.
- Ring current (about 75V, 16Hz), in series with the exchange battery, and the windings of relay S8 is applied to the 'B' subscriber's line, ringing his telephone bells.
- Ring tone, i.e., a signal suggesting the sound of the telephone bell, is applied to the 600 ohm winding of relay S5. This relay is acting at this stage as a transformer to transmit ring tone to the 'A' party.

At this stage the signalling conditions previously applied to the SR terminals by the register have been duplicated by the same conditions applied by the SR relay set. The register is no longer required and is released by a circuit which is not shown.

When the 'B' party answers the call, a dc path is completed over the line, operating relay S8 (ring trip relay) which then locks on the 850 ohm winding. Contacts of S8 disconnect ring tone and transfer the 'B' party speech path wires from relay S8 to relay S5, completing the speech connection.

Relay S5 operates to the 'B' party's line loop, and its contact operates S9. S9 disconnects its operating circuit, and changes to a holding circuit dependent on relay S1. A contact of S9 applies earth potential to the 'r' wire to repeat 'B' party answer to the line relay sets of public telephone lines.

The circuit is now in the speaking condition and remains so until the calling party clears.

The 'B' party may clear and re-answer with no effect, as the release and re-operation of S5 now causes no change.

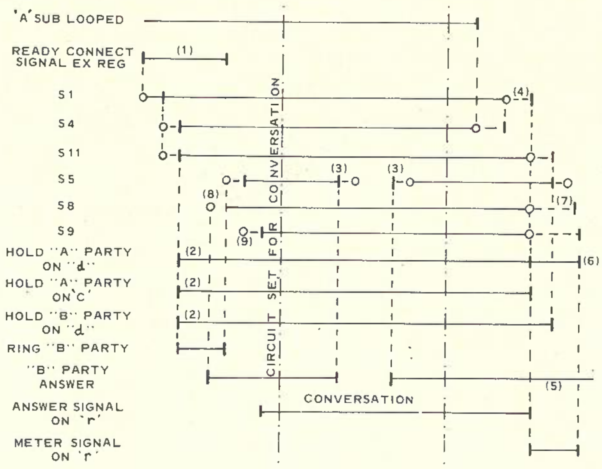
When the calling party restores his handset, relay S4 releases, and commences a sequence which clears the connection. The winding of relay S1 is short-circuited by the contact S4 21-22, and releases slowly. This ensures that a brief interruption to the loop is ignored, as some subscribers equipment can generate short breaks. Once S1 has released, the disconnection of the call proceeds irrevocably, since S1 contacts have now disconnected relay S4 from the 'A' party's line. The release sequence is:

- S1 releases S11, which releases promptly, and S8 and S9, which release slowly.
- When S11 releases, S5 is disconnected from the 'B' party's speech wires, and if it still operated, it now releases. The release of S11 also removes the hold condition from the 'd' wire on the 'B' side, releasing the selectors.
- The release of the 'B' side selectors opens the 'c' wire, and the 'B' party LR/BR relays either release, or change to line lockout.
- When S1 releases it also changes the condition on the 'r' wire from ground potential (answer) to –ve via 220 ohms, which operates the subscriber's meter.
- This latter state continues for the release time of relay S9, which is a slow releasing relay.
- The release of S9 removes holding ground from the 'd' wire on the 'A' side, completing the release of the connection. (Note: This release could not be permitted until the call was metered.)

Fig. 5-18 is a time sequence chart of the relay operations, and Table 5-7 is a chart showing the combination of relays in the SR relay set needed to achieve certain conditions. These two charts present a more compact representation of the operation of the circuit than the preceding description. Sequence charts in one form or another are widely used as a means of describing the operation of a relay circuit, and Fig. 5-18 is one of the standard types of representation with considerably more explanatory detail than is usually provided.

SR Circuit Operation — Junction Calls

The SR relay set is also used for outgoing calls, in which case the 'B' side is signalling to a junction instead of to a subscriber, and for unit fee calls the signals required are those in the second column of Table 5-3. This requires the relay configuration similar to that shown earlier in Fig. 5-7 and means of switching from the previous circuit (Fig. 5-17) to this. These extra segments are shown in Fig. 5-19. On junction calls relay S10 is operated from the register before S1 (Fig. 5-17) and changes the circuit elements associated with the 'B' party side of the speech path to a circuit involving a retard Dr and two relays, S6 and S7, with rectifiers so that S6 operates on reverse polarity and S7 on normal polarity. S6 has contacts which duplicate the function of S5, and contacts of S10 ensure that the appropriate relay, either S5 or S6, is effective.



NOTES: (1) REGISTER READY CONNECT SIGNAL GIVEN WHEN "B" PARTY IS CONNECTED.

(2) THESE HOLD CONDITIONS TAKE OVER FROM HOLD APPLIED BY REGISTER.

(3) DURING CONVERSATION "B" PARTY MAY (BUT NEED NOT) CLEAR AND REANSWER WITH NO EFFECT ON SR CIRCUIT.

(4) S1 IS SLOW RELEASING DUE TO S/C WINDING. DELAY PREVENTS SHORT BREAKS FROM RELEASING CALL.

(5) RELEASE OF SELECTORS TO "B" PARTY CAUSES LINE TO BE SET IN LINE LOCKOUT. THIS WILL CONTINUE. REGARDLESS OF THIS CIRCUIT TILL "B" PARTY CLEARS.

(6) CLEARING OF CONNECTION TAKES PLACE ONLY AFTER ALL RELAYS NORMAL.

(7) DELAY ON RELEASE OF S8 IS INCIDENTAL TO CIRCUIT OPERATION AND UNAVOIDABLE CHARACTERISTIC OF RING TRIP RELAY.

(8) CONTACTS 11-12 OF S8 MUST MAKE BEFORE 21-22 OR 24-25 BREAK. SO THAT HOLDING CIRCUIT IS MAINTAINED.

(9) CONTACTS 21-22-23 ARE MAKE BEFORE BREAK SPRINGS SO THAT DURING OPERATION S9 IS CONTINUALLY HELD ON S5 OR S1.

Fig. 5-18 — Sequence Chart for SR Relay Set.

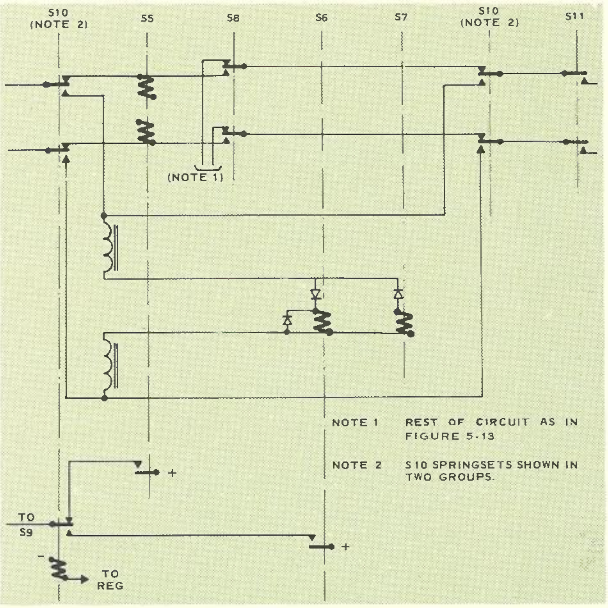


Fig. 5-19 — SR Circuit Elements for Junction Traffic.

TABLE 5-7

Relay	Operate Condition	Remarks
S1	(1) Ground on Ready Connect Lead. (2) S1 Op + S4 Op + —ve from LR/BR on C wire.	When S4 releases, S1 releases with a delay.
S4	S1 Op + A party calling (Looped).	
S5	S8 Op + S11 Op + B sub answering (Looped).	
S8	(1) S11 Op + B sub answer + S8 not operated. (2) S8 Op + S1 Op.	Springsets of S8 adjusted so that these two states overlap.
S9	(1) S5 Op + S9 non Op. (2) S1 Op + S9 Op.	S9 21-22-23 is made before break to ensure that these states overlap.
S11	S1 Op	

Signal	Condition for Signal	Remarks	
Hold to 'A' party on 'd' wire	S9 Op or S11 Op or S8 Op	Holds Switches	All these signals can also be provided from Register during set up of call.
Hold to 'A' party on 'c' wire	S1 operated	Holds LR/BR	
Hold to 'B' party on 'd' wire	S11 operated	Holds Switches	
Hold to 'B' party on 'c' wire	Signal present permanently	Only effective when call is connected.	
Ring 'B' party	S8 Op and S11 Op		
Answer on 'r' wire	S1 Op and S9 Op		
Meter on 'r' wire	S1 not Op and S9 Op		

In this state the SR must work with the outgoing (FUR) relay set, which is required to prevent the junction being seized if a back busy condition Is applied at the distant end and switch the speech path through when seized. Towards the exchange the FUR signals on one lead only, (the 'd' lead), and the signals are as shown in Table 5-8.

TABLE 5-8

(1) back busy — O/C 'd' wire	signalling to the exchange
(2) idle — batt via 1000 ohms	
(3) seize and hold — ground on 'd' wire	signalling from the exchange
(4) release — O/C 'd' wire	

Only FUR signals (3) and (4) involve the SR relay set.

FIR Circuit Operation

For incoming traffic, an incoming (FIR) relay set controls the connection within the exchange and holds forward. A simplified circuit is shown in Fig. 5-20. In the idle condition, all relays are released, including the vertical magnet of the associated selector inlet, and battery and ground is fed to line via relay F1, which is the call detecting relay.

A call operates F1, from a loop applied at the distant exchange, and F1 operates F2 after a short delay which in turn applies ground to the 'd' wire to call the incoming selector. Signalling and selecting take place using MFC information signalling until the circuit is extended to a subscriber's line relays. Relay F6 then operates over the 'c' wire, in series with the LR/BR relays in the subscriber's line circuit, and connects the relays F3 and F4, which ring the 'B' party's telephone, detect the answer condition and repeat it back to the calling end as a polarity reversal. These circuit elements are almost identical to the corresponding part of the SR relay set.

At the end of the call F1 releases, followed after a delay by F2, and the remaining relays, the last being F4, which is slow to release. Only when this relay and the crossbar selector vertical magnet are restored is battery re-applied to the line to indicate to the far end that the circuit is again available. Note also that the key BK can be operated to 'back busy' the junction. If this is done while a call is in progress the key is ineffective until that call is released.

In the circuits so far described, the 'c' wire is used as a means of signalling between SR or FIR relay sets, and the subscriber's LR/BR relays, and the signals used can be described as:

- Seize and/or hold subscriber's line.
- Busy test for subscriber's line.
- An indication that connection has been extended to a subscriber's line (and therefore ringing should commence).

Other Signalling Needs

The 'c' wire is also used for signals needed between other types of relay sets, these signals being necessary because of the design concept of ARF. From the description of the 'd' wire signalling it should be apparent that the ARF switching stages are inherently forward holding and that it is desirable that the incoming relay set or SR should provide the signalling and transmission bridge. However, this requires the 'B' side to be capable of signalling to all types of outgoing lines from the exchange, and as this is not always possible one of the following methods is used to overcome the problem:

(1) A limited number of signalling options can be provided on the 'B' side of the incoming relay set. The SR as described has two, and in the complete circuit a third is provided for Karlsson signals.

(2) Outgoing relay sets with transmission bridges and acting as signalling converters can be used on outgoing lines for which the incoming relay sets do not provide the necessary signalling conditions.

(3) Outgoing relay sets with transmission bridges can be provided, with 'A' side signalling to suit the most common form of 'A' side signalling, and for a call from this kind of incoming circuit the outgoing relay set can assume control, switching the transmission bridge out of circuit on the incoming relay set.

All three methods are used in the ARF system (Fig. 5-21), the choice depending on the particular circumstances, and each has requirements for inter-relay set signalling for which the 'c' wire is used. Within a local network, serving a town and its surrounding rural area, or a large city, the two most common signalling conditions are those for subscribers lines, and for 2 wire junctions with 'B' party switch-hook conditions. These two options will often cope with 90% or more of signalling needs and solution (1) is the most suitable. However, there are also requirements for a limited number of external

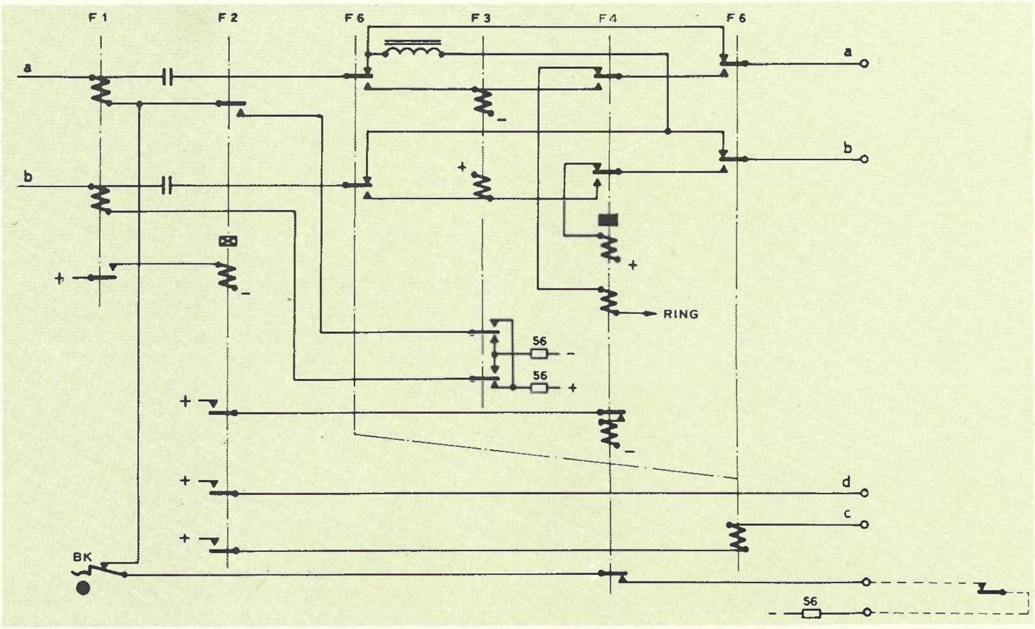
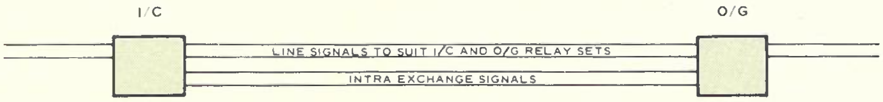
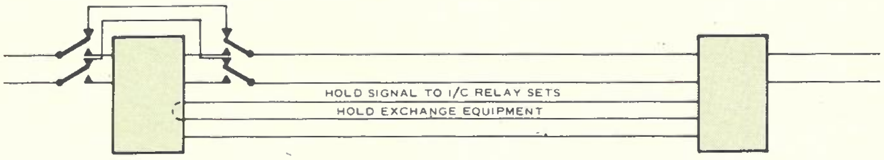


Fig. 5-20 — Simplified FIR Relay Set.

CASE 1 INCOMING RELAY SET HAS "B" SIDE CONDITIONS TO SUIT OUTGOING LINE.



CASE 2 OUTGOING RELAY SET HAS SIGNALLING CONVERSION REQUIRING TRANSMISSION BRIDGE, BUT WITH HOLDING STILL PROVIDED IN INCOMING RELAY SET. I.E. TRANSMISSION BRIDGE IN BOTH RELAY SETS.



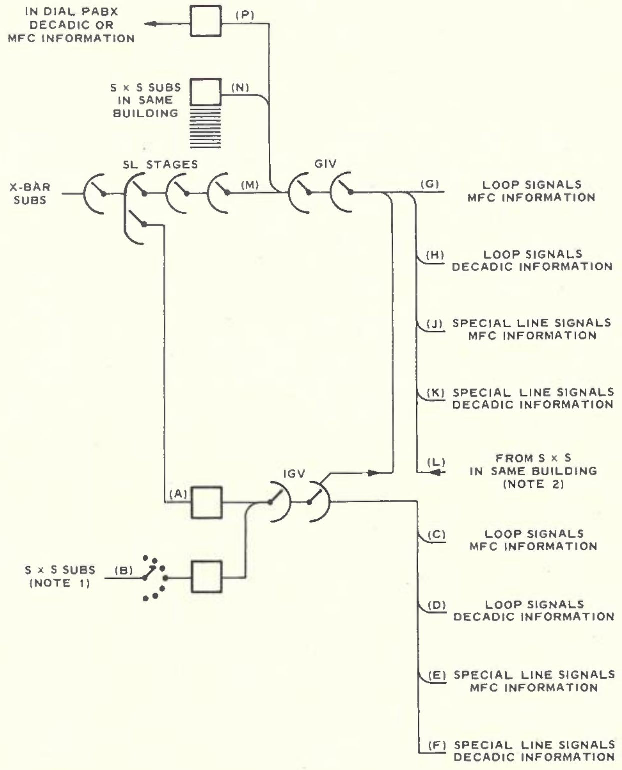
CASE 3 OUTGOING RELAY SET HAS TRANSMISSION AND SIGNALLING BRIDGE WITH "A" SIDE MATCHING INCOMING LINE. TRANSMISSION BRIDGE SWITCHED OUT OF INCOMING RELAY SET. HOLDING FROM OUTGOING RELAY SET TRANSMITTED TO INCOMING RELAY SET AND THEN FORWARD (ON "d" WIRE).

circuits with other signalling such as carrier channels with E and M lead signalling, and 2 wire junctions with Karlsson signalling.

Furthermore, the ARF exchange described so far is a 'pure' crossbar exchange in which all junction circuits are 2 wire lines, with MFC information signalling, and no interworking with step-by-step equipment. In most cases, however, an ARF exchange is installed as an extension to an existing network, with a large step-by-step component, and is often an extension of an existing step-by-step exchange. It may also have a PABX connected with facilities for direct in-dialling using decadic pulses. Allowing for all these possibilities, as well as the possibility of lines with special signalling (such as carrier channels), an ARF terminal exchange may have all the types of relay set connected that are shown in Fig. 5-22.

It is convenient in discussing this exchange to deal with the originating and terminating portions separately. The originating section is comprised of the 1GV stage and the devices connected to it, and the inlets to this stage may be switched to any outgoing circuits connected to the exchange. All the 1GV inlets come directly from subscribers (via a concentrating stage) and require register access. There are two possible groups, crossbar subscribers switched to an SR relay set as previously described, and sometimes step subscribers connected to a similar relay set known as SR (B). This is done when for some reason it is desired to give the subscribers the calling facilities of crossbar without replacing the uniselectors and final selectors.

Both relay sets are identical in their B side facilities and can interwork with 'B' party subscriber condition, 2 wire junctions with 'B' party switch-hook signalling and 2 wire junctions with Karlsson signalling. The choice between the three is made by signals from the register which decides by analysing the dialled code, and sometimes as a result of backward MFC signals.



NOTE 1 STEP SUBSCRIBER'S GIVEN ACCESS TO CROSSBAR 1ST SWITCHING STAGE.

NOTE 2 ROUTE FOR STEP TRAFFIC FROM OWN EXCHANGE TO THE CROSSBAR PORTION MAY ALSO CARRY TRAFFIC TO THE S x S PORTION OF EXCHANGE.

Fig. 5-22

Of the outgoing junctions connected to the 1GV stage, those which are 2 wire circuits need no signalling repeater as the SR relay set provides the necessary line signals for all types of junctions. This means that the speech wires pass through the outgoing relay set, and line signals, decadic information and MFC information can all be transmitted freely. The two categories (C) and (D) representing MFC and decadic signalling cases thus have the one type of relay set.

Outgoing junctions other than those with loop signalling (i.e. categories (E) and (F)) have relay sets which include a signalling bridge, but use it for signal conversion and repetition only, and do not provide any holding signals. Because provision for decadic signalling increases the cost, different relay sets are available in some cases for circuits which do and those which do not need this facility. The SR and SR(B) relay sets must always have a transmission bridge because the exchange internal signals are different on the A and B side of the relay sets. At the same time its intimate association with a register makes it possible and economical to provide the three main types of 2 wire loop signals on the 'B' side without needing 'c' wire signals. The incoming (GIV) stage has a variety of incoming junctions from other exchanges, as well as internal trunks from the 1GV stage, and must connect all of these to three types of lines:

- Crossbar subscribers (M)
- Step-by-step selectors switching to SxS subs (N)
- Indialling PABX's (P)

None of these present any new condition to the SR relay sets, but for incoming traffic there are several new requirements. Firstly, the incoming relay sets may not have register access and need some other way than a signal from the register to indicate the types of line signalling needed. There are here only two types needed, 'B' party subscriber conditions on calls to crossbar subs and 'B' party switch-hook junction conditions on calls to the step section or to indialling PABX's. There are also some opportunities to switch out the incoming signalling bridge on calls to SxS. This arises because SxS is inherently backward holding and a call to a SxS subscriber will always have a signalling bridge in circuit in the final selector.

For this reason, the relay set for loop signalling junctions from crossbar (G in Fig. 5-22) provides the options of 'B' party subscriber signals and a through metallic path, with provision for holding from the step equipment, which is essentially Case 3 of Fig. 5-21. This requires:

- A relay in the incoming relay set which switches out the signalling bridge.
- A signal from the SxS inlet (actually from the GIV when it selected the SxS inlet) to operate this relay.
- An extension of the holding signal from the SxS equipment.
- The signals between the FIR and the LR/BR relay set as in Fig. 5-20 are still needed.

The switching signal (2) is a pulse of +ve battery on the 'c' wire, followed by the holding signal which is earth potential on the 'c' wire.

Fig. 5-23 shows part of the relay set, and should be read in conjunction with Fig. 5-21. The 'c' wire connects via diodes to relays F6 and F7, so connected that on a call to crossbar F7 does not operate and the circuit is in fact identical in operation to Fig. 5-21, and battery on the 'c' wire operates relay F6 to start 'B' party ring.

On a call to a step-by-step number, the positive battery pulse on the 'c' wire operates relay F7, which switches the speech pair to a through metallic path, and applies a holding ground to the 'd' wire. F7 then connects its other winding to the 'c' wire and this winding holds to the ground potential returned from the step-by-step equipment. This holding signal is repeated from the private wire of the step equipment via a simple relay set, which has no connection to the speech path.

The other type of circuit requiring junction signalling conditions is the indialling PABX line (P). These are provided with outgoing relay sets which include a sig-

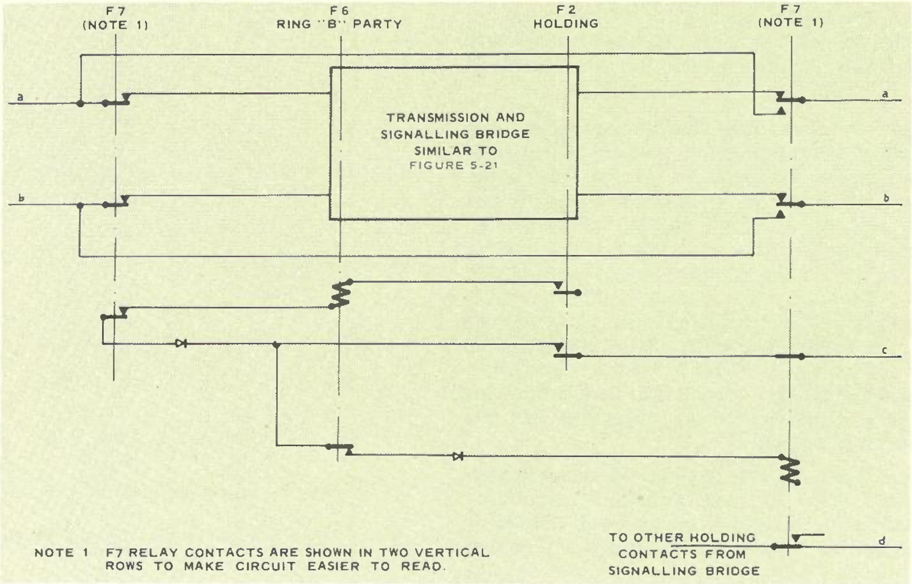


Fig. 5-23

nalling bridge and hold over the 'c' wire precisely as the step-by-step circuits. The number of this kind of circuit is never large and in many exchanges none at all are needed, so this is a more economic solution than providing the facility to interwork with 'B' party junction signals in all incoming relay sets.

For loop signalling circuits incoming from step-by-step (i.e. (H) and (L)), it is necessary to provide a register, but the same line signalling conditions are needed, and on calls to SxS or indialling PABX's the incoming relay set switches to a metallic path precisely as for group (G) except that the decision on switching is made in the register. In group (L), there is an additional requirement for metering signals to be transmitted from calls which switch metallic to step-by-step selectors or indialling PABX's. This signal is a +ve battery pulse on the 'c' wire.

The remaining types of relay set (J) and (K) have signalling other than loop on the junction side. These, of course, cannot switch through on calls to (N) and (P), and must have facilities on the exchange side to signal either to 'B' party lines or junctions with 'B' party switch-hook signals. The change over is made either in response to 'c' wire signals, or by decisions in the register if one is associated.

A full schedule of the signalling on the 'c' wire in an ARF crossbar **Terminal** exchange is given in Table 5-9.

TABLE 5-9 — C WIRE SIGNALS IN ARF TERMINAL EXCHANGES

Signal	From	To	Electrical Condition
Switch to Junction Type Signals	FUR	FIR	Pulse of +ve50V
SR Connected	SR	FUR-L3F-C	+ve via 1000 ohms (must not precede signal "switch to junction conditions.")
Backward Hold	Some FUR'S	Some FIR's	+ve on 'c' wire
Metering	Some FUR'S	Some FIR's	+ve50V pulse on 'c' wire

Other types of crossbar exchange, including the various ARF tandem configurations, ARK terminal exchanges, and ARM trunk exchanges have similar means of internal signalling, with a schedule specifically designed for each of the different cases. Detailed information is available in relevant APO Engineering Instructions.

Chapter 6 – Information Signalling and Registers, Principles

INTRODUCTION

For reasons which have already been discussed, a crossbar network requires a high speed information signalling system to transmit the called subscriber's number from the register to the common control equipment of the various switching stages. In the L. M. Ericsson system the element of the common control equipment to which the register signals is known as a code receiver, and this designation will be used here.

The signalling system should be able to transmit signals in both directions simultaneously, and in a manner which allows the code receiver to control the timing. In addition to these requirements, a network with alternative routing requires a flexible means of supplying each code receiver with the particular part of the called party's number needed by the associated common control equipment.

The need for this can be seen from the network configuration shown in Fig. 6-1. This diagram shows the possible routing of a call to the number 36 1025, from one exchange in a network. The digits 36 identify the exchange, and there are two alternative routings, the first being on direct trunks to exchange 36, and the second via a tandem exchange.

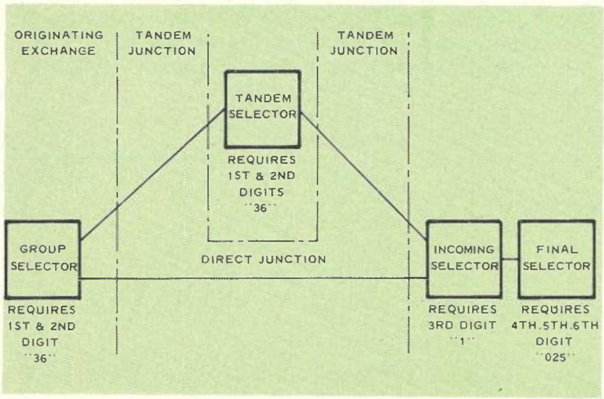


Fig. 6-1 — Typical Signalling Requirement

For either routing, the selector stage in the originating exchange uses the first two digits "36", to determine the route and the selector will connect the call to a direct junction if available, or alternatively if the direct junctions are all busy it will connect the call to a junction to the tandem. In the first case, the incoming selector at the "36" terminal exchange only requires the third digit "1" and subsequent stages require the remaining digits. On the other hand, if the route to the tandem is selected, the tandem selector stage requires the first two digits "36" to allow it to select the outgoing junction route to the "36" exchange, after which the terminal exchange requires progressively the last four digits as before. In some networks much more complex sequences of signalling are needed.

INFORMATION SIGNALLING METHODS

These requirements can be met in two essentially different ways. One is for the complete B party's number to be transmitted to every code receiver in turn and for the code receiver to ignore the surplus information. The other is for the code receiver to specifically request the digits it needs.

Various other parts of a crossbar telephone system are influenced by the choice of the information signalling method, to such an extent that it is not possible to compare the two signalling methods in themselves, but only

TABLE 6-1 — MFC SIGNALLING FREQUENCIES

Forward Signal Frequency	**1,380 Hz**	**1,500 Hz**	**1,620 Hz**	**1,740 Hz**	**1,860 Hz**	**1,980 Hz**
Backward Signal Frequency	**1,140 Hz**	**1,020 Hz**	**900 Hz**	**780 Hz**	**660 Hz**	**(540 Hz)***
Signal No. 1	x	x				
Signal No. 2	x		x			
Signal No. 3		x	x			
Signal No. 4	x			x		
Signal No. 5		x		x		
Signal No. 6			x	x		
Signal No. 7	x				x	
Signal No. 8		x			x	
Signal No. 9			x		x	
Signal No. 10				x	x	
Signal No. 11	x					x
Signal No. 12		x				x
Signal No. 13			x			x
Signal No. 14				x		x
Signal No. 15					x	x

* **Note.** 540 Hz Frequency reserved but not in use.

to compare complete switching systems, employing, as part of their overall design, different information signalling methods.

The first method — signalling the whole B party number — is used in the Trunk and local networks of USA, Canada and Mexico, which have developed a unified trunk signalling technique. This network accommodates without difficulty a wide variety of plant in local networks, under the ownership of many separate companies, and the fact that it places very few restrictions on the design parameters of the local networks is valuable in this situation. One feature is that the information signals are repeated at every trunk switching point by intermediate registers so that all signalling is link by link and each register is only required to know the characteristics of the network as far as the next switching point. Another feature is that only one backward information signal is needed to initiate the transmission of the B party number, when the register is ready to receive it, and this signal uses the line signalling system. More detailed description of the design of trunk and local switching equipment used by the Bell System is available in various papers in the Bell System Technical Journal.

The second method was first used on a large scale in the introduction of LME crossbar in the APO local and trunk networks.

It has proved to be extremely powerful and capable of elaboration to provide facilities that were not originally envisaged. At the same time it is much more demanding in its need for co-ordination and control of the network. This has not been an unmanageable requirement in the context of the Australian telephone network which is under the control of a single administration, and has relatively little variety in switching plant. Similar systems are in use in other countries and there is now a series of international recommendations covering this type of signalling.

MFC SIGNALS

The information signalling system needed for this latter method of signalling must meet a number of requirements:

- It must be capable of transmitting the B party's number digit by digit, i.e. there must be at least 10 distinct forward signals.
- It must be capable of transmitting a number of distinct backward signals.
- It should have a considerably higher signalling speed than decadic signals. Several digits per second is adequate, but higher speeds could give economies by reduced common equipment holding time.
- It must be suitable for end to end signalling over several tandem junctions, whose performance may vary widely in attenuation, frequency response, noise etc.
- The signalling system must allow the code receiver to control the timing of the signalling.

The end to end signalling requirement over a variety of speech paths makes it necessary to use a VF signalling system capable of tolerating a considerable distortion over the path.

The variable timing requirements imposed by the delay access to code receivers, and the fact that the signalling is between a number of different devices on each call makes it desirable to have a system in which timing is not an inherent feature of the signalling code (i.e. the signals should be essentially steady state) and this moreover makes it easier to allow for delays in access to code receivers.

These requirements are met by a signalling code in which each forward signal is composed of two specific frequencies at equal power levels, the frequencies being chosen out of a set of 6, giving 15 combinations. The requirement that two, and only two, frequencies must be present at approximately equal power levels gives a considerable degree of error detection, while the signal is essentially continuous in that the information is present all the time the two frequencies are applied to the line. The actual frequencies, and the combinations used are listed in Table 6-1, and each combination is "labelled" with a numerical designation from 1 to 15. The signals 1 to 10 are usually used (but not always) to convey the numerical digits 1 to 9 & 0, while the remaining signals are used for other purposes.

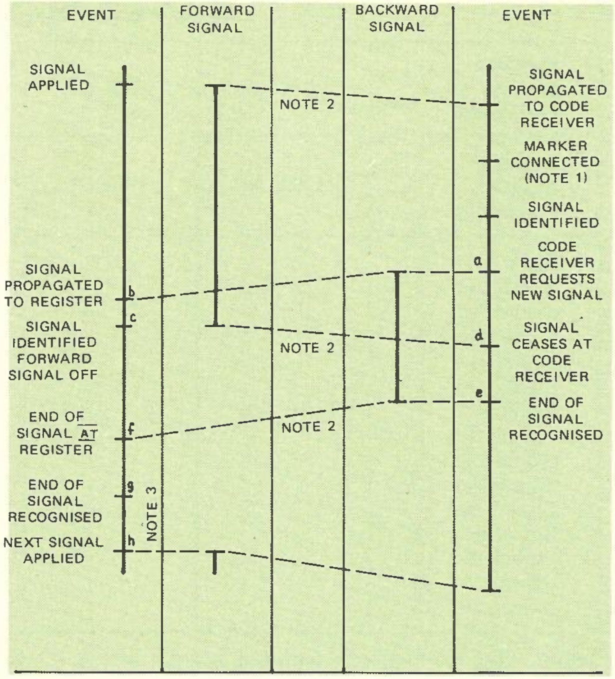
In the backward direction a similar code is used which employs 5* signalling frequencies, so that a 2 out of 5 code gives 10 different signals. These are also listed in Table 6-1, with numerical designations. These designations are merely "labels" to allow for reference to the signals. Thus "backward signal 3" is the signal which comprises frequencies 1020 Hz and 900 Hz simultaneously transmitted.

It will be noted that the forward and backward frequencies are "grouped," in that all the forward signals use frequencies of 1380 Hz and above, and the backward signals use frequencies of 1140 Hz and below. This allows the two directions of signalling to be separated in the signalling equipment by high and low pass filters, and also allows forward and backward signals to be present simultaneously.

This type of signalling is called Multi-Frequency Code Signalling and is usually abbreviated to MFC.

COMPELLED SEQUENCE SIGNALLING

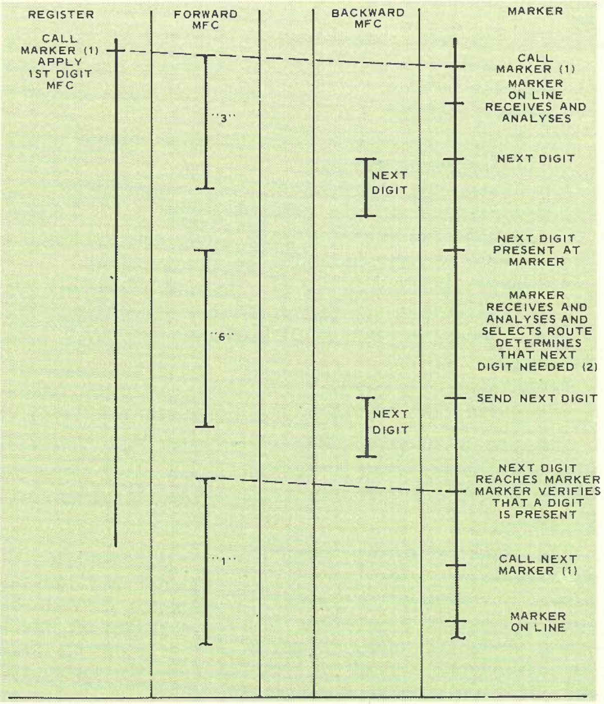
The timing of the signal to suit the needs of the common controls is achieved by a system known as compelled sequence and illustrated in Fig. 6-2. The signalling takes place in sequences made up of one forward and one backward signal and commences with the application of a forward signal by the register. This signal stays on line until the device which uses it recognises the signal and requires it to be changed. At this stage, the code receiver returns the appropriate backward signal at time "a" on Fig. 6-2. After a propagation delay (a-b) this signal arrives at the register at time "b". The register takes a short time (b-c) to recognise and identify the signal, and when this is complete, at time "c" the forward signal is removed as an acknowledgement to the marker of the receipt of the backward signal. After a propogation delay (c-d) and the time needed to recognise the cessation of the signal (d-e), the marker removes the backward signal at time "e". After the propagation delay (e-f) and the time required for recognition (f-g) the next forward signal is applied at time "h", starting a new sequence.



NOTES

1. IF THIS IS THE FIRST DIGIT SENT TO THIS CODE RECEIVER, IT WILL BE PRESENT BEFORE THE CODE RECEIVER IS CONNECTED. FOR SUBSEQUENT DIGITS THE CODE RECEIVER IS ALREADY CONNECTED AND WAITING.
2. PROPAGATION DELAYS.
3. THE REGISTER HAS THE TIME BETWEEN "c" AND "g" TO DETERMINE THE NEXT SIGNAL AND THIS IS USUALLY SUFFICIENT FOR THE NEXT SIGNAL TO BE READY AT TIME "g". THE INTERVAL g-h IS THEN EXTREMELY SHORT.

Fig. 6-2 — MFC Compelled Sequence



(1) THESE ARE LINE SIGNALS.

(2) IF NEXT MARKER NEEDS SAME DIGIT, NEXT MARKER IS CALLED AT THIS POINT WITH NO FURTHER MFC SIGNALS.

Fig. 6-3 — Signal Timing in Group Selector

This is called compelled sequence, because each step in the sequence is initiated by a preceding step and the sequence of events must follow the laid down pattern and cannot get out of step, making it a very reliable and robust system. It is also a fast system of signalling, since every signal is applied only long enough to be recognised, whereas in the more conventional timed pulse system each signal must be long enough to guarantee reception in the most adverse case, and may be 2 to 3 times as long as the **average** signal in the compelled sequence system.

The maximum signalling speed of the compelled sequence system used in LME crossbar is 7 digits per second or about 10 times the speed of decadic signalling.

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* A sixth signalling frequency of 540 Hz is reserved for possible use in the event of the ten backward signals proving inadequate. At present this seems extremely unlikely.

It should be noted that this compelled sequence system starts with the application of a forward signal. It would also be possible to make the first signal a request from a marker for information, and this would appear to be more logical. However, the chosen sequence has timing advantages because it allows the first digit required by a marker to be present before the marker is connected, and also allows considerable overlapping of signalling times and logic operations. This is illustrated by Fig. 6-3 which shows the timing of signals for a group selector requiring digits "36" to switch to a terminal exchange which then requires the third digit "1" as the next signals. This signalling sequence requires only one backward signal, which has the significance "send next digit".

Note that:

- The first digit is applied to the line at the same time as seize forward, e.g. when the group selector is called, at which time the code receiver associated with the group selector is not yet connected, not ready to receive the digit.
- Any forward signal remains on line until the appropriate code receiver has received it and determined what signal is next required from the register. Timing is therefore controlled by the code receivers and delays in switching to outlets and/or coupling to code receivers are automatically absorbed.
- The interval between the time when the register disconnects a forward signal and when it recognises the end of the backward signal is available to prepare to send the next digit. This is usually adequate.
- The code receiver for one device (e.g. this group selector) must set the register so that it is sending forward the first digit needed by the **next selector** and confirm the presence of this digit. This process usually overlaps part of the selector switching time.
- If the last digit used by one selector is also the first needed by the next selector, the call can be switched without any further backward signal, the forward signal remaining on the line and being sent to the next selector.

A BASIC SET OF SIGNALS

In order to control the register a number of backward signals are needed, and three essential signals are:

- Send next digit — used as described above.:
- Restart (or send first digit). This allows the digits already sent to one code receiver to be re-used, and, for example, in the network of Fig. 6-1, if the group selector chose a junction to the tandem centre, this signal would ensure that the first digit received by tandem selector is the start of the B party's number. A restart signal followed by one or more next digit signals from one code receiver can set the register to transmit any digit required as the first received by the next code receiver.
- "End of Selection" signal, which indicates that the information signal now present is the last needed to switch the call, and that the register is no longer required.

Although the above signals are sufficient, they have been expanded in many ways to provide extra facilities. Only one of these additions needs to be discussed at this point. "End of Selection" may occur:

- Because the switching is completed to the "B" party's line, or because the B party's line has tested busy, and the call cannot be connected, or
- because all junctions comprising a link involved in the connection are in use.

It is desirable (not necessary) for the register to take different action on each of these conditions and therefore three "end of selection" signals are provided. For reasons which are partly historical, these signals are "two part" signals.

The first part of the signal has the meaning "Next signal is an End of Selection Signal" and directs the register to prepare to receive that signal in a new code. The second part then has one of the three meanings:

- End of selection, idle subscriber.
- End of selection, busy subscriber.
- End of selection, equipment congestion.

In order to maintain the compelled sequence, the register must reply to the first part of the "end of selection" signal with a "dummy signal", i.e. it must transmit a signal to the code receiver purely to allow the code receiver to return the second part of the signal to the register.

Each of the backward signals described here is allocated a specific one of the 10 possible signals listed in Table 6-1. Table 6-2 lists the allocation used in a basic MFC signalling system. It should be noted that backward signal 1 can mean "next digit" or "end of selection, and idle subscriber", depending on the context of the signal in a signalling interchange.: For this reason, the signals are listed under two headings, or categories "3A" and "B". It will be seen later that most of the blank spaces in each category are also used, and that there are several other categories of signals.

For the present, however, this limited vocabulary is sufficient to allow the structure of registers to be described.

TABLE 6-2 — SIMPLIFIED BACKWARD SIGNALLING SCHEDULE

Signal Number	Significance	
	In Series 3A	In Series B
1	Send next digit	'B' subscriber idle
2	Restart (i.e. send 1st digit)	'B' subscriber busy
3	End of selection next signal is in Series B	Not used
4	Not used	Congestion

REGISTER DESIGN PRINCIPLES

Coupling to Speech Paths.

The essential function of a register in a crossbar exchange is to provide a bufferstore and signalling converter in respect of information signals (dialled digits) transmitted from the calling (A) subscriber. In order to do this, the register must have two signalling paths, one to receive signals from the "A" subscriber and the other to signal towards the various switching stages required to connect the code to the "B" subscriber.

In ARF exchanges these paths are provided by bridging the register across the speech path at a point immediately ahead of the 1st group selector (1GV) stage as shown in Fig. 6-4.

When a subscriber originates a call, his line is connected via the preselection stages of the subscriber's stage (SLA & SLB) to a free first group selector inlet. A register finder switch associated with this inlet connects it to a free register and the coupling relay springsets shown in Fig. 6-4 extend two signalling paths to the register.

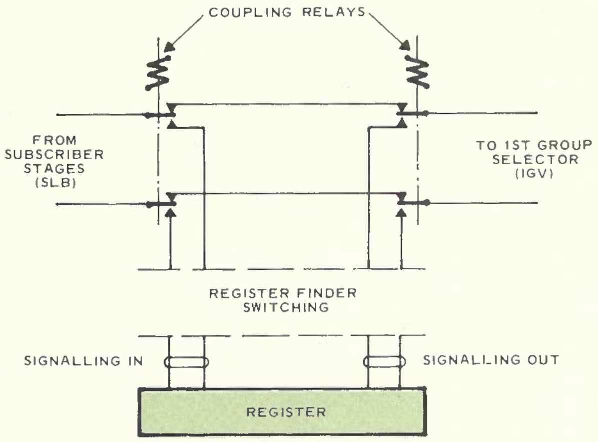


Fig. 6-4 — Register Coupling Arrangement

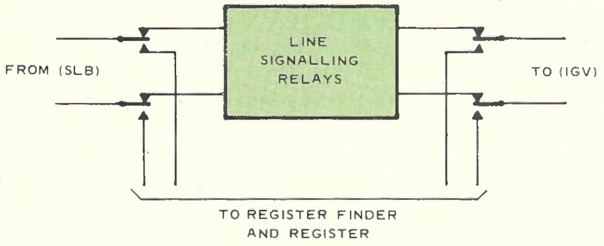


Fig. 6-5 — Position of Cord Circuit

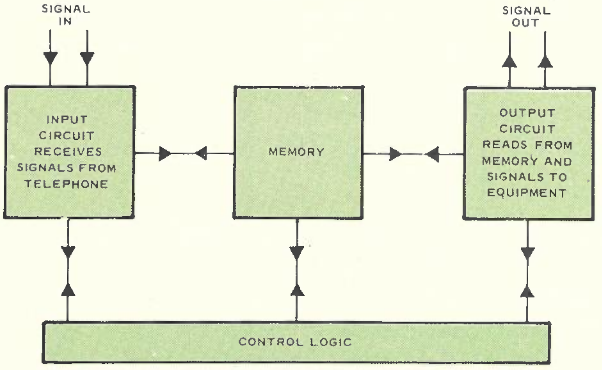


Fig. 6-6 — Major Register Elements

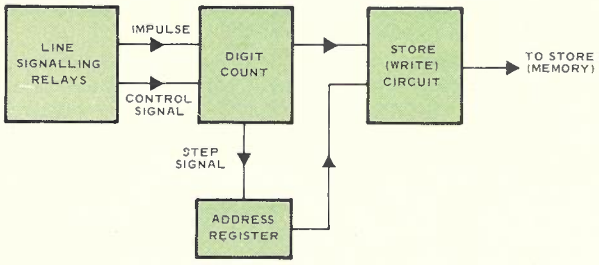


Fig. 6-7 — Detail of Register Input Circuit

The path marked "signalling in" extends the subscriber's line circuit to the register and allows the register to receive dialled information signals from the subscriber. The path marked "signalling" out is used by the register to signal to the various switching stages and set up the call to the "B" party.

When all necessary signalling is complete and the call is extended to the "B" party's line the register causes the coupling springsets to be switched so that the speech path is continuous from the SLB stage to the 1GV inlet, thus connecting the two telephones together, while the register is disconnected and can be used to control another call.

The link between the subscriber's stage and the 1st selector, across which the register is connected is the most appropriate location for the device known as a cord circuit and described in the previous chapter. Thus, instead of the simple circuit shown in Fig. 6-4, there is a relay set similar to Fig. 5-17 in Chapter 5, with additional relays to call and couple to a register and to split the speech path, as shown in Fig. 6-5.

Main Elements of Register

A register is made up of four main elements, interconnected as shown in Fig. 6-6. Central to the whole register is a digit store or memory within which the called subscriber's number is stored. A second element is the input circuit, which receives and counts the impulses from the calling subscriber's dial, and writes, or stores the called subscriber's number in the memory. A third element is the output which sets up the call to the B party using the information stored in the memory. These three elements are under the overall control designated "control logic" in Fig. 6-6, which controls the sequence of operation of the various circuit functions.

Input Circuit

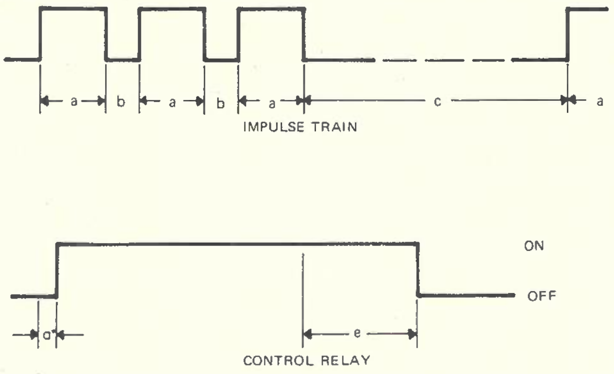
The input circuit can be further subdivided into four major elements as shown in Fig. 6-7. Firstly there is a group of line signalling relays to provide for the reception and transmission of line signals from and to the "A" party. These are necessary because while the register is connected the line signalling relays in the cord circuit relay sets are by-passed. These relays also segregate the decadic information signals from the dc line signals, to be used by the digit counting and storage part of the input circuit.

The rest of the input circuit comprises a "digit count" element, which counts the number of impulses in each digit train, an "address register" to record where to store each digit and a "store" element to transfer the digit to the store.

These latter elements are operated by the short duration breaks in the loop current caused by the dial, and depend on the timing of these breaks in a manner shown in Figs. 6-8 and 6-9. Each impulse train is made up of breaks of 66ms nominal, while there is a make period between each impulse train of approximately 400 ms minimum in the normal case. This period can be much longer if the subscriber delays his dialling.

A relay is provided which operates on the first break of an impulse train and remains operated until there is a remake period greater than the longest possible interval between impulses of one train. With the tolerances needed in relay design this relay usually releases about 100 ms after the last remake of an impulse train, leaving at least 300 ms before the start of the next impulse train.

The digit counting element counts the number of break periods during one operate period of the above relay and when that relay releases this count is transferred to the store location indicated by the store address counter. When the digit is stored the digit count circuit is reset to



TIME INTERVALS

a — ONE BREAK OF AN IMPULSE TRAIN 66 M.SEC. NOMINAL

b — REMAKE BETWEEN BREAKS OF AN IMPULSE TRAIN 34 M.SEC. NOMINAL

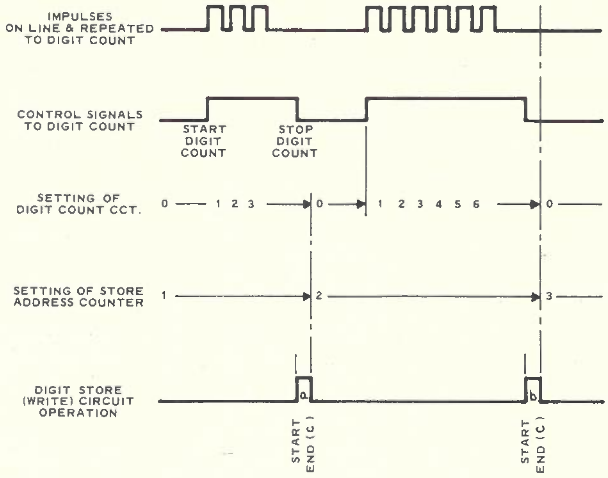
c — INTERVAL BETWEEN TWO IMPULSE TRAINS. DEPENDENT ON DIAL CONSTRUCTION AND SUBSCRIBERS BEHAVIOUR ASSUMED > 400 M.SEC.

d — OPERATING DELAY OF CONTROL RELAY.

e — RELEASE DELAY OF CONTROL RELAY GOVERNED BY REQUIREMENT THAT RELAY DOES NOT RELEASE DURING NOMINAL 34 MS REMAKES OF AN IMPULSE TRAIN

TYPICAL VALUE 100 M.SEC.

Fig. 6-8 — Timing of Digit Reception



(a) DIGIT 3 STORED IN ADDRESS 1

(b) DIGIT 6 STORED IN ADDRESS 2

(c) AT END OF EACH WRITE OPERATION DIGIT COUNT IS RESET AND STORE INCREASED BY 1.

Fig. 6-9 — Digit Counting and Storing

zero, the store address counter is increased by one, and the input circuit is now ready to receive the next impulse train.

Output Circuit

When sufficient digits have been stored by the input circuit, the output circuit of the register is able to set up the call to the "B" party. Fig. 6-10 shows the output circuit separated into three major elements, similar to those of the input circuit. These are:

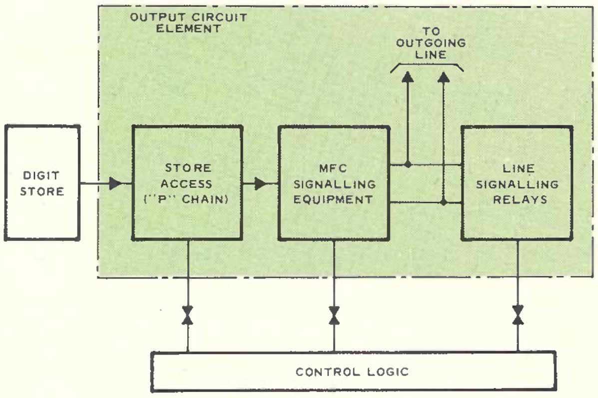


Fig. 6-10 — Structure of Output Circuit

- Line signalling element.
- MFC signalling element.
- Store (memory) access element.

In addition, the output circuit is rather closely interconnected with the register circuit element designated "control logic" in Fig. 6-6.

The line signalling element is needed to provide line signalling in the direction of the "B" party until the register is disconnected and the SR relay set takes over the line signalling functions. Its main functions are to seize forward when the register is ready to set up the call, and to recognise and act on any line signals received while the call is being set up.

The MFC signalling element applies forward MFC signals corresponding to the digit it is desired to transmit from the store, and detects MFC backward signals received over the speech path, transferring them as dc signals to the control logic circuits. It also controls the sequencing of MFC signals.

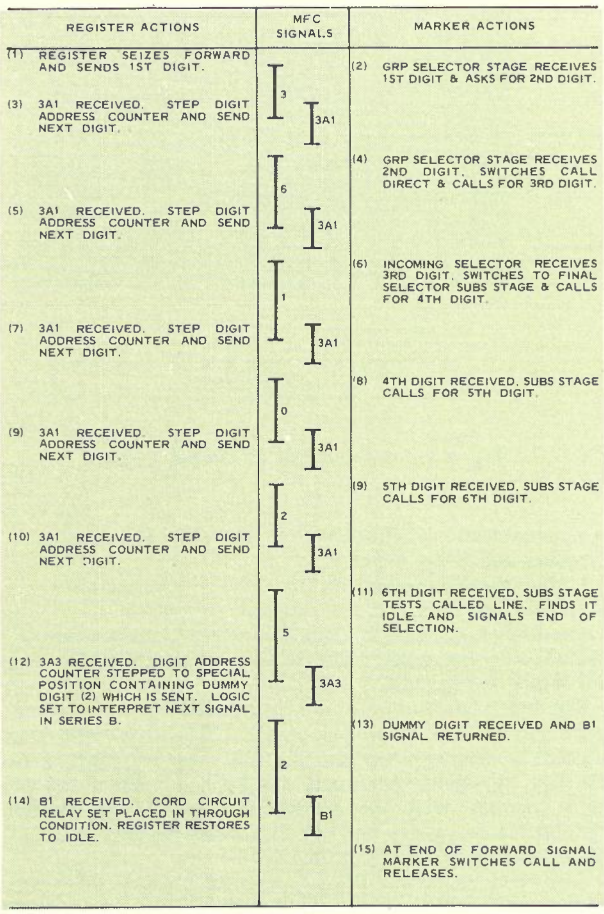
The store access element, under the control of the rest of the register circuit transfers the appropriate digit to the MFC signalling element. Its main part is a "read address counter" which specifies the digit to be read and transmitted.

All registers in use in the APO crossbar system at present use relay logic, and the "read address counter" takes the form of a chain of relays, with one relay for each address. The relays are always designated P1, P2, P3, etc., for the 1st, 2nd, 3rd digit and this circuit element is very widely referred to as the "P chain". However, for the present description the more general term "read address counter" will be used.

Control Logic

The information signalling interchanges needed for the first stage of switching a call in the example shown in Fig. 6-1 have already been described in terms of the signals present on the line. In producing this sequence, this register carries out a number of operations, shown in Fig. 6-11 and discussed in more detail in the following paragraphs.

When the control logic circuit determines that it is time for the register to seize forward (in this case, after 6 digits have been stored) it directs the line signalling element to seize the group selector, the store access element to transfer the first digit to the MFC signalling element, and the MFC signalling element to commence signalling. The group selector is thus seized, with the first address digit



REGISTER ACTIONS	MFC SIGNALS	MARKER ACTIONS
(1) REGISTER SEIZES FORWARD AND SENDS 1ST DIGIT.	3	(2) GRP SELECTOR STAGE RECEIVES 1ST DIGIT & ASKS FOR 2ND DIGIT.
(3) 3A1 RECEIVED. STEP DIGIT ADDRESS COUNTER AND SEND NEXT DIGIT.	3A1	
	6	(4) GRP SELECTOR STAGE RECEIVES 2ND DIGIT, SWITCHES CALL DIRECT & CALLS FOR 3RD DIGIT.
(5) 3A1 RECEIVED. STEP DIGIT ADDRESS COUNTER AND SEND NEXT DIGIT.	3A1	
	1	(6) INCOMING SELECTOR RECEIVES 3RD DIGIT, SWITCHES TO FINAL SELECTOR SUBS STAGE & CALLS FOR 4TH DIGIT.
(7) 3A1 RECEIVED. STEP DIGIT ADDRESS COUNTER AND SEND NEXT DIGIT.	3A1	
	0	(8) 4TH DIGIT RECEIVED, SUBS STAGE CALLS FOR 5TH DIGIT.
(9) 3A1 RECEIVED. STEP DIGIT ADDRESS COUNTER AND SEND NEXT DIGIT.	3A1	
	2	(9) 5TH DIGIT RECEIVED, SUBS STAGE CALLS FOR 6TH DIGIT.
(10) 3A1 RECEIVED. STEP DIGIT ADDRESS COUNTER AND SEND NEXT DIGIT.	3A1	
	5	(11) 6TH DIGIT RECEIVED, SUBS STAGE TESTS CALLED LINE, FINDS IT IDLE AND SIGNALS END OF SELECTION.
(12) 3A3 RECEIVED. DIGIT ADDRESS COUNTER STEPPED TO SPECIAL POSITION CONTAINING DUMMY DIGIT (2) WHICH IS SENT. LOGIC SET TO INTERPRET NEXT SIGNAL IN SERIES B.	3A3	
	2	(13) DUMMY DIGIT RECEIVED AND B1 SIGNAL RETURNED.
(14) B1 RECEIVED. CORD CIRCUIT RELAY SET PLACED IN THROUGH CONDITION. REGISTER RESTORES TO IDLE.	B1	
		(15) AT END OF FORWARD SIGNAL MARKER SWITCHES CALL AND RELEASES.

Fig. 6-11 — Details of MFC Signalling

applied almost immediately to the line (and certainly before the associated MFC receiver is ready to receive it).

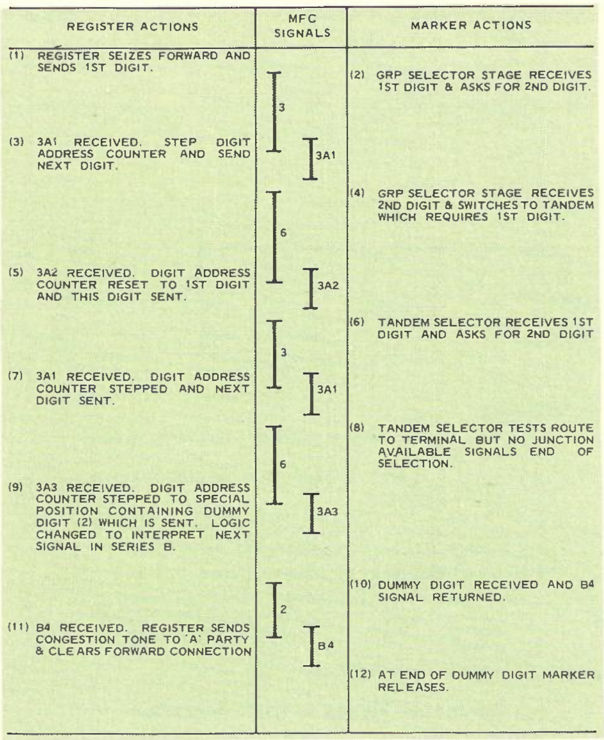
A backward signal "send next digit" or signal 1 from the code receiver is received by the MFC signalling element and transferred to the control logic circuit, where it initiates a sequence of stepping the "read address counter" to read the second digit (6), and then causing the MFC signalling element to transmit it.

Subsequent "next digit" signals step the "read address counter", while a "restart" signal if received, restores that counter to the first digit position, and sequences of these two signals can be received and acted on to suit any network configuration.

Fig. 6-12 shows an alternative sequence in which the 1st two digits are required twice.

For a successful call, after the 6th digit (5) has been transmitted a backward signal "3A3" is sent as the first half of an "end of selection" signal. When this is received the control logic circuit steps the read address counter to a position where it reads a preset "dummy digit", and operates a relay which transfer the wires carrying the dc conditions corresponding to backward signals to different parts of the control logic circuit. This arranges that the next backward signal will be given a different meaning than it would have if it were not preceded by the "end of selection" signal, i.e. it will cause a different response in the control logic circuit.

For a successful call, the next backward signal is "B1", indicating an idle subscriber. On receiving this the control logic circuit causes the register to switch the SR relay set into the through condition so that the two parties are now connected, and releases the register.



REGISTER ACTIONS	MFC SIGNALS	MARKER ACTIONS
(1) REGISTER SEIZES FORWARD AND SENDS 1ST DIGIT.	3	(2) GRP SELECTOR STAGE RECEIVES 1ST DIGIT & ASKS FOR 2ND DIGIT.
(3) 3A1 RECEIVED. STEP DIGIT ADDRESS COUNTER AND SEND NEXT DIGIT.	3A1	
	6	(4) GRP SELECTOR STAGE RECEIVES 2ND DIGIT & SWITCHES TO TANDEM WHICH REQUIRES 1ST DIGIT.
(5) 3A2 RECEIVED. DIGIT ADDRESS COUNTER RESET TO 1ST DIGIT AND THIS DIGIT SENT.	3A2	
	3	(6) TANDEM SELECTOR RECEIVES 1ST DIGIT AND ASKS FOR 2ND DIGIT
(7) 3A1 RECEIVED. DIGIT ADDRESS COUNTER STEPPED AND NEXT DIGIT SENT.	3A1	
	6	(8) TANDEM SELECTOR TESTS ROUTE TO TERMINAL BUT NO JUNCTION AVAILABLE SIGNALS END OF SELECTION.
(9) 3A3 RECEIVED. DIGIT ADDRESS COUNTER STEPPED TO SPECIAL POSITION CONTAINING DUMMY DIGIT (2) WHICH IS SENT. LOGIC CHANGED TO INTERPRET NEXT SIGNAL IN SERIES B.	3A3	
	2	(10) DUMMY DIGIT RECEIVED AND B4 SIGNAL RETURNED.
(11) B4 RECEIVED. REGISTER SENDS CONGESTION TONE TO 'A' PARTY & CLEARS FORWARD CONNECTION	B4	
		(12) AT END OF DUMMY DIGIT MARKER RELEASES.

Fig. 6-12 — Alternative MFC Signalling Sequence

If the subscriber is busy, a backward signal "B2" is received, instead of "B1". In this case, the logic circuit applies "line lockout" conditions to the calling party who thus receives busy tone, from the LR/BR relay set as described in Chapter 5 and then releases the register and SR relay set, and the path previously set up to them from the LR/BR relay set.

A final variation is required if the call encounters congestion at some earlier stage, as in Fig. 6-12. In this case, an end of selection signal (3A3) is transmitted instead of next digit and the response to the "dummy digit" is signal B4, indicating plant congestion. On receiving this signal the control logic circuit causes the register to transmit a congestion tone signal to the calling party and release the forward connection.

In general, the control logic circuit responds to each backward signal by altering the setting of the "read address counter", in order to send a different forward signal, or by performing some local logic operation such as through switching the SR relay set, or arranging a new translation of backward signals, and in some cases the response involves both actions.

ADDITIONAL REQUIREMENTS OF MODERN NETWORKS

Facilities

The facilities described above would be sufficient for a simple network, made up entirely of crossbar exchanges, in which the only requirement is for subscribers to call one another, and perhaps call a trunk operator for long distance calls. Not so many years ago, subscribers would be satisfied with this, and indeed until the late 1950's the telephone systems in Australian capital cities provided very little more, but many new demands are now being made, and telephone systems are expected to provide a variety of additional services. For example:

- There is a technical requirement of a new telephone system to interwork with existing exchanges. This is not an additional service from the subscriber's viewpoint, but is needed for the simple economic reason that the capital investment and size of a network, much of which at any time is almost new, make it impossible to convert it "in toto" to a new system. In particular, this means that provision must be made in the Australian network for switching to and from Step-by-Step Exchanges.
- Subscriber dialling of trunk calls (STD) is now regarded as a normal facility. This not only requires the ability to switch over a much more extended and complex network, but also introduces the need for access control, since certain types of public telephones and some subscribers must not be allowed to dial multimetered calls. The permitted access may be somewhat different for trunk barred subscribers and public telephones, so the access control must be fairly flexible.
- With STD the one trunk network is used by both operators and subscribers and it is necessary to provide the operators with facilities that are not available to subscribers. Typically operators require access to routes and destinations which are barred to subscribers; they may also require priority of access to trunks in some situations.
- On very long distance calls (greater than 2500 miles) it may be necessary to insert echo suppressors to provide satisfactory performance and in an STD network this must be done automatically, whereas in a manual trunk system the operators could exercise some control.
- Data transmission over the telephone network is now possible with special equipment at the subscriber's premises, and while the present data equipment will operate over any normal connection future higher speed data may make special demands on transmission quality and require special action in routing this traffic.
- A wide range of services known by the generic title of "Interception" is being offered to subscribers in some overseas networks; these include connection of calls to a telephone answering service or temporary diversion to a different number. Such services are proving very popular and the APO plans to introduce them in the near future.

Storage in Register

The facilities just mentioned make additional demands for information to be available at various points and times during the setting up of a call. Since most of this information is related in some way to the calling subscriber the easiest way to provide it is to store the additional information in the register and expand the forward and backward signalling codes to allow the information to be called for as required. This causes no great change in the nature of the register but it does require a larger store, together with additional logic circuitry. It is necessary to input the additional data to the store, recognise and act on a wider repertoire of backward signals. Some backward signals, the most important being those which call for decadic information signals to step-by-step selectors, require additional logic circuitry. Collectivelly these needs result in the register being much larger and more complex.

The additional information which is, or may be stored in the register includes the following:

- the calling or "A" party's National number. The first four or five digits of this number is constant for one exchange and can be wired in the register (i.e. a "read only" memory). The other digits are known in the subscribers marker when the register is being connected, and are transferred from the marker at this time.
- the calling party's "class of service", which is a classification indicating the facilities to which he is entitled. About 12 different categories are already reserved, although not all are in use at present. This information is also transferred from the marker when the register is first seized.
- the "charging zone" in which the exchange is located. For trunk charging purposes groups of exchanges are included in one "Charge Zone" and the charge is based on the radial distance between zones. Charging is determined in centralised charging equipment which usually serves several different zones and the "zone of origin" information, together with the initial digits of the called number is needed to determine the charge. The zone designation used for this purpose is a local one, peculiar to the charging equipment through which that exchange's trunk calls are switched. This information is fixed for any one exchange but in some situations one group of registers may control several exchanges in different charge zones.

The need for some of the above information storage and facilities was recognised in the initial development of crossbar for Australian conditions, others have been added to meet further needs that were not originally foreseen; while still others are recognised as future needs but not yet fully incorporated into the APO system. In fact, the 10 years of crossbar development in Australia has seen a surprising growth in the facilities which are being included in the crossbar network. One result of this is that there are two different local registers in use in the network designated Reg. L.M. & Reg. L.P., with different design principles and at present different signalling potentialities.

Information Signals

For both the Reg-LM and Reg-LP, the total number of forward and backward signals required is so great that each of the available MFC frequency combinations must be given several meanings, depending on its context (i.e. the sequence of preceding signals). A typical expanded signalling scheme, which at present only the Reg-LP can fully utilise has five main forward and three main backward signalling schedules.

The forward signalling schedules are designated group 1, group 2, group 3, group 4 and group 10. Thus a signal designated group 1-3 is the signal No. 3 as shown in Table 6-1; i.e. 1500Hz and 1620 Hz applied at time in the signalling sequence when it is interpreted as being in group 1. The backward signals are designated as series 3A, B & C so that signal 3A2, is backward signal No. 2, i.e. 1140 Hz and 900 Hz, applied at a time when it will be interpreted as being in series 3A.

The meaning applied to each of these signals is listed in tables 6-3 and 6-4. Of the forward signals, group 1 is used mainly to forward the "B" party's number as described previously, but in addition to signals to cover digits 1 to 0, there are 5 additional signals which can be used to direct calls to destinations other than subscribers, or to direct the call to follow a predetermined path. The first forward signal from a register is always a group 1 signal.

TABLE 6-3 — MAIN MFC FORWARD SIGNALS

MFC CODE No.	GROUP 1 B-Party's Number Extra Routing Prefixes Response to A-1 & A-2 (Series 1A, 2A, 3A)	GROUP 2 A-Party's General Category Response to A-3 (Series 1A, 2A, 3A,)	GROUP 3 A-Party Category & Restrictions Response to 3A-9	GROUP 4 Zone of Origin Response to 3A2 + 3A2	GROUP 10 A-Party's National Number Response to C-6
1	Digit 1	Call from Operator	Operator	Zone 1	Digit 1
2	" 2	" " Subscriber	Unrestricted subscriber	" 2	" 2
3	" 3	" " Test Position	Test Position	" 3	" 3
4	" 4	" " Interception Centre	Multi-Coin Telephone	" 4	" 4
5	" 5	Spare	STD Coin Telephone	" 5	" 5
6	" 6	Call from Data Service	Data Service	" 6	" 6
7	" 7	" " Overseas Subscriber	Barred to STD	" 7	" 7
8	" 8	" " Overseas Operator	" " Trunk Operator	" 8	" 8
9	" 9	Spare	" " STD & Trunk Operators	" 9	" 9
10	" 0	Reserved for Internal use in MFC, PABX.	Category not available	" 10	" 0
11	Route to Interception Centre	Spare, but not usable in Network at present.	Spare	" 11	Spare-not used
12	Priority Call	"	Reserved	" 12	"
13	Echo Suppressor req.	"	Spare	" 13	"
14	Spare	"	"	" 14	"
15	**Local**-Route to Charge Centre **Trunk**-Route to International Exchange. **International**-End of Number	"	Reserved for shift to new group of categories.	" 15 **or** Zone not available	End of available information (a) Number not available **or** (b) End of Area Code **or** (c) End of Number

Group 10 provides the facility to forward the "A" party's national number, and includes signals for digits 1 to 0, and in addition signal 15 is provided to indicate that the number is complete. For some years, many registers will be unable to forward any part of "A" party number, or may be able to forward only the initial digits. In such cases signal 15 is sent to indicate that the register has sent all the available information, if any.

Group 2 and group 3 provide two different descriptions of the "A" party category, and in both cases the number of signals is reduced by grouping some categories together, in a different way in each case. The subdivision in group 2 is needed by the subscriber's switching stage to control access on the basis of the kind of caller. For example, a test position (signal group 2-3) is allowed to connect to subscribers on line lockout or busy, in order to carry out tests on faulty lines. The group 2 categories are unrelated to charging considerations.

The group 3 categories on the other hand are specifically for access barring related to charging and for example signal group 3-4 allows a trunk operator to receive an indication that the call is from a public telephone and that coins must be collected.

Group 4 signals indicate the zone of origin to charging equipment.

The additions to the backward signalling code needed to allow inter alia the above signals to be called, require 3 series of signals as already stated. The earlier description of a simple register had two series of backward signals and these form the nucleus of series 3A and B. 3A1, 3A2 and 3A3 are the signals for "next digit", "restart" and "end of selection", while B1, B2 and B4 are the signals for "idle subscriber", "busy subscriber" and "congestion". There is one important change to the preceding description in that the reply to signal 3A3 is now a category signal from group 2 instead of being a meaningless "dummy digit" and signal 3A3 is a request for this information, as well as an indication that the next signal is in the "B" series.

Of the remaining 3A signals, 3A10 is added to give more flexibility in calling for MFC digits, and sometimes is more convenient than a sequence of 3A2 and one or more 3A1 signals.

3A4 to 3A8 are self explanatory, and the register responds by ceasing MFC signals and sending all stored digits in decadic form, starting at the specified digit, and then through switching the SR relay set and releasing.

Signal 3A9 calls for the "A" party category in the group 3 format and causes the subsequent backward signals to be interpreted as in series "C", to call for the "A" party number. This means that the "A" party number cannot be called without also calling for group 3 category. As the main application is for trunk call charging, this is not a serious limitation and avoids having two separate backward signals. The "C" series of backward signals has an "escape" back to the basic 3A series, which is often needed.

The calling zone of origin is called for by a sequence 3A2 + 3A2. This sequence cannot occur in normal signalling since "Restart" + "Restart" is meaningless. This is always followed by 3A1, which causes the first digit of the "B" party number to be sent and the normal 3A sequence follows.

TABLE 6-4 — MAIN MFC BACKWARD SIGNALS

Series	MFC Code No.	Description of Signal
3A	1	Send next digit MFC
	2	Re-start MFC (Note 1)
	3	End of selection. Send group 2 signal; change to B Series (Note 15)
	4	Start Decadic Pulsing 1st digit of Local Number
	5	" " " 2nd " " " "
	6	" " " 3rd " " " "
	7	" " " 4th " " " "
	8	" " " 5th " " " "
	9	Send "A" Party's category (Group 3 signal), Change to C series
	10	Send previous digit MFC
B	1	"B" Party idle
	2	"B" Party busy
	3	No timeout before answer
	4	Congestion
	5	"B" Party idle, non metering
	6	"B" Party control; "B" Party idle; no timeout before answer.
	7	"B" Party control; "B" Party idle; non-chargeable.
	8	"B" Party interception; re-route to interception centre.
	9	Send "A" Party category; Change to C Series.
	10	Spare
C	1	Send next digit MFC, change to 3A Series
	2	Re-start MFC
	3	End of Selection, send Group 2 signal, change to B Series
	4	Spare
	5	"
	6	Send "A" Party's National number
	7	Spare
	8	"
	9	"
	10	"

NOTE 1 — Signal 3A2 followed by 3A2 is used for signal "Send Zone of Origin (Group 4) Signal".

The "B" series signals, except for B8, give indications about the state of the SR relay set appropriate to the called number, allowing the register to place that relay set in the appropriate state before releasing.

Signal B8 is the key to a wide range of special facilities and indicates that the number called has been marked for "interception". The register's response to this signal is to release the connection which has been set up, and to set up a new call with the signal group 1-11 applied to the line. This one signal directs the call to the interception centre, via as many switching stages and intermediate tandem centres as necessary. This is possible, as previously mentioned, by arranging that each selection stage switches the call without sending any backward signal.

At the interception centre a code receiver requests the "B" party number originally called using backward signals A2 + A1 etc., and uses this number to interrogate a memory device which will probably be a magnetic disc store, and receive information about the action to be taken on the call.

Many different actions are possible and full details of the facilities to be offered have not yet been determined. Some possibilities are:

- If the number has been changed, the call can be diverted to an operator who will advise the new number. Conceivably a synthetic voice announcement could replace the operator.
- The call can be switched through the interception centre to a different number, allowing a businessman to transfer after hours calls to his home or a telephone answering service.
- The call can be diverted to an interception operator, who can hold some calls and allow others to proceed. This facility could be useful in tracing malicious calls.

Signals B6 and B7 from the interception centre can ensure that the call cannot be released by the calling party and have been included with the malicious call tracing facility in mind. It should also be noted that a call from the interception centre to a subscriber on interception will be allowed to proceed on receipt of signal group 2-4 as a reply to 3A3. The need for this is obvious. The marking of a subscriber's line for interception service will be performed from the interception centre at the same time as the details of the service required are recorded in the centre. This marking will be carried out over the junction network using a further series of MFC signals.

The remaining forward signals in group 1 are used for special routings in a similar manner to the use of signal 11 for interception service. These signals cannot be generated by subscribers and are either generated in the register on analysis of information stored in it or inserted by switchboard operators, who have special keys for the purpose. Any one signal can have several different meanings depending on the switching stage to which it is transmitted.

In order to provide the elaborate repertoire of facilities implied in the preceding section the output circuit of a register contains a number of discrete assemblies of relays for specific functions, together with control logic circuitry to direct the execution of each function as required. This control logic circuitry must make numerous decisions on the basis of information stored in the register and the backward signals it receives.

Number Length and Starting Point Analysis.

Two of the most basic decisions are to determine when to start signalling forward and when the register function is complete. In a full crossbar network forward signalling must be delayed until a complete number is stored, and in such networks it is usual to have uniform number lengths (5, 6, or 7 digits) so that this decision is easily made. Also in a full crossbar network a positive end of signalling indication is given (A3 + B).

However, in a mixed SxS and crossbar network it is desirable to seize forward as soon as enough digits are stored to switch the call to SxS equipment. For example, in Sydney, numbers commencing 432 are Step-by-Step and only the digits 432 are signalled MFC, while calls commencing 439 are crossbar, and all digits are signalled MFC. Therefore on code 432 the register can seize forward after 3 digits, while on 439 it must wait until the full number (7 digits) are dialled. Also, since there is no positive "end of selection" signal on calls to step-by-step, the register needs to know the number length.

Both "starting point" and "number length" analysis of the "B" party number can become very complicated in a large network with a mixture of step-by-step and crossbar.

Chapter 7 – Information Signalling and Registers – Practice

REGISTER DETAILS

- **Structure of Reg-LP**
- **Reg-LM Facilities**
- **Waiting Place**
- **Reg-I**
- **Intermediate Registers**

  Subsidiary Buffering to Reduce Post Dialling Delays.

  Subsidiary Analysis of Number Length and Type of Terminating

  Equipment.

  Providing Signalling Code Translation.

  Signal Regeneration.

- **Types of Intermediate Registers**

OTHER REGISTER FUNCTIONS

CODE RECEIVERS

- **Definitions and Functions**
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REGISTER DETAILS

Structure of Reg-LP

The two main registers used in ARF crossbar are designated Reg-LP and Reg-LM. The Reg-LP is the later design and is standard for new installations. It will be described first, although at present it is greatly out-numbered by the earlier Reg-LM design.

Some parts of a register are used for a relatively small part of its total holding time, and just as registers are shared by a number of speech paths, some of the register functions are transferred to peripheral devices, shared by a number of registers. In the Reg-LP, this is done for the analysis function, the MFC signalling equipment; and for the decadic signalling equipment. The analysis function occupies less than 1 second for each call, enabling 22 registers to share one analyser. The MFC signalling equipment is used on the average for 25% of the register holding time and is known as a Code Sender (KS). The decadic signalling equipment is used only on calls to step-by-step numbers, and then only for 6-8 seconds per call, and is called a Decadic Sender (DS). The register is connected to these peripherals as required. by suitable coupling devices and at times determined by its own internal logic. The structure of a Reg-LP and its peripherals is shown in Fig. 7-1.

Reg-LM Facilities

The other main type of register. Reg-LM, has a different repertoire of signalling, originally confined to forward signals in groups 1 and 2 and backward signals in four series 1A, 2A, 3A and B. the first three of which are listed in Table 7-1. It will be recognised that series 3A is similar to that used by the Reg-LP except that 3A9 is

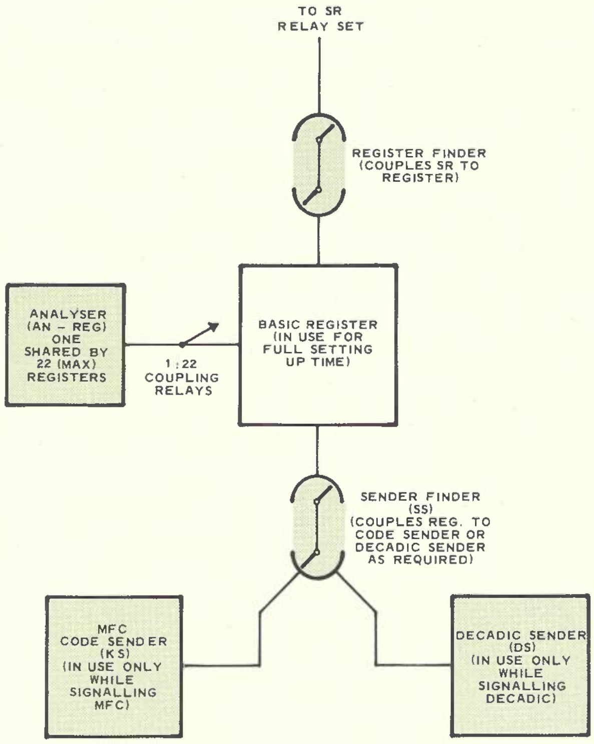


Fig. 7-1 — Reg-LP Peripheral Units.

TABLE 7-1 — REG-LM BACKWARD SIGNALS SERIES 1A, 2A, 3A

Series	MFC Code No.	Description of Signal
1A	1	Send next digit MFC
	2	Re-start MFC
	3	End of selection, send Group 2 signal, change to B Series
	4	Terminal Exchange MFC, 5 digit send same digit, change to 2A Series
	5	Terminal Exchange MFC, 6 digit send same digit, change to 2A Series
	6	Terminal Exchange MFC, 7 digit send same digit, change to 2A Series
	7	Terminal Exchange SxS, 5 digit send same digit, change to 2A Series
	8	Terminal Exchange SxS, 6 digit send same digit, change to 2A Series
	9	Terminal Exchange SxS, 7 digit send same digit, change to 2A Series
	10	Terminal Exchange SxS, number length unknown, change to 3A Series
2A	1	Send next digit MFC
	2	Re-start MFC
	3	End of selection, send Group 2 signal, change to B Series
	4	Start decadic pulsing 1st digit of local number
	5	Start decadic pulsing 2nd digit of local number
	6	Start decadic pulsing 3rd digit of local number
	7	Waiting place next digit, change to 3A Series
	8	Waiting place re-start, change to 3A Series
	9	Waiting place same digit, change to 3A Series
	10	Waiting place previous digit, change to 3A Series
3A	1	Send next digit MFC
	2	Re-start MFC
	3	End of selection, send Group 2 signal, change to B Series
	4	Start decadic pulsing 1st digit of local number
	5	Start decadic pulsing 2nd digit of local number
	6	Start decadic pulsing 3rd digit of local number
	7	Start decadic pulsing 4th digit of local number
	8	Start decadic pulsing 5th digit of local number
	9	Start decadic pulsing 6th digit of local number
	10	Send previous digit MFC

used for decadic sending. The need for signalling zone of origin, the group 3 type of A party category, and A party number were not originally foreseen. In order to introduce new signals, the use of 3A9 by Regs-LM has been discontinued, and in due course these registers will be modified to give a suitable response (probably giving A party category but responding to the subsequent C9 signal with group 10 signal 15 to indicate that no information is available). Also, as required Regs-LM are being modified for zone of origin signals in response to 3A2 + 3A2.

Waiting Place

Series 1A and 2A are used only in the originating exchange and were provided as a means of reducing post dialling delays in mixed step-by-step and crossbar networks. In the early stages of introduction of crossbar into the Australian capital city network, tandem switching was provided by the existing step-by-step main exchanges. Consequently the total switching time was much greater if the call was overflowed via the tandem than if switched direct. In a conventional crossbar system, switching cannot start until a full number is stored and Fig. 7-2 shows that the post-dialling delay on calls to the same destination would vary widely depending on the routing of the call. This variation would be reduced if the seize-forward took place earlier on calls switched via the step-by-step tandem, but this involves proving beforehand whether the call will be switched on the direct or the alternative route, which is logically impossible.

The solution adopted with Reg-LM is to seize forward as soon as sufficient digits are available to switch through the originating exchange and to provide a subsidiary buffering, or waiting place, on calls which are switched crossbar all the way. This is also illustrated in Fig. 7-2, showing how the call which is switched partly step-by-step goes ahead as quickly as possible while the crossbar switched call must wait after local switching is completed, until the full number has been dialled by the calling subscriber.

The waiting place is provided at the outgoing junction, and the facility relies on the fact that the internal line signalling is independent of the inter exchange signalling. Therefore a junction can be seized and busied at the originating end over the "d" wire, while the distant end is only seized when a loop is applied over the "a" and "b" wires, as shown in Fig. 7-3.

The 2A signalling series provides four "waiting place" signals, which cause the register to temporarily suspend forward information signals until the full number is stored, at which time it extends the call to the distant exchange and applies an appropriate MFC signal to the line as previously specified by signal 2A7 to 2A10. On the other hand, if the call is switched via the step-by-step network, the "send decadic" signals 2A4, 5 and 6 are executed without any delay.

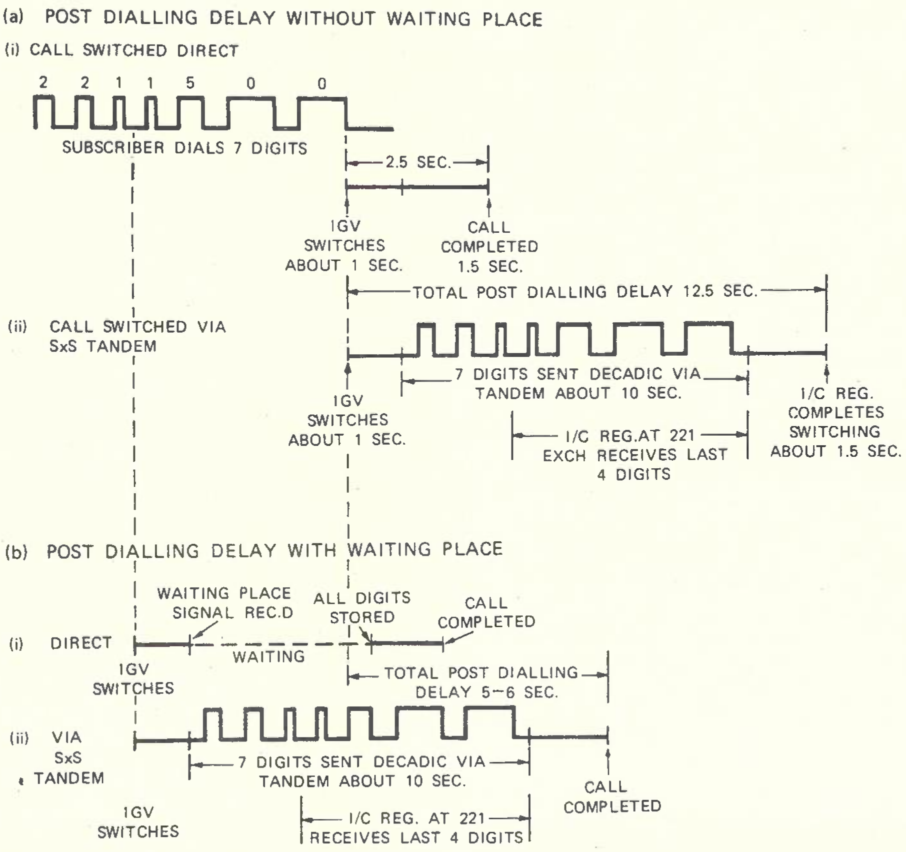


Fig. 7-2 — Use of Waiting Place on Calls between Crossbar Terminal Exchanges.

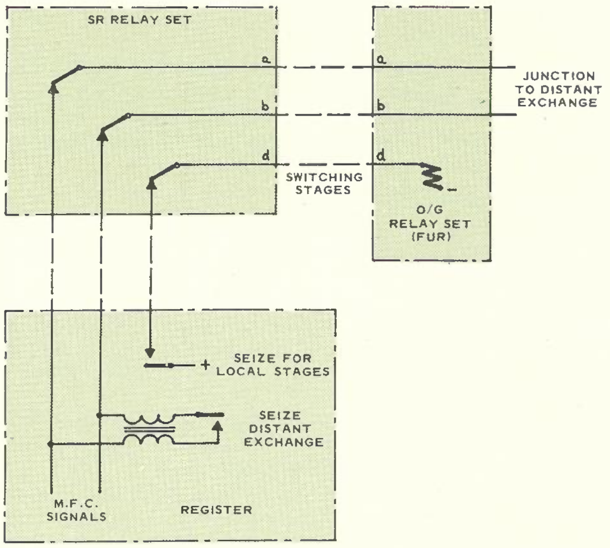


Fig. 7-3 — Waiting Place Circuit Details.

Since the group selector needs to analyse the codes for route and Type of Terminating Equipment (TOTE) in order to return the 2A signals, it is convenient to use this same analysis facility to determine Number Length (NL) and TOTE for the register and the 1A series of backward signals provides the facility to transmit this information. As a result, the Reg-LM has no separate analyser as is the case for Reg-LP, (except that a small amount of internal analysis is provided individual to each register for determination of local code, STD codes and short codes of 3 and 4 digit length). The only part of the Reg-LM functions provided by peripheral devices is the MFC signalling, located in a Code Sender. Decadic sending is built in as a permanent part of each register.

The nature of the MFC information system is such that a uniform signalling code is used over the whole of a network, and any change to the code requires co-ordinated action. An example of this is the change in use of 3A9, which requires as a first step the phasing out of its original function, before its reuse for a new function. In the Reg-LP a strapping field is provided which allows any meaning to be assigned to any backward signal within the limits of the registers' available functions, and includes facilities for a further 4A series if required, but there are no immediate plans for its introduction.

Reg-I

As well as being required as the interface between crossbar subscribers and the rest of the system, registers are also needed to handle calls which originate in step-by-step exchanges and, after being switched through one or

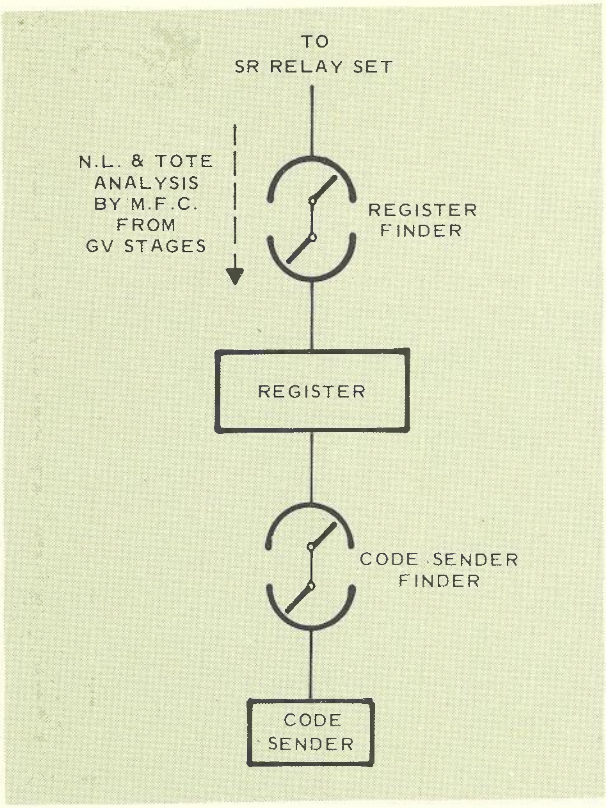


Fig. 7-4 — Reg-LM Peripheral Units.

more stages, terminate in a crossbar exchange. This is a relatively simple application and a register known as Reg-I is provided for this purpose. It is similar to the Reg-LM and uses the same code sender, but is much simpler, needing only to respond to a limited range of 3A and B series signals. Many Regs-I need no decadic signalling and the decadic section of the register is therefore a separate unit, which can be omitted if not necessary.

Intermediate Registers

In principle, one register at the originating exchange can control calls through a network of any size and complexity, but there are practical limitations; there are problems in doing this for say the whole of the Australian telephone network, and for various reasons it is desirable to provide intermediate registers. These registers are similar to the register already described except that the input circuit accepts MFC signalling from the originating register instead of decadic signals from a subscriber. The facilities which such register can provide are as follows:

Subsidiary Buffering to Reduce Post Dialling Delays.

With only one register, the setting up of a call can only start when sufficient digits are stored to satisfy any backward signalling request. For long distance calls the setting up time can be very long, and in most cases, the last digits will not be needed for most of the time. Thus on a call from Cairns to Kalgoorlie, 090-xxxxxx, the greater part of the switching time shall be involved in switching through the trunk network to Kalgoorlie using only the digits 090. Thus setting up could commence after the third dialled digit, so long as there is some provision against the possibility that the switching will get ahead of the subscriber's dialling. This can be done with an intermediate register at Kalgoorlie which receives the last 6 digits from the register at Cairns and does not allow the call to progress beyond that point until all digits of the called number are received. If the switching has taken longer than the time used by the subscriber to dial the last digits, then the call proceeds without further delay. This type of intermediate register is often called a Terminating Register.

Subsidiary Analysis of Number Length and Type of Terminating Equipment.

In the above example, the originating register at Cairns need only know how many digits are needed to reach the terminating register which makes a further decision on number length and starting point. Carried out systematically, this greatly reduces the analysis needed at originating registers. In fact without terminating registers, changes in the network anywhere in Australia would have to be recorded in analysers in every exchange in the country, and this is a completely unmanageable situation.

Providing Signalling Code Translation.

The input and output sides of an intermediate or terminating register need not have identical signalling codes. Even though a standardised system is used throughout Australia, there are occasional local variants and the intermediate registers allow for such variations.

One such variant is that the response to 3A2 may be either the first digit of the National Number or of the local number. Also, when the signalling codes are changed, as with the new 3A9 signal, it is useful to have different parts of the network isolated from each other to avoid the need for simultaneous conversion. Of course in signalling to networks with different signalling methods an intermediate repeater is essential, and this is the case for calls to overseas destinations. Registers for this purpose are installed at International Gateway Exchanges operated by the Overseas Telecommunications Commission, which is the operating authority for overseas calls.

Signal Regeneration.

MFC signalling is capable of operating end to end over the Australian network except when echo suppressors are needed, and the intermediate registers are retained to repeat signals past the echo suppressors and incidentally to regenerate them.

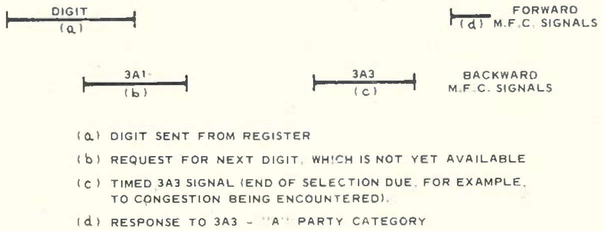
Types of Intermediate Registers

The APO system includes three types of intermediate or terminating registers. One is associated with ARF minor centres and is designated Reg-Y1(LP). It is similar in most respects to Reg-LP, mounts on the same racks, and uses the same peripheral devices. The design of this register is just completed and none are yet in service in the field, but it will play a large part in future network development.

The other two intermediate registers are associated with ARM trunk exchanges and designated Reg-H1 and Reg-Y1, the main difference between them being that Reg-H1 can determine the charge for a trunk call and set the charging equipment in the associated relay sets. Both registers can perform the functions of intermediate or terminating registers and also form the code receiver portion of the exchange marker so that they can best be described in association with ARM exchanges. A feature of both registers is that if the buffering function of the register is not needed they can disconnect and allow signalling to take place without them being present.

With intermediate registers a situation can arise where the compelled sequence of MFC signalling cannot be maintained. This occurs when an intermediate register has requested a digit which is not yet available and before this digit is signalled the intermediate register has determined that the information is not required.

Provision is therefore made that a second backward signal can be sent, with the effect of replacing the previous signal. Such a signal must be a timed pulse, since there is no forward signal present on the line. This sequence is illustrated in Fig. 7-5, where, before the originating register has been able to respond to a 3A1 signal, the intermediate register has established that the call cannot be completed. The timed 3A3 "end of selection" signal is received at the register and cancels the earlier 3A1. The response, a class of service signal from group 2, starts a new compelled sequence.



(a) DIGIT SENT FROM REGISTER

(b) REQUEST FOR NEXT DIGIT, WHICH IS NOT YET AVAILABLE

(c) TIMED 3A3 SIGNAL (END OF SELECTION DUE, FOR EXAMPLE, TO CONGESTION BEING ENCOUNTERED).

(d) RESPONSE TO 3A3 – "A" PARTY CATEGORY

Fig. 7-5 — Use of Timed Backward Signal.

OTHER REGISTER FUNCTIONS

It will be realised that a register is a fairly elaborate device which is capable of acting in many different ways in response to the digits dialled into the register and the backward signalling sequences received from the particular markers encountered during the routing of the call.

Its operation is further complicated in that two or three actions can take place simultaneously and almost independently but with some constraints on their relative timing. Thus the output circuit and the input can be in action simultaneously, but with the restriction that the output circuit operation must halt if it needs a digit which has not yet been dialled into the memory; in parallel with both actions is a series of time supervision circuits which cause the call to be aborted and the register to release if excessive time is taken to execute some function. This is necessary to avoid, for example, a register being held indefinitely when it is seized, not for a genuine call but because of a line fault, or because the handset of a telephone has been accidentally dislodged.

These separately timed activities can interfere with each other in unexpected ways and a register must be able to cope with many rather infrequent and not easily foreseeable contingencies: the "A" subscriber may release at precisely the moment when the B subscriber answers; the output circuit may seek to send a digit at the moment it is being stored, and so on. The designer of a register naturally attempts to foresee all of these conditions and design the circuit to perform properly in all cases, but invariably at the prototype testing and field testing stages conditions are encountered when the register fails to perform properly, and modifications are needed.

The result of all this is that any register includes a number of circuitry details which are incidental to the main sequences but which nevertheless obscure the general pattern and make the circuit difficult to follow. Moreover, because of the large number of different possible sequences, circuit descriptions are a problem. The usual circuit description confines itself to two or three basic types of call together with the most common variations; even in this form is lengthy and difficult to follow.

The simplest register in use in the APO system is the Reg-I, and this is recommended as a starting point for further study.

CODE RECEIVERS

Definitions and Functions

The markers to which registers signal are generally organised so that the signalling portion is separate from the rest of the circuit and is called a "code receiver". The main functions of a code receiver are:

- To signal to the register in order to obtain the necessary routing digits.
- To analyse these digits and indicate the desired route or outlet from the switching stage to which the marker must connect.
- To signal to the register, on conclusion of switching, and under the direction of the marker, in such a way that the correct signalling is provided for the next stage, which may require either a specific digit in MFC or decadic signalling; or alternatively to signal "end of selection" if the call is completed, or encounters congestion.

The code receiver has two well defined interfaces, one towards the line and thence to the registers, signalling in MFC and one towards the outlet selection and switching part of the marker, with some form of dc signals.

Translation Fields

The translation of the called subscribers number into route identities needs considerable flexibility, as is illustrated by Table 7-2 based on the actual routing of the 1st selectors in a small terminal exchange in a fairly large provincial network.

It will be seen that for codes 1, 3, 4, 6, 7, and 8, the route is determined by the first digit, while for the remaining codes two and sometimes 3 digits are needed. A fairly standardized circuit technique is used to translate these codes to routes and is illustrated in Fig. 7-6.

There are ten wires from the MFC part of the code receiver and when a digit has been received and identified, ground is applied to one of these wires.

TABLE 7-2

Route No.	Carries Calls to Numbers Commencing with
1	921
2	922
3	24 and 25
4	3, 4, 6, 7 8 and 01
5	96
6	52
7	02
8	All other numbers

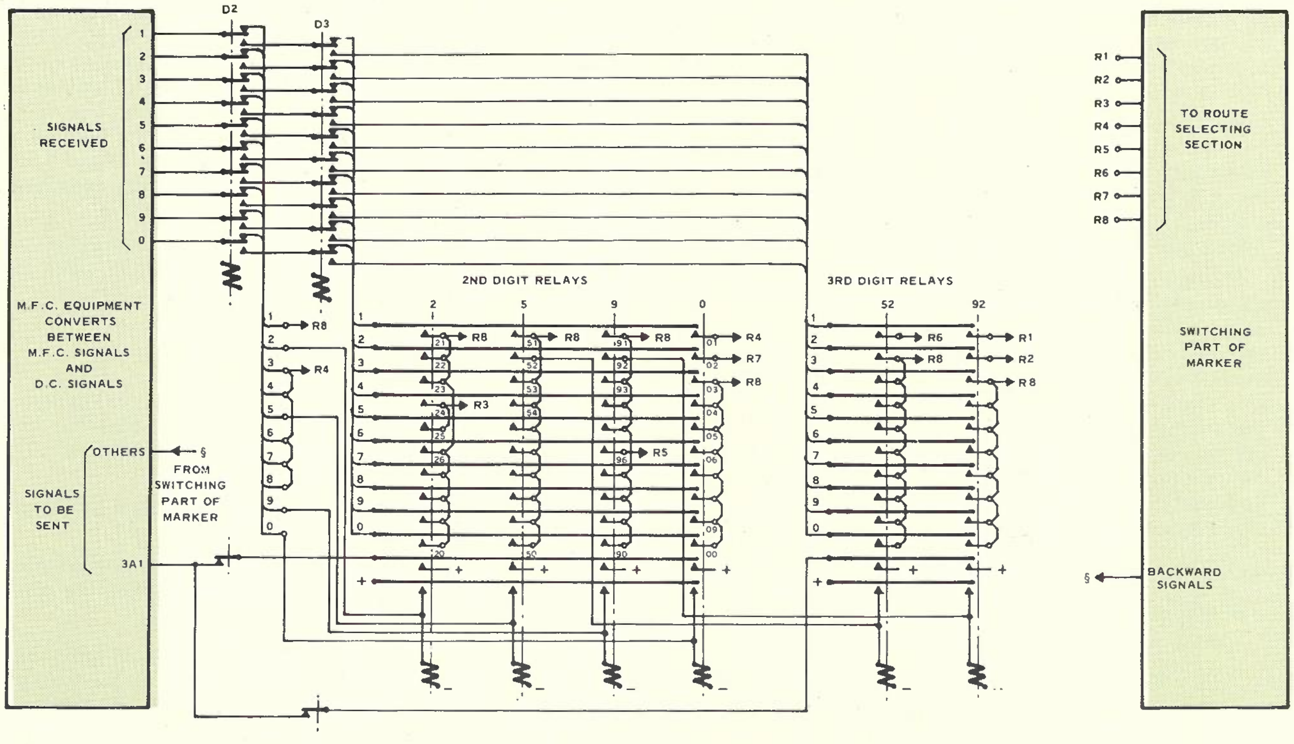


Fig. 7-6 — Principle of Analysis Relay Sets.

When the first digit is signalled to the analyser, the ground potential is applied to the appropriate one of the terminals designated "1st digit" and this terminal can be strapped either to extend the ground to a "route relay" in the route selection part of the marker or to operate a "second digit analysis" relay. In the first instance the marker then proceeds to select and switch, and eventually control the final backward signalling sequence, but until then the forward signal is allowed to remain. In the second instance, one of the springsets of the analysis relays causes the MFC part of the code receiver to call for the second digit, and to separate relay D2 so that the second digit when received is extended to the 2nd digit analysis relay contacts. The action on receipt of the second digit is again either to signal to a route relay or operate a "3rd digit analysis" relay and call for the 3rd digit.

The principle is clearly capable of extension to any number of digits and any degree of complexity of routing analysis merely by adding further relays. All the analysis relays are RAM type multicoil relays, as shown in Fig. 3-16 in Chapter 3, and all those for a particular digit have one side of the contacts multipled to minimise the amount of wiring. It is usual to provide a "basic" analyser with sufficient relays for the majority of requirements and provision for adding further relays in convenient modules of the maximum possible requirement.

This type of analysis circuitry is used in many other parts of LME crossbar equipment wherever it is necessary to identify some characteristics which are related to numerical codes; for example, it is used to determine number length and type of terminating equipment, and in charging equipment to determine the charge rate from the zone of origin and the dialled code.

Chapter 8 — Marker Principles

GENERAL

REGISTER FINDER STAGES

- Structure of Crosspoint Arrays
- Mechanical Details of Switches
- Path Identification
- Marker Operating Sequence

PRINCIPLES OF MARKER OPERATION

- Use of Set Theory
- Testing and Selecting Circuits
- Constructional Details
- Time Supervision
- Delay Working and Traffic Considerations
- Overload Problems
- Characteristics of 1:N Marker Coupling
- Incidental Bypaths

TWO STAGE GROUP SELECTORS

GENERAL

The main functions of a marker have already been implied in the earlier chapters of this book. In brief, it is required to control the setting up of connections between the inlets and outlets of an assembly of crosspoint arrays, each such connection being in accordance with a request from a register.

For the reasons given in Chapter 3, the crosspoint arrays are usually connected as a link trunked system in a manner which requires a fairly large assembly of equipment to be treated as a unit, and depending on the size of the unit, one or several markers may be required.

In most cases the units have between 40 and 200 inlets, and several hundred outlets, and in this size range a single marker can control all switching through the unit. Less frequently, larger units are used which require several markers to operate simultaneously within the unit, each setting up a different connection. The largest such unit used in the APO with relay markers is the ARM trunk exchange which may have 4000 inlets and 4000 outlets, and is designed to have as many as 20 markers.

The number of different connections which one marker may be required to establish is extremely high and to take two typical examples, a standard ARF group selector marker can establish 64,000 different paths, whilst a subscribers' stage marker can establish over 12,000,000. In each case the marker must make due allowance for the presence of as many as 100 existing connections each drawn from the same range of possibilities. In fact the number of distinct states which may exist in the switching stage at the time the marker attempts to set up another connection is astronomical, leading to the situation that a marker is quite unlikely in its whole lifetime to encounter precisely the same set of conditions twice.

This is a factor which must be allowed for in all activities relating to markers, including their design, installation and commissioning and subsequent maintenance, as well as in any description of their operation. One result of this fact is that a marker is of necessity a large, expensive item of equipment, and the overall economics of exchange design can be significantly affected by improvements in marker design. Every manufacturer, as a result, has developed his own specific practices relating to marker design and construction and claims for it some unique and overwhelming advantages. There is such a variety of these designs that it is impossible to do them all justice within the scope of the present book, and so, in this chapter, L. M. Ericsson practice will be dealt with exclusively. This is less of a restriction than it would appear, since, no matter how organised, there are many basic things which a marker must do in one way or another.

An average LME marker contains some hundreds of relays, which may be located on several racks, so that, although the basic principles are fairly simple it is difficult to present circuit drawings in which these details are not completely obscured in a maze of wiring details. One of the smallest markers in ARF crossbar is the Register Finder Marker (RSM) which controls the Register Finder (RS) stage. By deleting some important but not absolutely essential features this circuit can be pruned to the point where it can be comfortably presented on a single drawing, and this will be used as an introduction to the operation of markers.

REGISTER FINDER STAGES

Structure of Crosspoint Arrays

Register finders are required to connect cord circuit relay sets (SR) or line relay sets (FIR) to registers and the particular register finder which will be discussed is the Incoming Register Finder (RS-I) mainly used to connect FIR relay sets to Regs. I on incoming circuits to a crossbar exchange from step by step exchanges.

The RS-I stage is organised in units connecting 64 FIRs to 20 Registers, and is made up of two stages of crosspoint arrays with a structure shown in full detail in Fig. 8-1. The first stage is made up of eight 8 x 5 crosspoint arrays, interconnected to a second stage made up of five 8 x 4 crosspoint arrays. It can be seen that every inlet has access to 20 outlets, that there is only one path between a specific inlet and a specific outlet, and that, if the necessary link is occupied, that outlet cannot be reached from that inlet, even if it is idle. In typical trunking configurations the loading on each link is about 0.1E, and thus internal congestion is relatively small.

There are normally several units of RS-I in an exchange, depending on the number of FIR relay sets needing register access, and the outlets of different RS-I units are interconnected in a homogeneous interconnection scheme.

Mechanical Details of Switches

It has been emphasised that the crosspoint diagram in Fig. 8-1 describes only the essential structure, and that its translation into equipment can take many different forms. In this particular case the translation from a crosspoint array to actual hardware can best be explained in several steps.

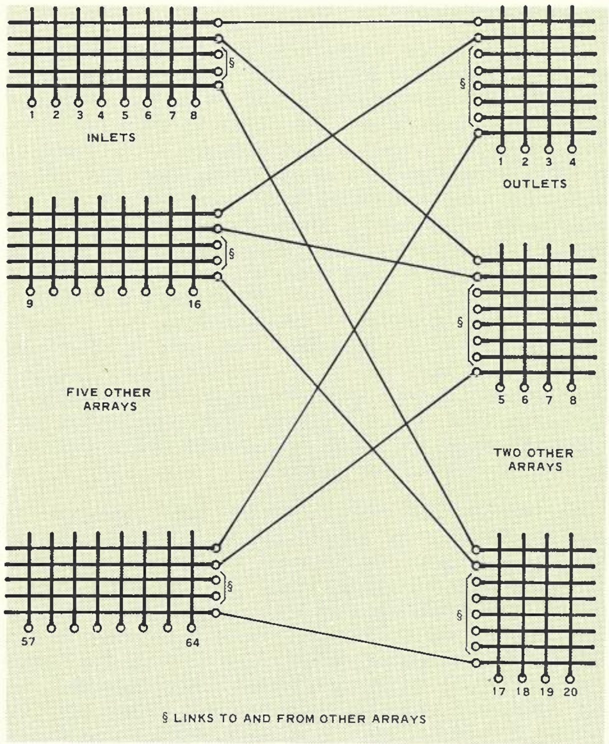


Fig. 8-1 — RS-I Crosspoint Arrays.

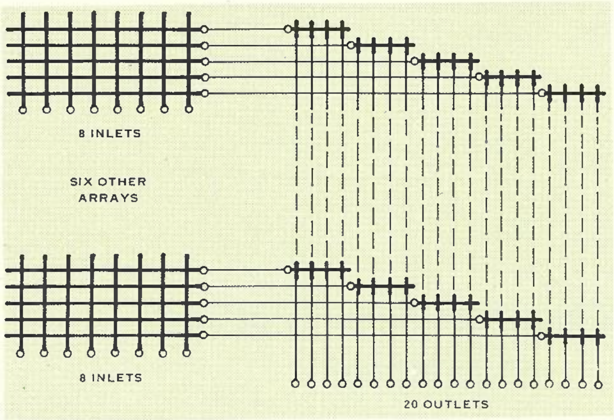


Fig. 8-2 — Re-arrangement of Fig. 8-1.

The basic unit of 64 inlets and 20 outlets can be re-drawn in the forms of Fig. 8-2, where the only change has been a re-arrangement of the positions of the crosspoints of the second partial stage in a form which gives an indication of how the partial stages can be broken up into switches. This drawing shows one way of breaking down the crosspoint arrays into smaller units. In this case the unit consists of an 8 x 1 crosspoint segment of the primary stage, connected by a link to a 1 x 4 crosspoint segment of the secondary stage, and forty such units form the complete RS-I stage.

Each of these units could be constructed from an 8 position switch and a 4 position switch connected back to back as shown in Fig 8-3A, or alternatively from a 12 x 1 array of crosspoints with facilities to operate one of the first 8, and one of the last 4 simultaneously as shown in Fig. 8-3B.

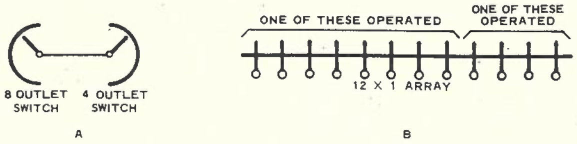


Fig. 8-3 — Basic Unit of RS-I Stage.

Each vertical of an LME crossbar switch has 12 springset assemblies and can be used as a 12 x 1 crosspoint array to give the facilities shown in Fig. 8-3B. The arrangement, detailed in Fig. 8-4, shows the contact wiring on a single vertical of a crossbar switch used in this way. In this configuration the first eight springset assemblies perform the function of the primary array, and the last four perform the function of the secondary array, while the interstage link consists of the multiple bars of the crossbar vertical. A total of 10 springsets is provided in each springset assembly so the final connection between the FIR and Reg. I can use 10 wires. It must be noted that this is an entirely different use of a crossbar switch from the 20 outlet per vertical configuration used in speech path switching stages where 5 or fewer wires are needed and described in Chapter 3.

In Fig. 8-2, each 8 inlets requires a primary array of 8 x 5 crosspoints, five links, and five 1 x 4 segments of

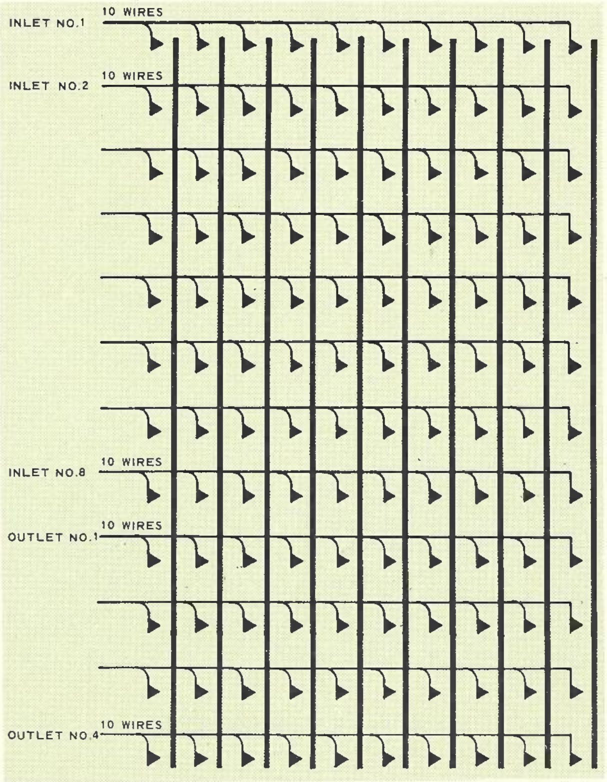


Fig. 8-4 — One Vertical of RS-I Switch.

the five secondary arrays. This requires five crossbar switch verticals, or half of a crossbar switch, while the full 64 inlets will require 8 such sub units, or 4 crossbar switches. Fig. 8-5 shows the detailed connections of the crosspoints on the five verticals serving inlets 1 to 8 and it can be seen that any of the 8 inlets can be connected to any register by operating two springsets on one vertical. For example, FIR No. 3 can be connected to Reg 19 by operating springsets 3 and 12 on vertical 4. (Provided, of course, vertical 4 is not being used for some other connection.)

The connections between switches in an LME link trunked system are usually illustrated by a method known as a "chicken diagram". The basic unit of this method of presentation is the symbol ○- which represents (usually) a crossbar vertical used as a 1 x N crosspoint array. The line, which may point in any direction, indicates the location on the diagram where the devices to which the crosspoints are connected are shown. Thus Fig. 8-6A shows a 1 x 5 crosspoint array switching to the 5 devices shown on the right. The method of showing several 1 x N arrays with their outlets multiplied is illustrated by Fig. 8-6B and simply involves lining them up in the one direction. The devices reached from one array may themselves be 1 x N crosspoint arrays, in which case the outlets must be shown in a different direction, as in Fig. 8-6C.

In the Register Finder, one crossbar vertical is used as two crosspoint arrays, and the special symbol ⫯- is used for the purpose, with two lines at 90° representing the two arrays, and the full diagram in this form for the register finder is shown in Fig. 8-7. Each of the 40 verticals is indicated by a separate symbol, with the

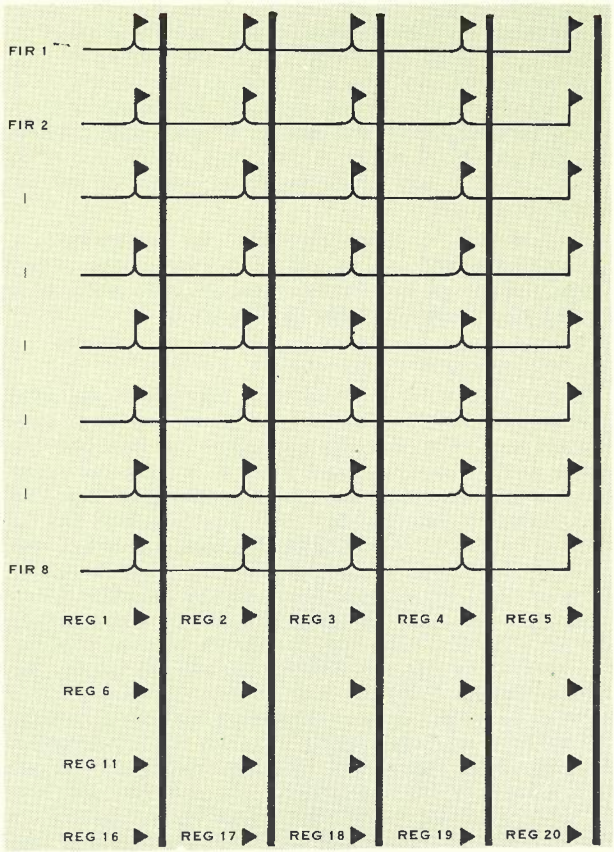
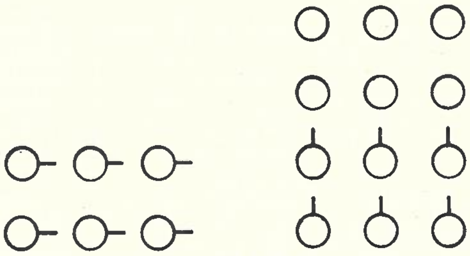


Fig. 8-5 — Portion of RS-I Stage.

(A) ONE SWITCH WITH 5 OUTLETS

(B) THREE SWITCHES WITH OUTLETS COMMONED



(C) TWO STAGE SYSTEM

Fig. 8-6 — Chicken Diagrams.

horizontal pointers indicating the eight FIRs to which it connects, and the vertical pointer indicating the four registers to which it connects. The symbols in the top row correspond with the connections shown in Fig. 8-5. As well as showing more precisely the connections in a link trunked system, this method of presentation allows the designation of many of the relays in the marker to be shown in a way which assists in understanding the circuit operation.

In practice, chicken diagrams are elaborated in various ways, and can provide in a small space a very large amount of detailed information. This account is limited to the features used in this book.

Path Identification

Because there is only one path between a particular inlet and a particular outlet, the full details of a connection can be defined by specifying the inlet and the outlet. In Fig. 8-7 designations of four series of relays located in the marker are given which allow the inlet and outlet to be specified. These are relays 1A1 to 1A8, and B1 to B8 which define the inlet and relays HR1 to HR4 and T1 to T5 which define the outlet. Combinations of these relays also define all the crossbar switch magnets which must be operated to set up a connection. Consider, for example, the connection between FIR No. 27 and Register No. 12. Relays 1A4 and B3 identify the FIR and relays HR3 and RT2 identify the register. This connection is set up by pre-operating horizontal magnets H3 and H11 on switch No. 2, and then operating vertical magnet V2 on that switch. The two horizontal magnets are defined by B3 and 1A4 for H3 and 1A4 and HR3 for H11, while the vertical is defined by 1A4 and T2. In other words, if relays B3 and 1A4 are operated the marker circuit must cause horizontal magnet H3 on switch No. 2 to operate and likewise for the other relay combinations.

The operation of the marker involves firstly the operation of one relay out of each group in order to define a combination of a calling inlet (FIR) and an idle outlet (Reg) for which the necessary link is idle, followed by the operation in sequence of the crossbar switch magnets defined by these relays to establish the connection.

Marker Operating Sequence

A marker circuit which will perform the above functions is shown in Fig. 8-8 (page 89). This circuit differs from the RSM actually used in ARF exchanges in that certain features have been omitted, practical limitations on the number of springsets which can be operated by one relay have been ignored, and the RSM and the switches controlled by it have been assumed to be constructed as a single unit.

The main steps in the operation of the marker will be described assuming that FIR No. 27 calls for a register and that the marker selects register No. 12. The object of the description is to show the sequence and point out how the circuit operation may be broken down into stages, so that a number of details will be glossed over. Most of these details are concerned with avoiding malfunctioning in unusual circumstances and ensuring that the marker will release correctly in all conditions, and can therefore be safely ignored in outlining the normal sequence.

As a guide in following the description, the operating and holding paths of the major relays have been indicated by coloured and numbered lines.

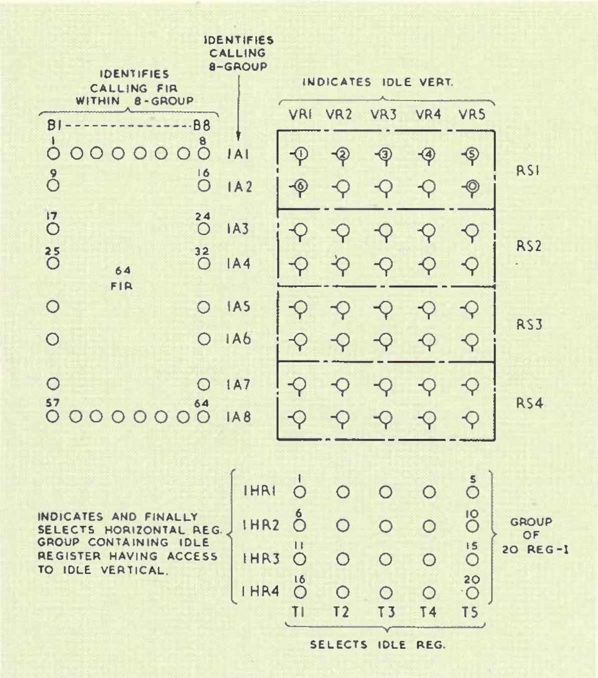


Fig. 8-7 — RS-I Grouping Plan.

The FIR initiates a call from a register by applying -ve battery to the call lead to operate relay 1A4 (path 1) which is then held over path 2 independently of the original operating circuit. The following features should be noted:

- The FIR call leads are parallel in sets of 8, each set being connected to the winding of one of the relays 1A1 to 1A8.
- The operation of one relay breaks the operating circuit of all other 1A relays so that when one relay has operated none of the others can.
- In the event of two calls arriving simultaneously the lower numbered relay breaks the operating circuit of the higher numbered relay. Thus, if 1A4 and 1A6 operated simultaneously only 1A4 would hold.

The operation of relay 1A4 indicates that the calling FIR is in the groups 25 to 32 and reference to Fig. 8-7 will show that these FIRs are connected to verticals V6 to V0 in Switch No. 2. From this point two actions take place concurrently to identify the calling FIR and to select a register.

Relay 2A4 operates as a slave to 1A4 with the result that the 8 leads from FIRs 25 to 32, which were connected in parallel to 1A4, are transferred as individual leads to the windings of relays B1 to B8, which form a selecting circuit similar to 1A1 to 1A8. The lead from FIR 27 with -ve calling potential operates B3 (path 3) which locks (path 4). As with the 1A chain, operation of B3 prevents operation of any other B relays, and in the event of two relays operating simultaneously the lower numbered relay takes precedence.

Reference to the grouping plan will show that to connect FIR 27 to one of the verticals requires pre-operation of H3 on switch 2 followed by the desired vertical magnet. This horizontal magnet is now operated via contacts of B3 and 1A4 (path 5).

Selection of a register takes place concurrently with the above action. Operation of 1A4 has identified the calling group, so that the path, which must be used to reach any register, is known. This information is displayed in Table 8-1. There are 20 registers, and any particular register can only be used if both it and the particular vertical to which it is connected are idle. It is necessary therefore to determine which registers meet the above condition and select one of them. This process of testing and selecting is carried out in two stages.

TABLE 8-1 — CONNECTING PATHS FROM FIRs 25 TO 31 TO REGISTERS

Register No.	Vertical Magnet	VR Relay	T Relay	Horizontal Magnet	HR Relay
1	V6 SW2	VR1	T1	H9 SW2	HR1
2	V7 SW2	VR2	T2	H9 SW2	HR1
3	V8 SW2	VR3	T3	H9 SW2	HR1
4	V9 SW2	VR4	T4	H9 SW2	HR1
5	V0 SW2	VR5	T5	H9 SW2	HR1
6	V6 SW2	VR1	T1	H10 SW2	HR2
7	V7 SW2	VR2	T2	H10 SW2	HR2
8	V8 SW2	VR3	T3	H10 SW2	HR2
9	V9 SW2	VR4	T4	H10 SW2	HR2
10	V0 SW2	VR5	T5	H10 SW2	HR2
11	V6 SW2	VR1	T1	H11 SW2	HR3
12	V7 SW2	VR2	T2	H11 SW2	HR3
13	V8 SW2	VR3	T3	H11 SW2	HR3
14	V9 SW2	VR4	T4	H11 SW2	HR3
15	V0 SW2	VR5	T5	H11 SW2	HR3
16	V6 SW2	VR1	T1	H12 SW2	HR4
17	V7 SW2	VR2	T2	H12 SW2	HR4
18	V8 SW2	VR3	T3	H12 SW2	HR4
19	V9 SW2	VR4	T4	H12 SW2	HR4
20	V0 SW2	VR5	T5	H12 SW2	HR4

The operation of 1A4 extends auxiliary contacts associated with the 5 verticals V6 to V0 in switch 2 to 5 to relays VR1 to VR5 (path 6) and each idle vertical operates the appropriate VR relay. Operation of these VR relays establish testing circuits for registers extended in groups of 5 to the 4 relays HR1 to HR4. Each testing circuit will extend -ve potential to an HR relay if the register concerned and the appropriate vertical are both free. Thus -ve potential will be extended to the coil of HR1 if at least one of the following conditions is satisfied:

- Register 1 and V6 are both free.
- Register 2 and V7 are both free.
- Register 3 and V8 are both free.
- Register 4 and V9 are both free.
- Register 5 and V0 are both free.

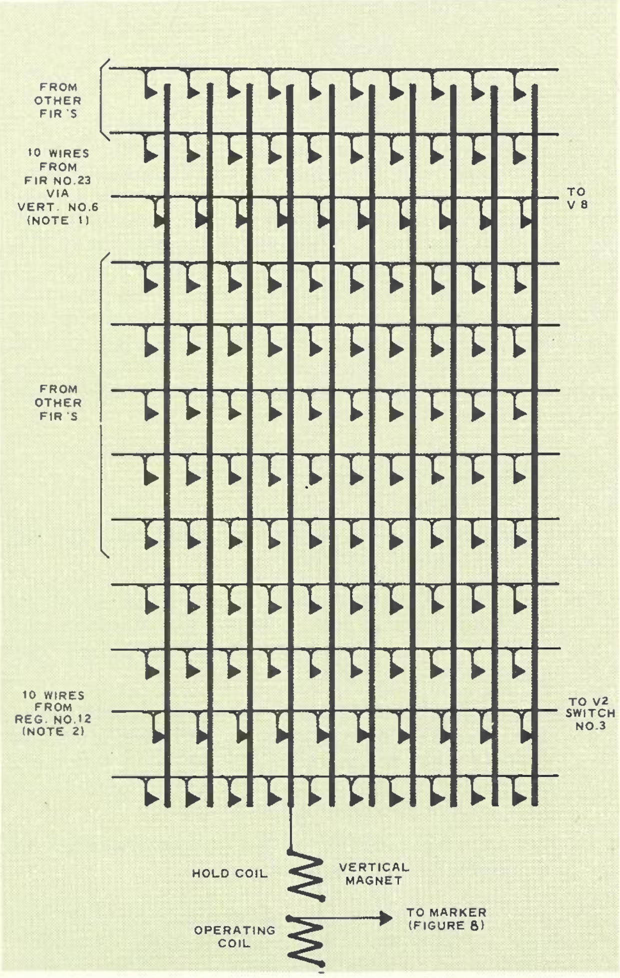
In other words -ve potential is extended to the coil of HR1 if at least one path is available which will involve the use of H9. Similarly, -ve will be extended to HR2, HR3 and HR4 if at least one path is available involving the use of H10, H11 and H12 respectively.

Assume that testing battery is extended to HR3 and HR4 only. Both relays will operate, and in the same way as described for the A and B relay groups, HR3 will take precedence and hold (path 7), thus releasing HR4. The operation of HR3 indicates that at least one of the registers 11 to 15 is free and can be connected to the calling FIR, and that the marker proposes to establish a connection to one of these. Whichever one is finally selected, its connection will require operation of H11 on switch 2, and HR3 in operating completes the operating circuit of this magnet (path 9).

It is now necessary to test the five registers 11-15 individually and select one. The testing paths (10) are completed by the operation of HR3 and extend test No. 2 leads from registers as follows:

- Register 11 via VR1 and HR3 to coil of T1.
- Register 12 via VR2 and HR3 to coil of T2.
- Register 13 via VR3 and HR3 to coil of T3.
- Register 14 via VR4 and HR3 to coil of T4.
- Register 15 via VR5 and HR3 to coil of T5.

The operating circuits of relays T1 to T5 are completed via a path (10) which includes contacts of HR1 to HR4 wired so that +ve is only extended to the T relays if only one HR relay is operated, thus ensuring that this test does not commence until HR selection is complete.



SPRING ASSEMBLY ON VERTICAL 7 OF SWITCH 2
WHEN REGISTER 2 IS CONNECTED TO FIR 27

NOTE 1. EACH OF THE 10 WIRES IS LOOPED ONTO A SPRING OF THIS CROSSBAR VERTICAL & CONTINUES ON TO THE SAME SPRINGS OF VERTICALS 8,9 & 10.

NOTE 2. THE 10 WIRES FROM REG.12 ARE LOOPED AS FOR THE FIR BUT MULTIPLED ON VERTICALS 2 & 7 ON ALL FOUR SWITCHES.

Fig. 8-9 — Holding Circuit for Vertical Magnet.

At least one of the T relays will have testing battery extended to it (this was ensured by the HR test) and therefore one T will operate. If more than one T relay sees testing battery, the lower numbered one will again take precedence. Assume that T2 operates. This indicates that the marker has selected register 12, which is reached from V7 on switch 2.

All the information needed to complete the connection is now stored in the marker. The connection requires the operation in switch 2 of H3 and H11 followed by V7. H3 and H11 have already been energised, and HV1 is now operated via path (11). Note that HV1 will only operate if one horizontal in H1-H8, one horizontal in the group H9-12 in the same switch and one of the relays T1-T5 are operated, in which case everything is ready for the operation of the vertical magnet, over path (12) as soon as HV1 operates.

This closes springsets 3 and 11 on the vertical and connects a 10 wire path calling FIR (No. 27) to the chosen register (No. 12).

Each of these wires extends from the FIR to a spring contact on springset 3 of vertical No. 7, via the vertical contact strip, to a spring contact on springset 11 of the same vertical and thence to the register. The fourth contact strip on this vertical is also connected to the coil of the vertical magnet and this provides a path whereby either the FIR or the register can hold the vertical magnet operated as long as the connection is required. This point is illustrated in Fig. 8-9 showing the completed connection. At the same time as it operates the vertical magnet, HV1 operates HV2, to prepare for the releasing sequence. Release is initiated from the FIR, which, when it is connected to a register removes the calling signal and releases B3. If HV2 has operated this causes 1A4 to release, followed in sequence by all the other relays, the last being HV2, followed by T2, which is held by HV2 during the release sequence. The marker is then free to receive a calling signal from another FIR.

PRINCIPLES OF MARKER OPERATION

Use of Set Theory

The operation of the marker as described can be separated into three functions:

1. Receiving the specification of a request to set up a connection. In this case the specification consists of the identity of the calling inlet as any idle outlet can be used.
2. Identifying, or selecting a connection which satisfies the specification, and is permissible in the present state of the switching stage. In this case it involves selecting an outlet which is idle and can be reached over an idle link.
3. Operate the crossbar switch magnets needed to establish this connection.

The first two functions can be conveniently and usefully described in terms of set theory. A block of switching equipment is capable of setting up a large number of different connections between inlets and outlets, and each of these can be regarded as an element of a set (U), which is the set of all possible interconnections. In the RS-I register finder this set contains 64 x 20 or 1280 elements.

The marker in performing functions (1) and (2) selects one element of (U) which satisfies various conditions:

- it starts at a specified inlet;
- it uses a link which is idle at this time;
- It terminates on an idle register.

This element is defined in the marker by being the only member of (U) which is common to four sub-sets of (U), each sub-set being defined by the operation of one relay out of a group of relays.

Thus Fig. 8-2 can be called a map of the crosspoints, on which any or all of the 1280 elements of (U) can be represented, and can be taken as a representation of (U). The first step in the operation of the RSM is the operation of one of the relays 1A1 to 1A8. For each of these relays, its operation indicates the general area in which the desired connection is located. Thus, when 1A4 is operated, the marker has determined that only those connections involving the fourth primary array can satisfy the specification. This sub-set comprises all the connections which can be established using the equipment shown in Fig. 8-10 and has only 160 elements. It can be designated as sub-set (A4).

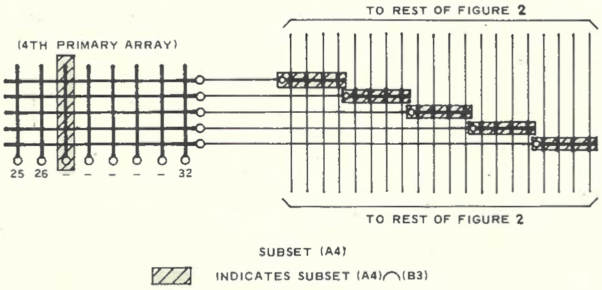


Fig. 8-10 — Subsets (A4) and (B3).

Similarly, the operation of relay B3 indicates that the call originates on one of the 8 FIRs connected to the third outlet of a primary array. It, therefore, also identifies a sub-set (B3) of (U), also containing 160 elements.

Only 20 elements of (U) are contained in both (A4) and (B3), and these are the connections which can be established by using the crosspoints shaded in Fig. 8-10.

Relay HR4 indicates that the desired connection is one which leads to a register in the group 16 to 20, and this is sub-set (HR4). Only 5 elements of (U) are common to (A4), (B3), and (HR4).

Finally, T2 identifies the sub-set (T2) whose elements are all connections involving the use of registers 2, 7, 12 and 17, and only one element of (T2) is also common to (A4), (B3), and (HR4). This, of course, is the desired connection and is shown in Fig. 8-11.

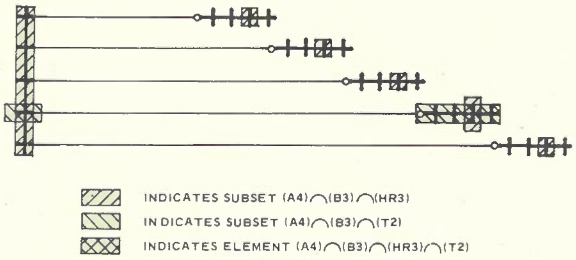


Fig. 8-11 — Subsets (HR3) and (T2).

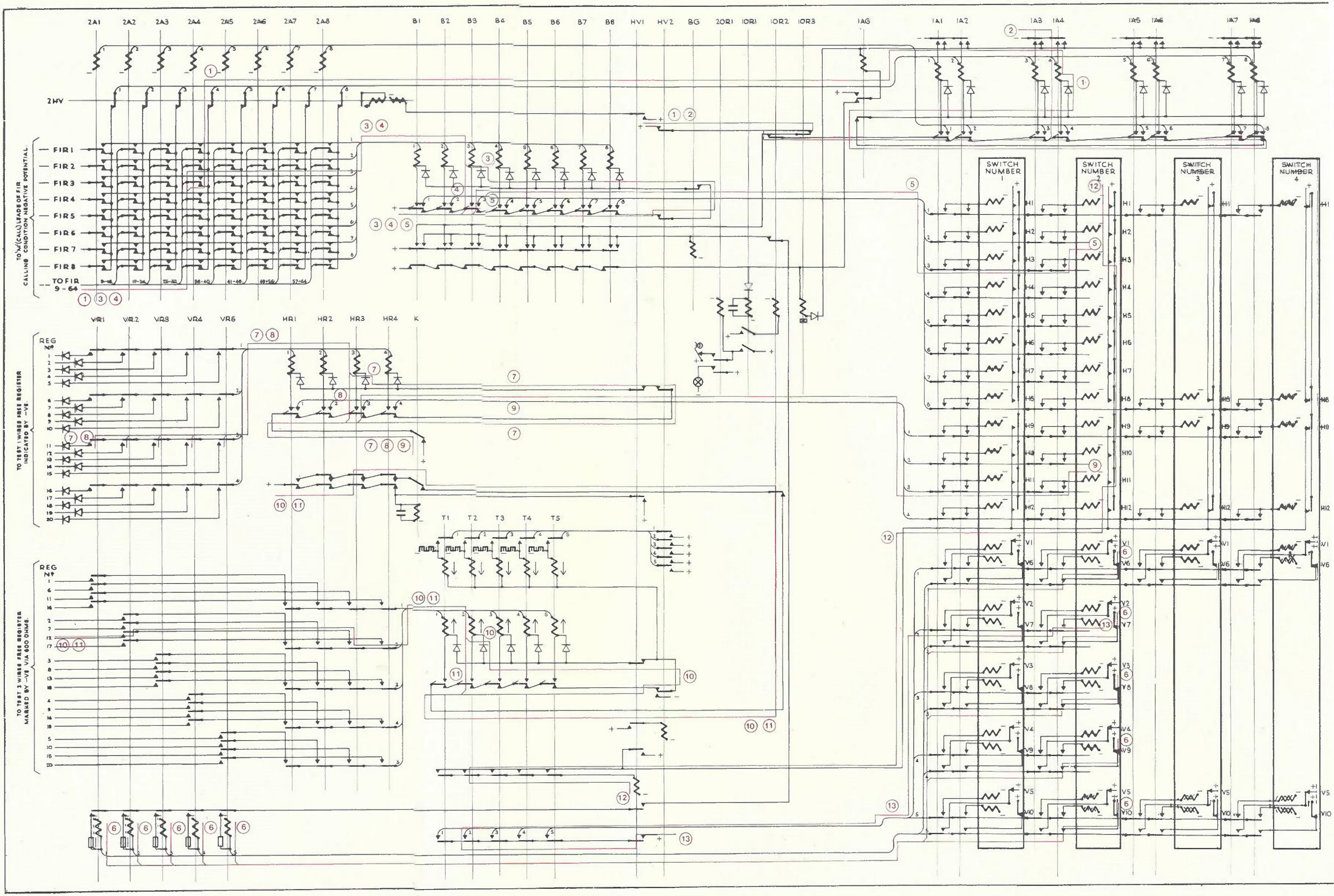


Fig. 8-8 — RS-I Marker Circuit.

Each of the sub-sets is selected from a number of similar sub-sets, by a circuit which combines two functions that can be described as testing and selecting. The testing function is a matter of establishing which of the sub-sets contains an element satisfying the relevant conditions, while the selecting function involves choosing one of these suitable sub-sets.

Testing and Selecting Circuits

The testing is performed by connecting each relay winding to a relay contact tree, so designed that the relay is energised only if some condition is met. For example, the testing circuit for relay A4 can only energise the relay if a calling condition exists on one or more of the FIRs, Nos. 25 to 32. Again relay HR3 can only be energised if in at least one of the five combinations, each consisting of a register in the group 11 to 15, and the link needed to reach that register, both the link and the register are idle.

In all cases in LME crossbar markers, the testing circuit is a "mapping" of part of the crosspoint arrays of the switching stage being controlled, on which the busy and idle states of links, inputs and/or outputs are plotted, in such a way that the map can be examined to identify a sub-set of connections containing one element satisfying the necessary conditions for the particular call. This can be seen most clearly in the testing circuit for the HR relays which is shown on Fig. 8-12 and can be compared directly with Fig. 8-10. Each of the 20 possible paths from a particular primary array to a free register is represented in the map of Fig. 8-12 in which contacts of relays VR1-4 record the busy or idle state of the links, while the state of the register is recorded on the busy test leads.

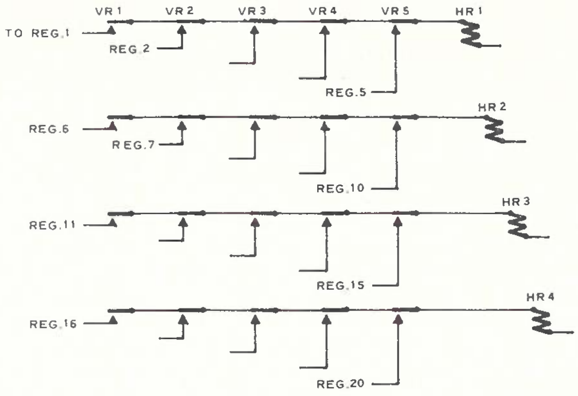


Fig. 8-12 — HR Relay Test Circuit.

In LME markers, a number of separate and relatively small mappings of discrete sections of the crosspoint arrays are called upon to serve as representations of the whole switching stage. Thus the mapping used to operate HR relays can be used for any A (x) sub-set, by associating the VR relays with the appropriate links, i.e., vertical magnets. An entirely different map is then used to operate the "T" relays, which also serves for 8 different A (x) sub-sets. This is only possible if there is strict similarity between the different sub-sets, but in any case this is usually a desirable situation with link trunking.

One important consideration in the design of testing circuits is the need to guard against mutual interaction between two or more markers. For example, two markers switching different calls to a common outlet would give triple connections. Two complementary techniques are used to achieve this. The first is simply to design the system so that points of interaction between markers are a minimum, by dividing the exchange into self-contained units each controlled, if possible, by a single marker. This is achieved in the register finder stage by providing a single marker for each unit of 64 FIR inlets. Consequently, the marker circuitry which identifies a calling FIR, and part of the circuitry which selects a path to a register can be designed in the knowledge that no other marker can disturb the conditions of the switches it controls.

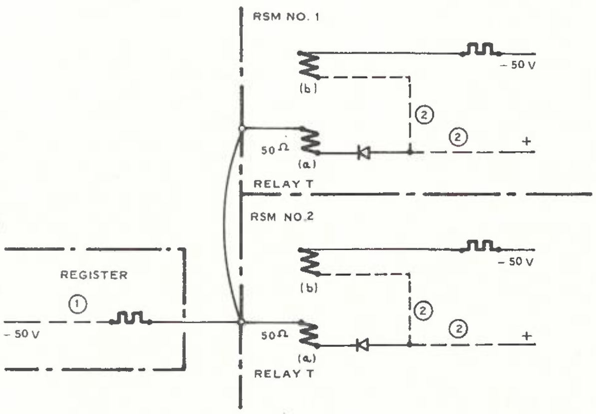
However, because the outlets of several register finder groups will usually be multipled, there is still competition in selecting a free register. In situations where competition cannot be avoided, the LME system employs types of selecting circuits which include elaborate safeguards against double seizure. The T relay circuit of the RS marker is of this type, and its action is illustrated by Fig. 8-13 showing two markers testing one register.

Each T relay has two windings, and at the point when selection is about to commence, the conditions are as shown in Fig. 8-13. Ignoring winding "b" for the moment, it will be seen that the current through winding "a" depends on whether or not the register is free, and whether other markers are attempting to select the same register. The possible conditions (ignoring the resistance of the diode) are:

- Register free, and only one marker attempting selection — 77mA.
- Register free and 2 or more markers attempting selection — 40mA or less.
- Register busy — 0mA.

Relay T must therefore be designed so that it will operate on 77mA but not on 40mA current through winding "a". In order to achieve this without excessively critical adjustments, winding "b" is energised in opposition to "a", with a current too small to operate the relay.

The specified adjustment of the "T" relays is such that two T relays in different markers cannot operate from one free register.



1 VARIOUS CONTACTS - CLOSED IF REGISTER IS IDLE

2 VARIOUS CONTACTS - CLOSED AT THIS STAGE IN TESTING

Fig. 8-13 — T Relay Test Circuit

When a T relay operates, one of its contacts opens the circuit for winding "b", and in this condition the relay will remain operated, even if other markers are attemptng to select the register and thereby reducing the current in winding "a".

Similar techniques are used in some step by step group selectors in order to avoid triple connections, but whereas in this crossbar marker the five "T" relays are shared by 64 inlets, 2 separate testing relays are needed for each switch in a step by step system, and it is usual to use less costly, and also less reliable, circuits. This is one example of the refinements that are possible in a marker controlled system, but economically impossible in step by step. In more recently developed circuits transistors are used to achieve even more reliable performance, and at the same time permit less critical relay adjustments.

The second process, the selection of one element out of a number of suitable ones, is closely tied in with the testing circuits, and in Fig. 8-8 it takes the form of a "chain" of contacts of the testing relays which ensures that the lower numbered relay always takes precedence. This is the simplest possible selection logic but is seldom used in practical circuits. With this fixed priority, some links and devices are more heavily loaded than others, and this gives greater internal blocking than if all links are equally loaded. Also, if a device with high priority is faulty it receives a disproportionate number of calls, and in the extreme case, if a first choice device is faulty, and traffic is very low (for example, over a weekend), all attempts by a subscriber to reach a particular destination may fail. Therefore most selection circuits in crossbar markers are designed so that any suitable device is equally likely to be selected.

The third process, the operation of the appropriate switch magnets, is fairly straightforward but there are two features of importance to be noted. Firstly it is possible for this process to overlap the previous steps and, for example, in this marker the horizontal magnets are operated before the vertical is selected. This can reduce the marker operation time, and allow one marker to control more inlets.

Secondly, whereas the selection process tends to view the switching stages entirely, or mainly as crosspoint arrays, the establishing of the paths must take account of the physical means whereby the arrays are constructed. Consequently, because one crossbar switch contains two first stage arrays, the same horizontal magnet is operated by either of the combinations A1 and B3 or A2 and B3.

On the other hand, if reed relays were used in the construction of a preselector with the same crosspoint structure, the parts of the marker used to identify the inlet and select a path could remain the same, however, entirely different circuits would be needed for the operation of the reed relays.

Constructional Details

In the circuit of Fig. 8-8, the 1A and 2A relays have more spring contacts than can be provided on standard relays, so in practice additional relays are provided with their coils in parallel, usually called "slave" or "relief" relays. By the time these relays are added to the marker and certain other additions made, the complete assembly involves four crossbar switches and over 80 relays, and is inconveniently large to be constructed as a single unit. In the real circuit of which this figure is a simplification, it is subdivided into 5 plug-in units. Four of these each contain a crossbar switch and a few relays, while the remaining relays are mounted in the fifth unit.

Examination of Fig. 8 reveals that nearly all of the 1A and 2A relay contacts are closely associated with the crossbar switch and therefore the amount of inter-unit wiring can be minimised by placing 1A and 2A relay slaves in the crossbar switch parts. When a circuit of this complexity has to be separated into several parts, considerations of this kind have a profound influence on the economy of design, and often present a difficult design problem.

The technique of associating some of the relays with a particular switch or group of switches is very widely employed in LME crossbar markers and is a very useful way of minimising wiring complexity. Such relays are often referred to as "marker coupling" or "rack" relays. Because of this dispersal of related elements, the word marker is used with two meanings. It may refer to all of the equipment used to control a switching stage, wherever it is located, or alternatively it may be limited to the centralised group of relays containing all the logic and exclude the remote relays. Both usages are useful, and it is usually clear what is meant by the context.

Time Supervision

Because failure of a marker will disable 64 FIRs, it is important to ensure that the marker is as reliable as possible. The marker is designed on a "compelled sequence" principle which requires the initiation of each step to wait on the successful completion of all necessary preceding steps. This ensures that the marker follows defined sequence, and avoids a very common and troublesome family of obscure faults sometimes called "relay races". This type of circuit has only one deficiency in that if a particular step fails, the marker "locks up" and will stay in this state indefinitely.

The marker, therefore, has an additional protective feature, known as "time supervision", which identifies such conditions and restores the marker to the idle state. It will then usually be able to handle further calls without failure, particularly as most of the "lock ups" are due to conditions external to the marker.

Fig. 8-8 includes three time supervision circuits. The slow operating relay lock operates if there is an excessive delay between the operation of 1AG (indicating that a 1A relay has been selected) and the operation of a B relay. This is most commonly caused by a transient seizure of an FIR lasting long enough to allow the A relay identification to be performed, but ceasing before the B relay operates. This would cause a permanent "lock up" if the time supervision facility was not provided.

The second time supervision circuit is provided by relay 10R1, which is normally operated even when the marker is idle, and only releases if there is an excessive delay between the operation of a B relay and the completion of switching, signalled by the operation of HV2. For perhaps one call in 1000 this can be caused by congestion preventing the switching of a call. It may also be due to a variety of marker malfunctions. By its nature it gives overall supervision of any failure which causes the marker to "lock up", regardless of the actual nature of that failure.

The third time supervision circuit involves relay K which releases if the T relay selection is not completed in a specified time. This does not release the marker but causes it to step back to the HR test, usually selecting a new horizontal row. This is part of the dual testing provision, since if two markers test the same register simultaneously their T relays will not operate.

Although operations of the time supervision features, generally called "time outs", do not necessarily indicate faults, the proportion of such incidents is a good indicator of the state of the exchange, and meters are provided to keep an accumulated count for each marker.

Delay Working and Traffic Considerations

A marker can make only one connection at a time, and if a second or third inlet calls the marker while one is being serviced, the later call or calls are ignored until the call in hand is serviced and therefore such calls are delayed. Such a procedure is referred to as delay working, or queueing, and its use is contingent on the switching system being able to adapt to such delays. It has been shown that this has wide repercussions in the design of signalling systems for use with crossbar. Delay working is inherently an efficient and economical way of organising markers and is universally employed in link trunked crossbar systems.

There are economies in making one marker control as much switching plant as possible, and the limits are set by the traffic loading of the markers. Every connection set up over the switching paths controlled by one marker involves a request to the marker which occupies it for a known period (of the order of 100 to 500 ms for most markers). Knowing the call arrival rate on the speech path inlets, and the marker holding time, it is possible to determine the delays which will occur and decide whether they are acceptable.

As an example, a group selector rack with 80 inlets could have 50 Erlangs of traffic, with average holding times of 150 seconds. With these conditions, the average interval between calls arriving would be 3 seconds and with a marker holding time of about 0.75 seconds (including signalling), the marker would be occupied for 25% of the time. For this condition it can be shown that the following delay characteristics would apply:

- 75% of all calls would be switched without delay.
- The average delay on the remaining 25% of calls would be 25% of the marker holding time, i.e., 188 ms.
- 1% of all calls would be delayed by more than 1.7 times the marker holding time, i.e., 1.27 seconds.

Such a pattern of delays is acceptable, and at the same time the marker is reasonably heavily loaded.

Overload Problems

For most markers there are certain abnormal operating conditions which result in unusually long operating cycles. In the previous circuit, for example, if no outlets are available, the marker "times out" only after relay 10R1 releases, and if there is a double testing condition on the T relays, it is necessary to wait for relay K to release to re-start the cycle. These abnormal conditions tend to be more frequent at times of heavy traffic, with the undesirable result that the marker is held up more by these "time out" types of operation at the very time when demand for the marker is a maximum. Some allowance has to be made for this in deciding how many devices one marker can control. This problem can be self-compounding if, for example, severe congestion causes the generation of large numbers of unsuccessful, short holding time calls, each of which occupies a marker, even though unsuccessful.

Characteristics of Single Marker Designs

The arrangement whereby a single marker is the sole control for a block of (say) N inlets is sometimes referred to as a 1 : N system of marker coupling. This is a particularly attractive method of marker operation and is the system most often used.

The most important characteristic of a 1 : N system is that the only point of interference between markers is in the selection of outlets, so that the circuits performing all other aspects of path selection and switch operation can be designed without any precautions against such interference. Also, the fact that only one marker is involved means that many test leads can be multipled which would have to be isolated in a system with more than one marker. For example, in Fig. 8-8, the horizontal springs used to connect the HV switching relays are multipled over all four switches. This could not be done if two markers were able to control different switches independently.

The most serious disadvantage of 1 : N marker coupling is that a marker failure disables the whole block of equipment with which it is associated. However, markers can be made very reliable, and by careful attention to details of exchange trunking it is possible to minimise the effect of a marker failure.

The number of inlets which can be controlled by one marker is a function of marker holding time, and speech path traffic characteristics. The upper limit with markers based on relays is in the vicinity of 150 Erlangs, and if an exchange cannot be subdivided into units of this size, more complex marker configurations are necessary.

Incidental Bypaths

During its operation there is a period when the marker contains information identifying the inlet and outlet being connected, and this information can be used to set up a "bypath" linking the inlet and outlet for the duration of the marker operation, which can be used to transfer information between them. In the RS-I circuit a bypath is sometimes provided in this way and the arrangements for one wire are shown schematically in Fig. 8-14. The wires are used in this case to transfer information about the type of FIR which is coupled to the register, while in other marker circuits bypaths are used to transfer other information of this kind.

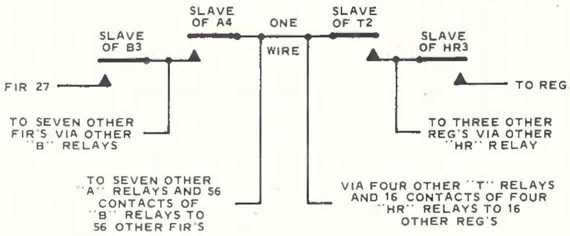


Fig. 8-14 — Bypath Circuit.

TWO STAGE GROUP SELECTORS

A two stage group selector has a similar type of crosspoint pattern to the RS-I, except that the arrays are usually larger. Ignoring this difference, and assuming there existed a need for a 20 outlet group selector with four routes of five outlets each, the RS-I switches could be used for this purpose. If some means is provided for indicating to the marker which route is needed, and this information is used to operate a specific HR relay, the marker and switches would become a group selector.

To indicate the desired route to the marker, it is necessary to signal address information from the calling inlet to the marker. As these signals are usually transmitted over the speech path it is necessary to provide a 2 wire switched path from the marker to the speech path wires, and this is conveniently arranged with a "contact tree" using the inlet identifying relays (or more usually their slave relays).

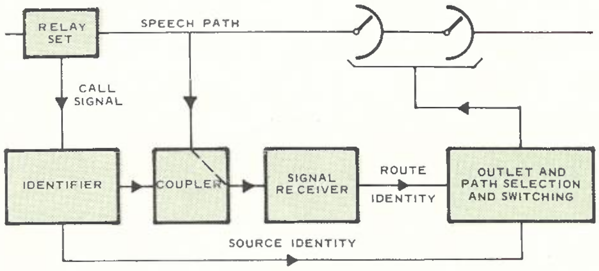


Fig. 8-15 — Group Selector Marker Organisation.

A group selector of this general form is shown in Fig. 8-15 subdivided into several units. The **Identifier,** corresponding to the A and B relays of the RS marker, identifies a calling inlet, and supplies this information to other parts of the marker. The **Coupling Circuit,** under identifier control connects signal wires (usually the speech path) of the identified inlet to the **Signal Receiver** or **Code Receiver** which receives the necessary information to identify the desired route. This route identity and the inlet identity is used by the **Outlet and Path Selection and Switching Circuit,** which carries out the rest of the marker function. In a circuit derived from Fig. 8-8, the signal receiver would cause one of the HR relays to operate, after which the T relays would select an outlet on the route.

The holding time of the RS marker is about 0.2 seconds but in a group selector marker the holding time is increased by the time taken to receive the routing information and is between 0.5 seconds and 1 second. The portion of the marker concerned with outlet and path selection and switch operation is only in use for a comparatively short time at the end of this period, and advantage can be taken of this by making this section co-operate with two or more sets of identifying and signal receiving equipment, as shown in Fig. 8-16. Here there are two blocks of group selector equipment, each with one set of call identifying and signal receiving circuits.

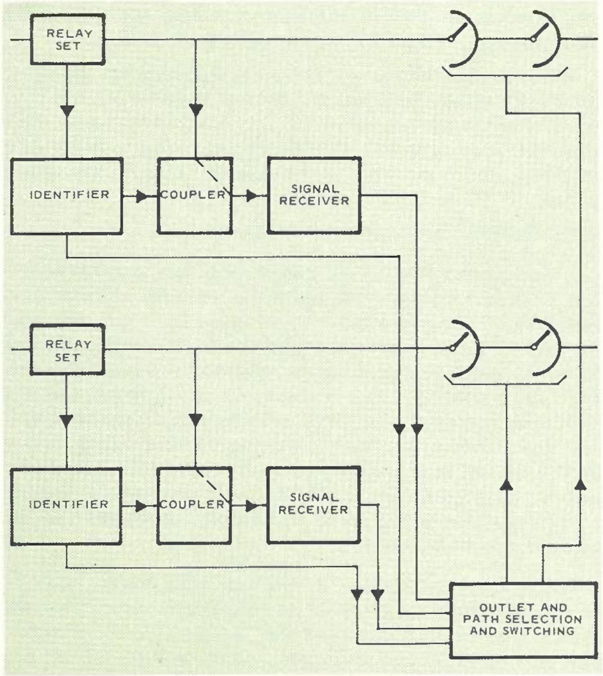


Fig. 8-16 — Two Code Receivers with One Marker.

These elements collectively are known as "code receivers", and the remaining circuit elements used to select an outlet and perform the switching is known as a "marker". When a code receiver has obtained all the information needed by the marker It transfers it to the marker which then controls the switching of the call. As the marker can only handle one call at a time, the code receivers may have to wait for each other, but this contributes very little extra delay and the advantage of this configuration is that, although only one marker is needed for two, or sometimes more, code receivers, the delays are little greater than if each code receiver had its own marker.

Chapter 9 — ARF Selector Stages and Markers.

THE ARF 1/80 GROUP SELECTOR STAGE

- Speech Path Trunking
- Marker Coupling
- Relay Locations
- Backward Signalling
- Provincial and GIV Markers

THE ARF 2/160 GROUP SELECTOR

THREE AND FOUR STAGE GROUP SELECTORS

- Group Testing
- Sequential Testing
- Screening

ARF THREE STAGE GROUP SELECTORS

- Speech Path Trunking
- Outlet and Path Selection
- Route Free Marking

ARF SUBSCRIBERS' STAGES

- Speech Path Trunking
  - *General*
  - *Details*
- Problems of Dual Marker Operation
- Structure of Common Control
- Marker Operation Sequence
  - *Call from Subscriber*
  - *Call to Subscriber*
- Design Features
  - *PBX Operation*
  - *Designs for Different Traffic Levels*
  - *Marker Modules*

THE ARF 1/80 GROUP SELECTOR

Speech Path Trunking

This common control structure is used in one of the most important ARF group selector stages, known as the 1/80 group selector (or GV) stage. The crosspoint pattern for this selector was described in Chapter 3 and is reproduced in Fig. 9-1. It will be noted that there are 6 primary arrays of 13 x 20 and 14 x 20, trunked to 20 secondary arrays each 6 x 20, giving a group selector unit of 80 inlets and 400 outlets. These 400 outlets are divided into 20 routes of 20 outlets each. The control equipment consists of one code receiver for each such unit of 80 inlets, while a single marker is shared by 2 code receivers, or 160 inlets.

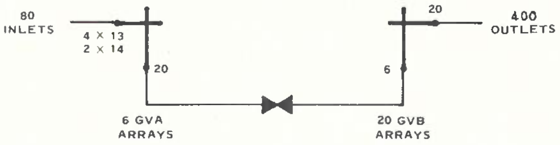


Fig. 9-1 — ARF Group Selector Crosspoint Arrays.

Fig. 9-2 shows in the form of a grouping plan the way crossbar switches are assembled into this group selector. For 80 inlets a total of 20 switches are required, 8 for the primary (or GVA) stage and 12 for the secondary (or GVB) stage. Two racks are needed to accommodate these switches, and by placing 4 GVA switches and 6 GVB switches on each rack they are made identical. It can be seen that the mixture of 13 x 20 and 14 x 20 arrays in the GVA stage is necessary to use all of the GVA switch verticals.

The designations of the main relays associated with path selection are shown in the figure and of necessity are organised similarly to those of the RS-I marker. Relays A and B identify the inlet, while T and W identify the outlet. For reasons elaborated in Chapter 3, a route of 20 outlets is comprised of those with a common W relay, and is specified by the W relay designation. Thus route 3 means all the outlets in the row designated by relay W3, and comprises the third outlet of each GVB array, each being reached by a different GVA-B link.

The A, B and W relays are contained within the code receiver part of the common control, as their selection can take place independently for each group of 80 selectors, but the T relays and selection circuit are located in the marker.

The general sequence of operation of the common control equipment is:

- When a group selector inlet is seized it extends a calling signal to the code receiver, which identifies the calling inlet, and operates the appropriate A and B relays (and their slaves).
- Some of the A and B slave relay contacts form a coupling circuit which connects the speech path of the calling inlet to the signalling equipment of the code receiver.
- MFC signalling takes place between the code receiver and the register until the code receiver identifies the desired route, and operates the appropriate W relay.
- The code receiver at this point signals the marker, and when free, the marker makes a test of combinations of outlets and links and selects one.

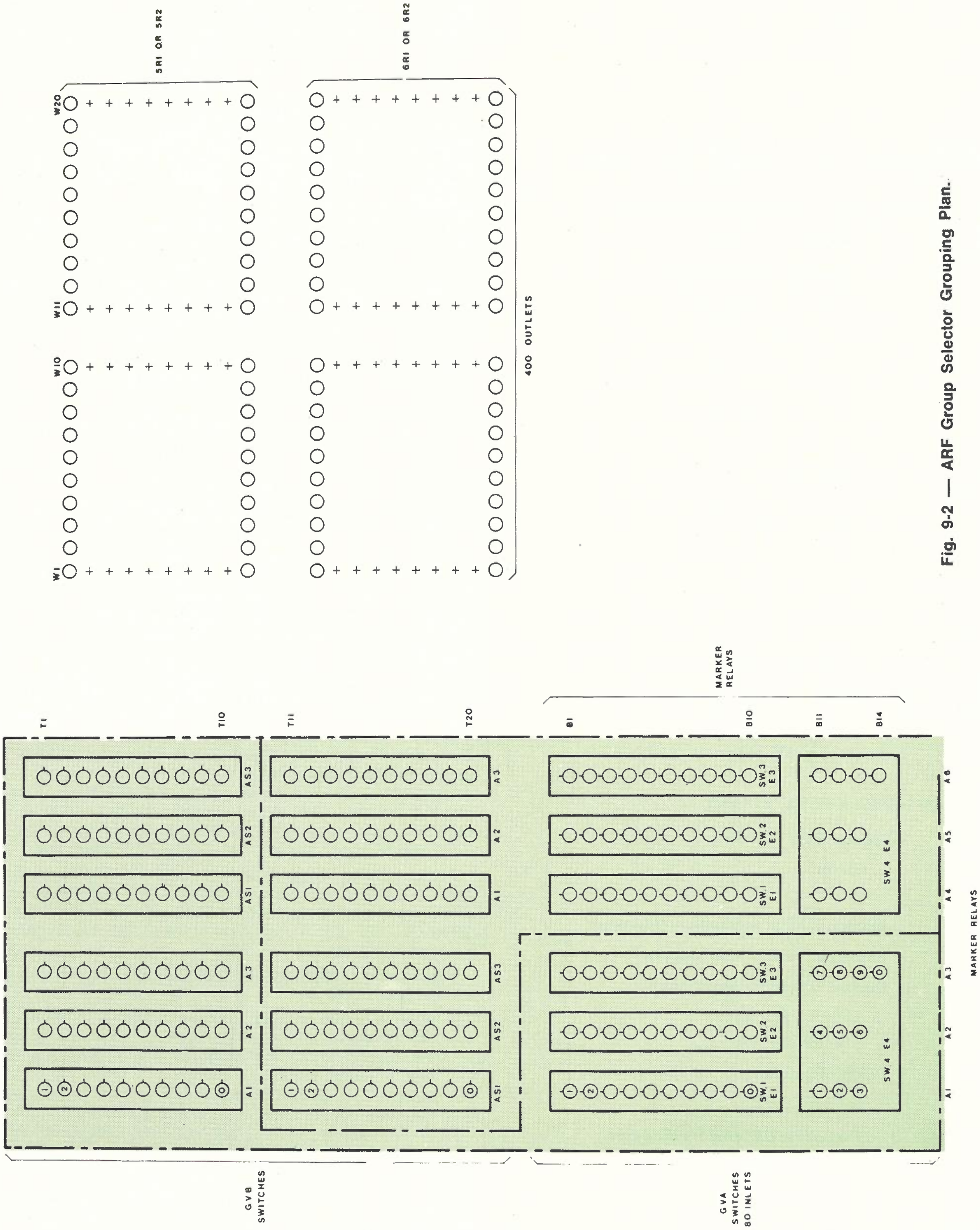


Fig. 9-2 — ARF Group Selector Grouping Plan.

- After some additional MFC signalling (see later) the path is set up, and the control equipment released.
- If there is no outlet which is both idle and accessible from the calling inlet, the marker returns a signal to this effect to the code receiver. If there is another route over which the call can be carried, the code receiver operates a new route (W) relay, and restarts the testing cycle of the marker. If not, it signals congestion to the register and releases.

The last facility can be used to create a route of availability greater than 20 by combining 2, 3 or a maximum of 4 routes, or to provide alternative routing facilities. There is a considerable requirement for routes of 40 availability, and special provision is made for such routes using W1 and W11, W2 and W12, etc., with a call distributor facility which ensures that each of the two parts is equally likely to be tested first.

There is also at times a requirement for routes of availability less than 20 and an "add on" relay set can be fitted which allows up to 15 routes of 20 to be subdivided into "half" routes of 10. When this is done T1-10 is one half and T11-20 is the other half. The coupling relays 5R1, 5R2, 6R1 and 6R2 referred to later arrange for half routes, by only extending the relevant 10 wires from the code receiver to the marker.

Marker Coupling

In order to allow one marker to be shared by two code receivers some precautions are needed. Since two code receivers may simultaneously have set up the testing contact trees used by the one marker, it is necessary to ensure that only one set is extended to the marker. In this equipment all the leads from the marker which go through the code receiver also pass through "coupling" relays in the marker, one set for each code receiver (operated when the code receiver calls), and interconnected so that only one can operate at a time. These relays are designated 1R1, 2R1, etc., for the code receiver associated with the first 80, and 1R2, 2R2, etc., for the code receiver associated with the second 80.

Relay Locations

The number of relays involved in the common control for this group selector is much larger than in the RS-I marker, and they are spread over a number of relay sets and locations. For 160 inlets there are 4 "switch" racks and one "marker" rack. All of the intelligence is located on relay sets on the marker rack while various dependent relays are located on the switch racks.

The equipment on the marker rack is designated as two code receivers and one marker, each made up of several relay sets, while the subsidiary relays on the switch racks are designated as "rack relays".

Both the marker and code receiver relays and the rack relays are shown on Fig. 9-2, the rack relays being placed within the rack boundaries. Most of these are slaves of A1 to A6 in the marker, but designated A and AS. It will be observed that the designations of the marker relays and the rack relays do not always correspond. For example, the slaves of A5 are designated A2 and AS2. This kind of ambiguity is a confusing but largely unavoidable characteristic of large common control circuits. Each of the A and AS relay designations on the drawing actually refers to several relays operating in parallel, i.e., A2 is an abbreviation for a set 1A2, 2A2, 3A2, etc.

There is also a set of E relays which identify the GVA switch being used for a call, in order to extend the contact trees needed to operate the horizontal magnets in the GVA switch. They are needed because the first stage arrays are made up of verticals in two switches. The E relays are operated via contact trees of A and B relays which are arranged to satisfy the conditions set out in Table 9-1.

TABLE 9-1 — OPERATION OF E RELAYS

E Relay Designation	A and B Relay Combinations Which Cause Operation
E1 Rack 1	A1 and one of B1 - B10
E2 Rack 1	A2 and one of B1 - B10
E3 Rack 1	A3 and one of B1 - B10
E4 Rack 1	One of A1 - A3, and one of B11 - B14
E1 Rack 2	A4 and one of B1 - B10
E2 Rack 2	A5 and one of B1 - B10
E3 Rack 2	A6 and one of B1 - B10
E4 Rack 2	One of A4 - A6, and one of B11 - B14

The use of the various relays to establish a call is illustrated by the call between the inlet and outlet marked on Fig. 9-2, which must go via the marked GVB vertical. For this call:

- Relays A5 and B11 operate to identify the inlet.
- Relays W11 and T8 operate to identify the outlet.

In addition slaves of all these are operated, including rack relays A2 and E4 on rack 2 and AS2 on rack 1.

In order to establish the call, it is necessary to operate:

(1) Horizontal magnet H8 on GVA Switch 4 Rack 2
(2) Horizontal magnet HA on GVA Switch 4 Rack 2
(3) Vertical magnet V4 on GVA Switch 4 Rack 2
(4) Horizontal magnet H1 on GVB Switch 5 Rack 1
(5) Horizontal magnet HB on GVB Switch 5 Rack 1
(6) Vertical magnet V8 on GVB Switch 5 Rack 1

These are reached by corresponding contact trees using relays as follows:

(1) E to identify the switch, and T to identify the magnet, with the T relay contacts wired so that the H magnet corresponds to the units digit of T, i.e., T8 and T18 operate H8.
(2) E to identify the switch and T to identify the magnet with T relay contacts wired so that T1 to 10 operate HA and T11 to 20 operate HB.
(3) A and B in a simple tree to operate the vertical magnet.
(4) AS (slave of A), and T together to identify the switch (T1 to 10 is switch in rack 1, T11 to 20 in rack 2), while the units digit of W identifies the magnet.
(5) As in (4) to identify the switch, while W1 to 10 operates HA, and W11 to 20 operates HB.
(6) T and AS in a simple tree to operate the vertical magnet.

In operating horizontal magnets in GVA switches, the E relays provide simple contact trees in which each E relay contact set performs a function which otherwise would have required many A and B relay contact sets.

Some of the complexity of these circuit arrangements results from the fact that GVA and GVB crosspoint arrays are spread over two switches, and some of it

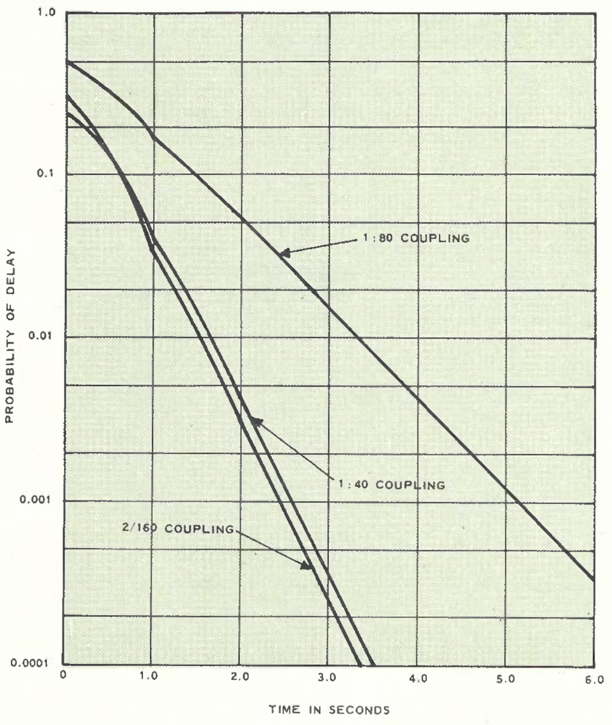


Fig. 9-3 — Delay Distributions.

is due to the value of having the two racks which together form a GV stage completely identical. Because of this desire, the racks are asymmetrical. It would also have been possible to put all the equipment in the columns corresponding to marker relays A1, A2 and A3 in one rack and A4, A5 and A6 in the other, but while this would have simplified some aspects, it would have also required many more wires between the two racks since all 400 outlets would have appeared on each rack. This is another example of the complexity of achieving economical wiring in a crossbar system.

Backward Signalling

When an outlet has been selected it is necessary for the code receiver to set the register so that the signal required by the next selector stage is being transmitted. If the switching scheme allows for alternative routing the signal needed by the next selector will differ depending on which route is actually chosen, and therefore this function of the code receiver must take place after the outlet has been selected, and until this is done, the switching of the selector stage cannot be completed.

Provincial and GIV Markers

There are actually two group selector stages of the above basic construction, differing in the details of the facilities provided. The marker of one of these is designated as a "GIV" marker and was designed for use in incoming selector stages in Metropolitan areas, where a fairly limited analysis capability is needed; it is capable of using a maximum of 3 digits for route analysis, which is sufficient for many applications. The second type is intended for use in first selector stages in provincial networks and its marker is designated as "Provincial GV" marker; it is capable of analysing a limited number of codes to a maximum of 5 digits, and has special backward signalling features suited to this application. Physically the same selector racks are used for both configurations, and the common control equipments differ only in the MFC signalling and analysis portion of the code receiver, and use identical racks (except some earlier GIV markers).

THE ARF 2/160 GROUP SELECTOR

There is a third group selector using the same 2 stage crosspoint configuration, intended for use as a 1st selector in Metropolitan areas. This selector is required to use up to 4 digits to determine the route, and make extensive use of alternative routing. As a result the code receiver holding time is about 1 second, and with the 1/80 coupling configuration the queueing delays would be excessive. The coupling of the code receivers is therefore arranged so that two code receivers serve 160 inlets and can be simultaneously coupled to any two calling inlets, provided they are on separate GVA switches. Fig. 9-3 shows the delay distribution for both 1/80 and 2/160 coupling and a third distribution for the case of one code receiver for each 40 inlets. It can be seen that both the 2/160 and the 1/40 configurations are suitable, but the 2/160 has a lower probability of long delays. As it requires 2 instead of 4 code receivers, it is more economical, even after allowing for the extra cost of the coupling which is required in this case.

In the 1/80 configuration an identifier and a coupling circuit are directly associated with each code receiver, but in the 2/160 case the two code receivers share a single indentifier and coupling circuit as shown in Fig. 9-4. The coupling circuit is a two stage crosspoint array built of relays and its arrangement is shown in Fig. 9-5. It allows any two inlets, provided they are in different sets of 10, to be coupled to two code receivers simultaneously.

The identifier now has a more complex function to perform and is virtually a "marker" controlling the coupling relays. When a selector inlet is seized for a call, the identifier first establishes the identify of the calling inlet. It then tests the two code receivers and

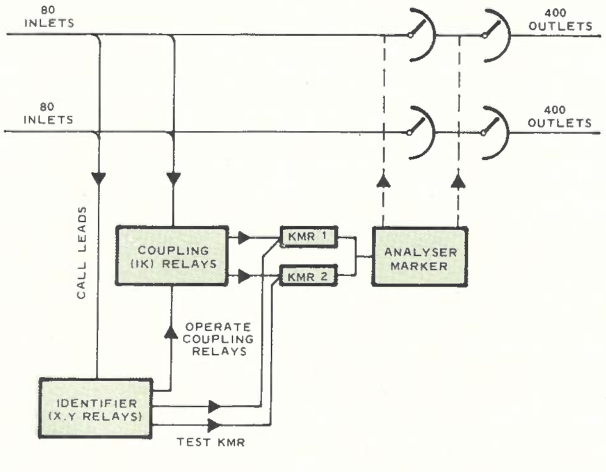


Fig. 9-4 — 2/160 Common Control.

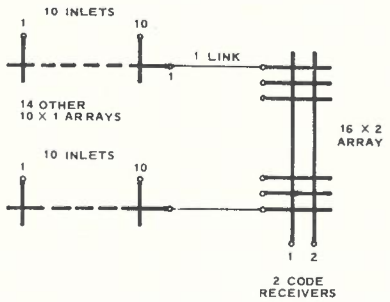


Fig. 9-5 — 2/160 Code Receiver Coupling.

selects an idle one. When these steps are completed it operates relays in the coupling circuit to connect the inlet and code receiver, after which the identifier is freed and available to establish further connections from inlets to code receivers.

The coupling relays also provide the code receiver with information about the calling inlet which will later be needed by the marker. This information is:

- The identity of the GVA array, in order later to operate A and AS relays on the rack and thus allow the marker to test the appropriate links and operate magnets in the GVB switch.
- The identity of the GVA switch, in order that the marker can operate horizontal magnets in that switch.

Another difference from the 1/80 configuration is that the analysis of the address digits received by the code receiver is performed in a separate analyser which is in effect a part of the marker. In this way, there is only one analyser needed for 160 inlets, instead of two as in the 1/80 selector, but this has the disadvantage that the two groups of 80 must have identical allocation of outlets to routes. In the large exchanges where these are used this restriction is of no consequence.

The facilities provided in the 2/160 group selector include:

- Analysis if needed of all 3 digit codes, and up to 300 4 digit codes.
- Analysis of TOTE and Number Length for Regs-LM when required, as described in Chapter 6.
- Subdivision of a route of 20 outlets into units of 5 or 10 with no limitation on the number of such small routes.
- Alternative routing to any number of successive choices, limited only by the effect of the increased marker holding time.

However, its analysis is not quite as flexible as a provincial 1/80 GV, and consideration is being given to extending its capabilities to the facilities needed in provincial networks.

THREE AND FOUR PARTIAL STAGE SELECTORS

The control of 3 or 4 link trunked partial stages is appreciably more difficult than for two partial stages, because of the much greater number of possible paths through the arrays which must be tested. For example, in the 3 partial stage group selector described in Chapter 3, there are 20 x 20 x 20 = 8000 possible paths through the system, and any one of the 1600 outlets can be reached over five independent paths. Consequently, to select an outlet on a route of 20 availability it is necessary to choose between 100 different paths, each with a different set of two links which must be idle if that path and outlet is to be used. With 4 partial stages, the number of paths is 160,000 and the selection process requires even more combinations to be tested.

Consequently it is necessary to devise more powerful testing techniques and to give careful consideration to the sequence of testing in order to construct markers capable of efficiently using such link trunked selectors.

These techniques can be divided, in respect of their logical function into three categories, which may be used singly or in combinations. There is no accepted designation for these, and for the purpose of this description they will be designated here as "group testing", "sequential testing" and "screening".

Group Testing involves testing the members of a set where each member is itself a set of smaller elements and choosing a member which contains at least one suitable element. This technique has already been encountered in the RS-I marker (Chapter 8), where the HR relays tested in sets of 5 elements, and the operation of an HR relay indicated that the relevant set of 5 contained one suitable element. Having narrowed down the choice to a specific sub-set of 5, out of the larger set of 20 elements, a second test selected a specific element. Group testing is used very extensively in marker circuits, and is a powerful technique. The group test has to operate over a "map" of the interconnection scheme, and this map is usually composed either of relay contacts or an array of diodes combined with relay contacts.

Sequential Testing is simply a process of testing several sets of paths one after another, ceasing when a set is tested that contains a suitable element. This has also been encountered in the group selector, where in order to provide routes of 40 outlets, they were tested in two lots of 20 sequentially. Although this is a slower procedure, it is often useful and is fairly widely used.

Screening is a process of selecting a sub-set in which it is highly probable, but not certain, that a suitable element exists. This sub-set is then examined and if one or more suitable elements do in fact exist, one such element is selected and the switching completed. If not, new sub-sets are chosen by the screening process and tested in turn until success is obtained. Screening is thus a preliminary to sequential testing and allows the number of successive tests to be reduced. The power of this technique relies on the existence of a simple test which can be used for screening and which gives a high probability of the subsequent detailed testing being successful. An example of this will be given later in describing the 3 stage group selector.

ARF 3 STAGE GROUP SELECTORS

Speech Path Trunking

There are two different 3 stage group selectors used in ARF exchanges, designated 2/160/1300 and 2/160/1600, based on the same grouping plan, but with slightly different facilities.

These selectors are designed in such a way that a 2/160 two stage group selector can be extended by adding the third stage in four increments and thus increase the outlets progressively from 400 to 1600. Fig 9-6 shows the inter-connection of the crosspoint arrays after the first increment when the total availbility is 700.

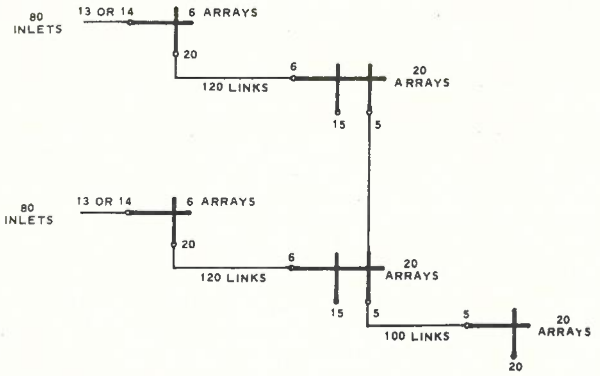


Fig. 9-6 — Three Stage Group Selector Crosspoint Arrays.

The first two stages consist of two normal 2 stage group selectors each of 80 inlets and 400 outlets. 100 of the outlets of the two selectors units are paralleled, and used as links to the third, or C stage. These 100 links connect to 20 arrays each of 5 inlets and 20 outlets to give 400 outlets, accessible from all 160 inlets. At the same time the second (B) stage outlets not used for links to the third stage can continue to be used in their original function. Consequently any inlet has access to 300 outlets from the B stage, and 400 from the C stage to give a total of 700.

The interconnection is shown in more detail in the grouping plans of Fig. 9-7 and 9-8. It will be observed that the C stage arrays require 10 crossbar switches, which, together with coupling relays, occupy a single rack.

The 400 outlets are divided into 20 routes of 20, defined by CW relays, which correspond to the W relays of the 2 stage group selector. Each outlet can be reached over five different paths, each of which involves a different pair of GVA-B and GVB-C links. This is necessary to ensure a minimum internal congestion, and has been done in such a way that the 5 GVB-C links to a particular outlet would have been a route of 5 outlets if the GVC stage had not been connected. This allows maximum use to be made of the marker equipment designed for 2 stage group selectors. A complete CW route of 20 outlets makes use of all 100 GVB-C links. A route can be subdivided into units of 5 or 10 outlets as in the 2 stage selector.

Additional GVC racks can be added, each using 100 GVB outlets and adding 400 GVC outlets, up to maximum of 1600 outlets. The possible combinations are shown in Table 9-2.

The internal congestion in reaching an outlet of the GVC stage is given by:

$p = (1 - (1 - b)(1 - c))^5$ where p is the probability of congestion
b is the loading of GVA-B links
c is the loading of GVB-C links

For $b = 0.4$ and $c = 0.39$, $p = 0.1$ and for this value of point to point internal congestion the performance is very little inferior to non blocking access. As 0.4 is the mean value of GVB link loading a rule has been adopted that the GVB-GVC link loading should not exceed 0.39 erlangs per link. However, this is not an absolute limit, but merely a recommendation.

Outlet and Path Selection

The process of selecting an outlet and a path is the same in both types of group selectors, the difference between the two being in the code receiver and the route selection process which leads to the operation of a route (CW) relay.

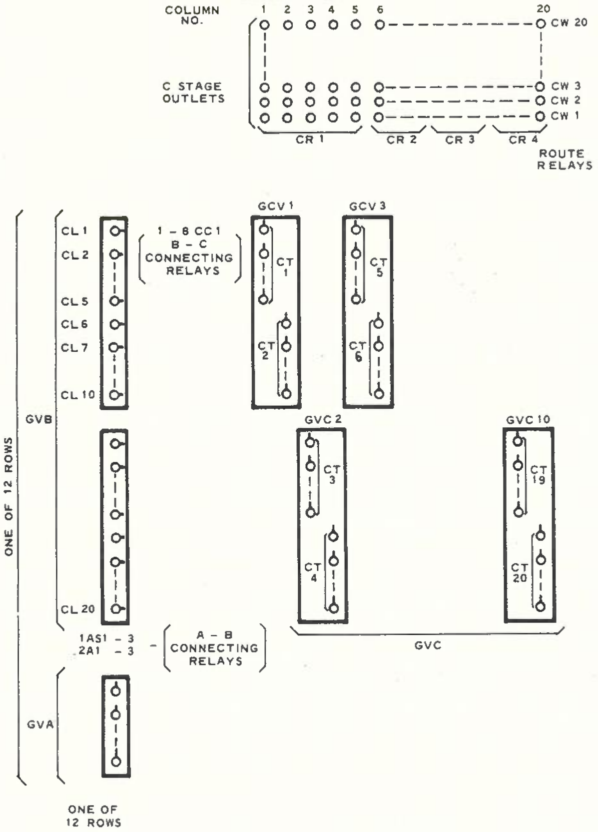


Fig. 9-8 — Portion of Fig. 9-7.

The outlets on a C stage route of 20 availability can each be reached over 5 combinations of one GVA-B and one GVB-C link, so that 100 combinations must be tested. To reduce this task to manageable proportions a system of group testing is employed.

The first step tests the GVA-B and GVB-C links in the sets of five corresponding to each outlet. The result of this test is recorded on 20 relays CT1 to CT20, which are shown on the grouping plan. Thus if CT1 is operated, at least one idle path is available to the first outlet of any C stage route, and the CT relay contacts can be regarded as the analogue of the vertical magnet contacts used to identify idle GVA-B links in the 2 stage group selector.

TABLE 9-2 — THREE STAGE GROUP SELECTOR SIZES

No. of GVX Racks	No. of Outlets		
	GVB	GVC	Total
0	400	0	400
1	300	400	700
2	200	800	1000
3	100	1200	1300
4	0	1600	1600

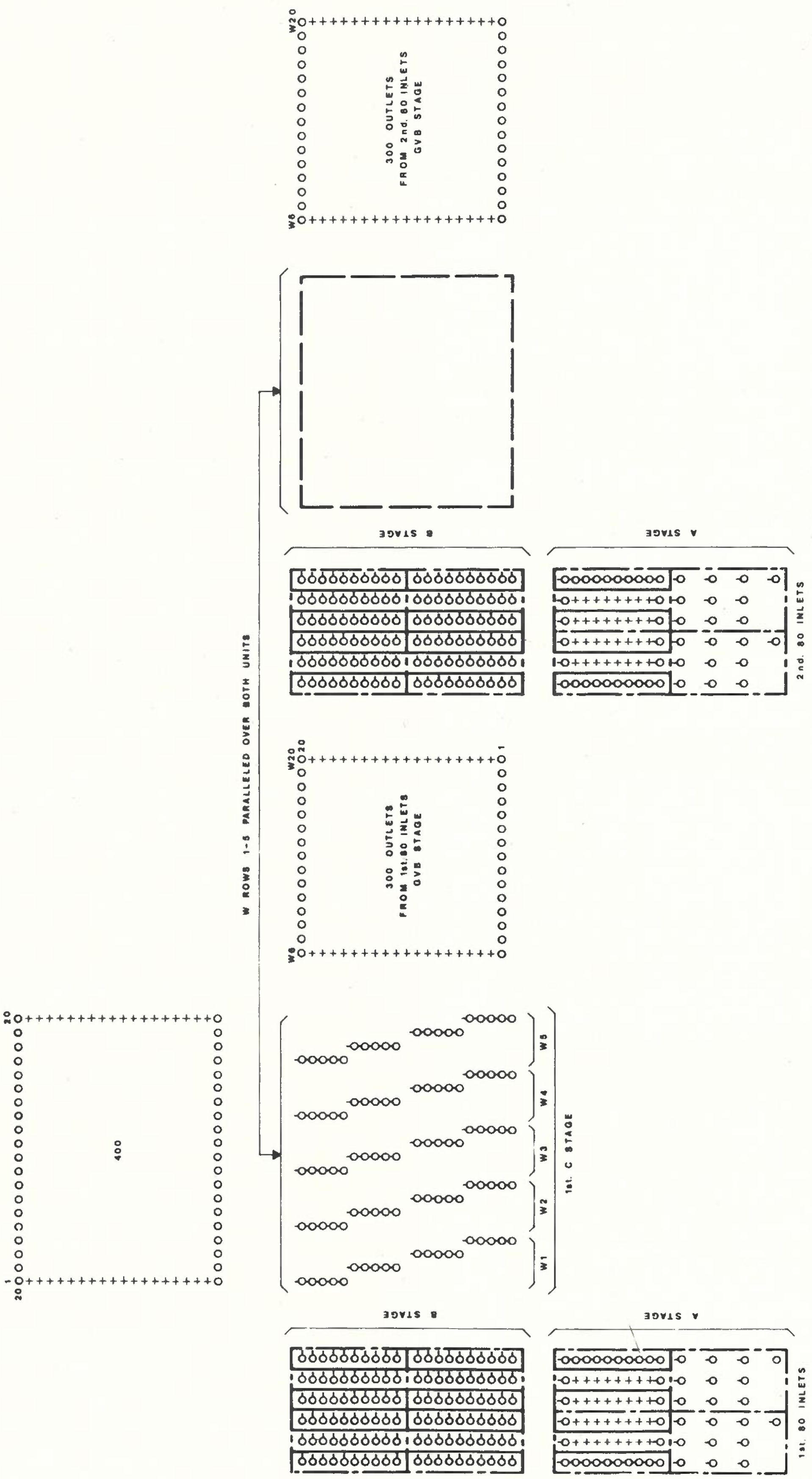


Fig. 9-7 — Three Stage Group Selector Grouping Plan.

The second step is a conditional test of the outlets of the route via the CT relay contacts and the selection of an idle outlet accessible via at least one idle pair of links.

Finally the five pairs of links which can be used to connect to this outlet are tested and a pair with both links idle is selected. (The first test ensured that such a pair exists).

As discussed, the CT relays identify the state of what could be called "virtual links", which correspond to the actual GVA-B links in a 2 stage selector. This allows the one outlet testing and selecting circuit to be used for outlets from 2 stage or 3 stage routes. The only difference is that in the 3 stage case, the outlet selection is preceded by the group test to operate the CT relays, and followed by an additional selection process to determine the details of the path.

The 2/160/1300 group selector is designed to allow an existing 400 outlet selector to be extended with a minimum of modification. The code receiver part is identical, and this limits the number of different routes to 80, with availabilities of 5, 10 or 20. Availabilities greater than 20 can be provided by sequential testing, but is limited to 80, to avoid excessive marker holding time.

The larger 2/160/1600 group selector differs mainly in the circuitry which analyses the address digits, and specifies the route to the path and outlet selection part of the marker. The number of possible routes is increased from the 80 of the 2/160/1300 marker to a maximum of 180, and an additional "screening" test is provided, known in this case as a "route free marking test", performed before the route identity is given to the outlet selection circuits.

Route Free Marking

The route free marking test relies on the fact that if an outlet connected to the third stage of the group selector is idle, the probability of being able to reach it is about 0.9, and therefore that if a route has at least one idle outlet, the probability of a test of that route being successful is at least 0.9. On the other hand, if a route has no idle outlets a test will of necessity fail. Consequently, by identifying routes with all outlets busy and by-passing them in the choice of routes to be tested, it can be ensured that every route test by the marker has a high probability of success, and so reduce marker operating time on large routes.

A "route free marking" test to determine whether or not at least one outlet is idle, without reference to the state of the links is a relatively simple test. It is arranged to test a number of such routes simultaneously, and select a route with a free outlet. In less than 10% of cases only will the second test fail, and in such cases the marker requests a new route selection.

"Route free marking" in this selector is organised so that the routes which it simultaneously tests may be several parts of a single route, or a direct route and it's alternatives, or both at once. The maximum possible number of outlets which can be made available for a particular code, including the direct route and various alternatives via tandem centres is 280, which, in the absence of free route marking would occasionally require the marker to sequentially test 14 successive sets of 20 outlets; the resulting marker holding time could not be tolerated.

The success of the technique depends on the existence of a simple "screening" test which allows sub sets of the possible range of connections to be selected which have a high probability of containing a suitable element, so that the number of times it is necessary to make another trial selection is kept low.

ARF SUBSCRIBERS STAGES

Speech Path Trunking

General

In ARF crossbar exchanges subscribers are connected to a unit known as an SL or subscribers stage, which handles both incoming and outgoing traffic. Each unit is designed to carry the traffic of 1000 subscribers and has three sets of terminations:

- 1000 terminations for subscribers lines
- Terminations for traffic incoming from these subscribers, which connect to cord circuit (SR) relay sets
- Terminations for calls outgoing to the subscriber, connected to outlets from group selector stages

The number of terminations in the second and third categories depends on the traffic of the 1000 subscribers, which may range from less than 50E in a quiet country town to over 200E in some city exchanges, so that a variety of designs is available to suit the traffic. In order to minimise manufacturing and stock holding problems, the various designs are built up in a modular manner from a limited range of racks. In the following description attention will first be concentrated on one of the many possible designs, and subsequently the methods used to provide for other calling rates will be explained.

The SL stage has four partial stages designated SLA, SLB, SLC and SLD, with subscribers connected to the SLA stage. The SLA and SLB stages carry both incoming and outgoing traffic, while the SLC and SLD stages carry only traffic outgoing to the subscribers.

The SLA and SLB stages are a traffic concentrating unit, which concentrate the traffic from 1000 subscribers onto a smaller number of SLB inlets, which are then segregated into two sets, one for incoming and one for outgoing traffic. The structure of these two stages is shown in the form of crosspoint arrays in Fig. 9-9, for the configuration known as grouping plan 8A. Viewed from the subscribers end it is a two stage concentrator, similar to the register finder stage described in Chapter

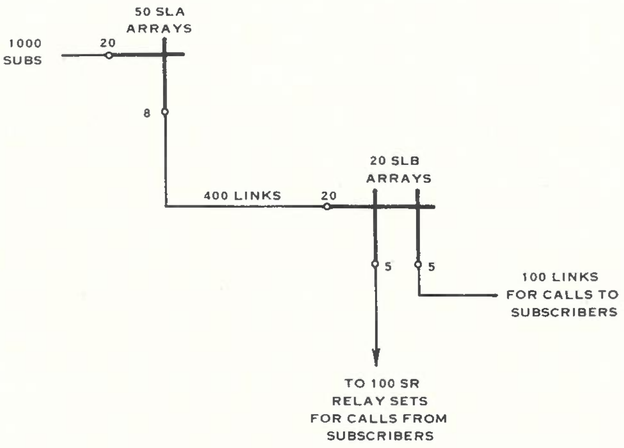


Fig. 9-9 — SLA and SLB Stages Crosspoint Arrays.

8. The first stage is 20 x 8 and the second 20 x 10 and they concentrate the traffic of 1000 subscribers to 200 "links/outlets". These are divided into 2 "routes" of 100 each. One of these is a conventional route of 100 outlets connected to 100 SR relay sets and used for traffic originated by the subscriber. The other 100 links are used for traffic terminating with these subscribers and are connected to the remaining two partial stages SLC and SLD.

For traffic originated by the subscribers, each subscriber can reach 40 of the 100 SRs since he has access to 8 SLB arrays, each of which has 10 terminations, 5 each for originating and terminating traffic and under these conditions, the traffic efficiency of the SR relay sets is reasonably high.

For traffic terminating with the subscribers, there are likewise 40 of the SLB links reserved for such traffic which can be used to reach a particular subscriber. The SLC and SLD stages enable a group selector outlet connected to an SLD inlet access to the 100 SLB links, via two partial stages. Fig. 9-10 shows the SLC and SLD stages in crosspoint arrays form with 80 SLD inlets. It is a standard 2 stage configuration with four 20 x 20 arrays for SLD and five 20 x 16 arrays for SLC. There are four possible paths from a particular SLD inlet to a particular SLB-SLC link.

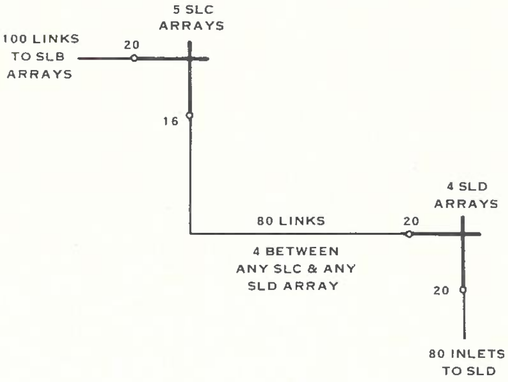


Fig. 9-10 — SLC and SLD Stages Crosspoint Arrays.

Details

Each SLA array is 8 x 20, and requires 8 crossbar switch verticals. Ten such arrays serve 200 subscribers and require 80 verticals or 8 complete switches, which is almost the full capacity of a rack and makes a convenient unit.

The detailed arrangement of the SLA stage is more complex than shown in Figure 9-10 and uses a system known as a "transposed multiple" to reduce congestion in the SLA-SLB links. Instead of serving 200 subscribers with ten 20 x 8 arrays, each serving an independent twenty subscribers, they are served by twenty 20 x 4 arrays, and each subscriber is served by two different arrays.

This is shown in the form of a grouping plan in Fig 9-11. The subscribers have been displayed in a square pattern, with the SLA switches arranged to the right and below. Each SLA vertical on the right has access to the 20 subscribers in the corresponding horizontal row, all of which have the same tens digit.

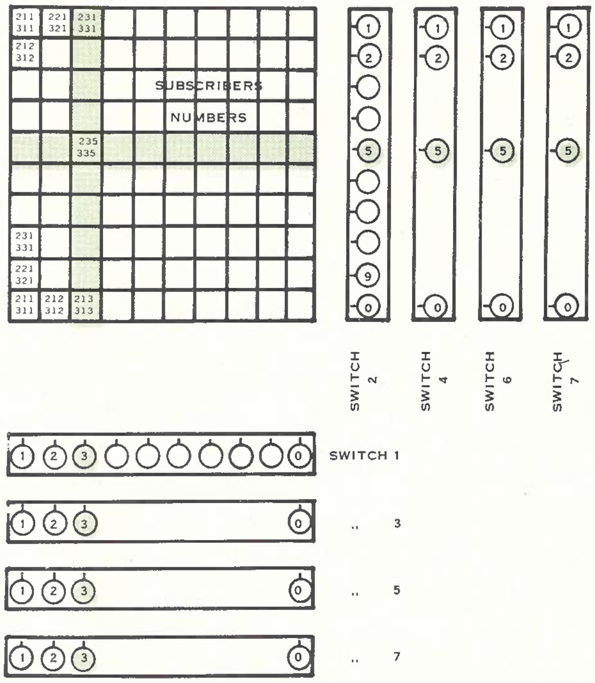


Fig. 9-11 — SLA Stage Transposed Multiple.

Each SLA vertical at the bottom of the diagram has access to the 20 subscribers in the same vertical line all of which have the same units digit. The SLA verticals giving access to subscribers 235 and 335 are indicated by shading as are the other subscribers reached by the same verticals. This method of connection allows all 80 crossbar verticals to co-operate and behave more like a single group than as separate blocks each serving 20 subscribers.

The arrangement of the crossbar verticals in each array is such that each of the 8 crossbar switches has one vertical giving access to any particular subscriber. Also the vertical and horizontal magnets needed to be operated to reach a specified subscriber are a simple function of the number.

Thus:

- For all switches HA operates if the hundred digit is even and HB if odd
- The horizontal springset H1 to H0 corresponds to the units digit on odd numbered switches and the tens digit on even numbered switches.
- The vertical magnet number corresponds to the tens digit on odd numbered switches and to the units digit on even numbered switches.

This, of course simplifies the design of the marker logic. Also, because it is a standardised pattern it is not usually shown on grouping plans.

The SLA and SLB stages are shown together in the form of a grouping plan in Fig. 9-12. Each SLB array is 20 x 10 and consists of a complete crossbar switch. Each such switch has 20 outlets, or SLA-SLB links and connects to the verticals of two SLA switches, in two different 200 groups. Thus, the switch designated SLB3 has access to the verticals of SLA switch 1 in the rack serving subs 200-399 and SLA switch 3 in the rack serving subs 400 to 599. Therefore the 10 verticals of

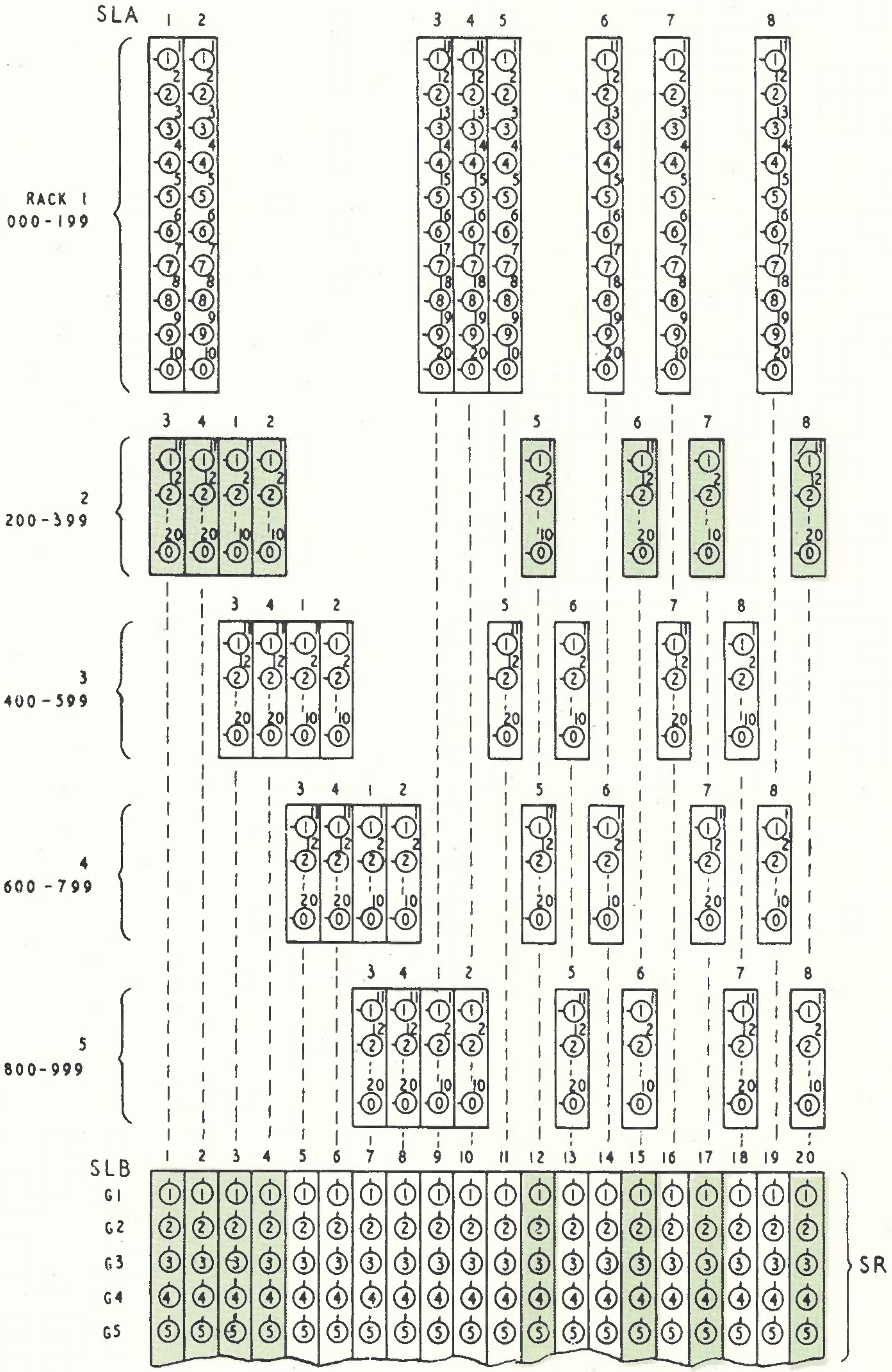


Fig. 9-12 — Outgoing Portion of Grouping Plan.

this switch serve subscribers 200 to 599. The interconnection is so arranged that all possible pairs of SLA racks are shared by some of the SLB switches, giving a homogeneous interconnection system.

The SLB arrays require a total of 20 SLB switches, 10 of these are mounted 2 to a rack on space on the SLA racks previously described, while the remaining 10 occupy an SLB rack.

The SLC and SLD stages are mounted together on SLC/D racks, each containing 4 SLC switches and 4 SLD switches. The interconnections of the switches on a rack are shown as a grouping plan in Fig. 9-13.

The four SLD switches are multipled in pairs to provide two 20 x 20 arrays, while the SLC switches are connected as five 8 x 20 arrays, by multipling two verticals in each switch. The complete rack has 40 inlets

(SLD verticals) and 100 outlets from SLC horizontals which are connected to SLB verticals with 4 paths from an inlet to any particular SLC-SLB link. Two such racks with their SLC outlets paralled to the same SLB verticals provide the 80 SLD inlets as shown in Fig. 9-14 which is the complete grouping plan. Each SLC/D rack is equipped with a code receiver to receive the last 3 digits of the B party's number on incoming calls.

Problems of Dual Marker Operation

In order that two markers can operate simultaneously, precautions are needed to prevent mutual interference. All previously described, markers have avoided such problems except in the selection of a free outlet. In this and in all other LME multiple marker designs, the problem is overcome by arranging that the first few steps in defining the path to be used define a sub-set of the possible connections which:

- Contains at least one suitable path, and
- Is completely independent of any sub-set in which another marker is operating.

It then pre-empts this sub set and prevents any other marker from attempting operations which will affect the sub set. From this point on, the marker need take no other precautions against interference from other markers.

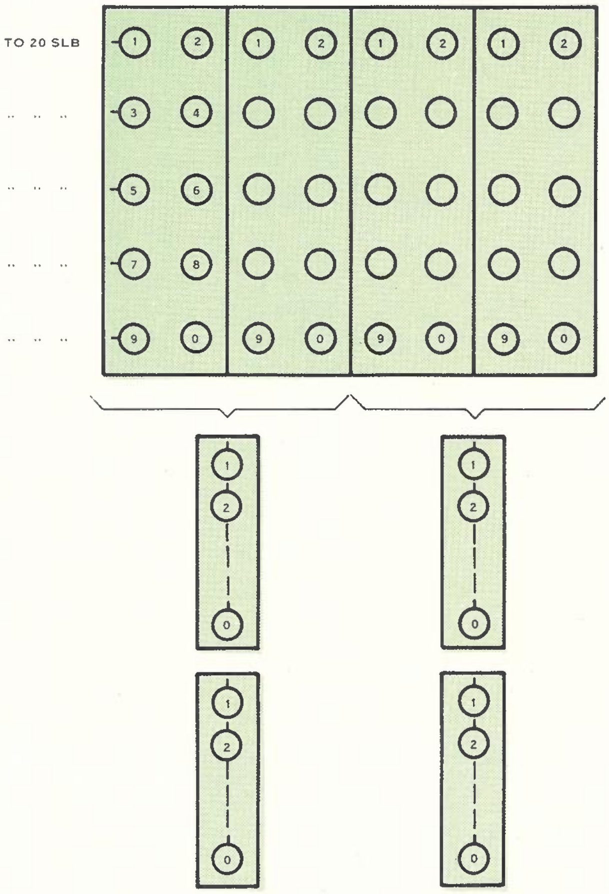


Fig. 9-13 — SLC and SLD Grouping Plan.

In the case of two SL markers sharing control of the same thousand group interference can be prevented by specifying that two markers cannot work together in:

- The same SLC/D rack, or
- The same 200 group, or
- The same SLB switch.

The first constraint sub-divides the SLC/D equipment into units which can conveniently be served by a single code receiver, and the code receiver coupling arrangements ensure that the constraint is always satisfied.

The second constraint divides the SLA switches into 5 self contained units and is fairly easily satisfied.

The third constraint is necessary because the SLB switches each serve 400 subscribers, and if two markers are each working in separate 200 line groups, there are some SLB switches which could be used for either line group. For example, if one marker is connecting a call in the first 200 line group and the other is connecting a call in the third 200 line group Fig. 9-14 shows that SLB switches number 11 and 16 are common to the two groups, and one marker or the other must be given exclusive use of each of them.

Structure of Common Controls

The common control equipment for 1000 lines is divided into three types of units: indentifiers, code receivers, and the marker itself, as shown on Fig. 9-15.

One identifier is provided for each marker and its function is to recognise the presence of a call from a subscriber, identify the calling subscriber and transfer this information to the marker. It can do this while the marker is occupied connecting another call to a subscriber.

One code receiver is provided for each SLC/D rack and performs the usual code receiver functions for the 40 inlets to the rack.

Either one or two SL markers can be provided and each can switch calls either from or to any subscriber. The two markers can operate simultaneously, subject to the conditions inposed to prevent mutual interference.

Marker Operation Sequence

Call from Subscriber

When a subscriber originates a call the LR relay operates as described in Chapter 5. This initiates a call to the identifier which ascertains the calling subscribers number. The identifier then pre-empts the use of this 200 line group, waiting if necessary if a marker is already using it. It then seizes the marker with which it is associated, waiting, if necessary, for it to be free and transfers to it the subscribers number and the fact that a call from the subscriber is being attempted.

There are only 40 possible paths which satisfy the conditions specified by the marker. Thus if the calling subscriber is number 235, the call must use one of the eight marked SLA verticals and one of the 40 marked SLB verticals in Fig. 9-12.

The first step in the marker operation is designed to pre-empt the use of SLB switches. This uses a test which identifies which of the 8 SLB switches are not already in use and applies a circuit condition which prevents the other marker using them. Since an SLB

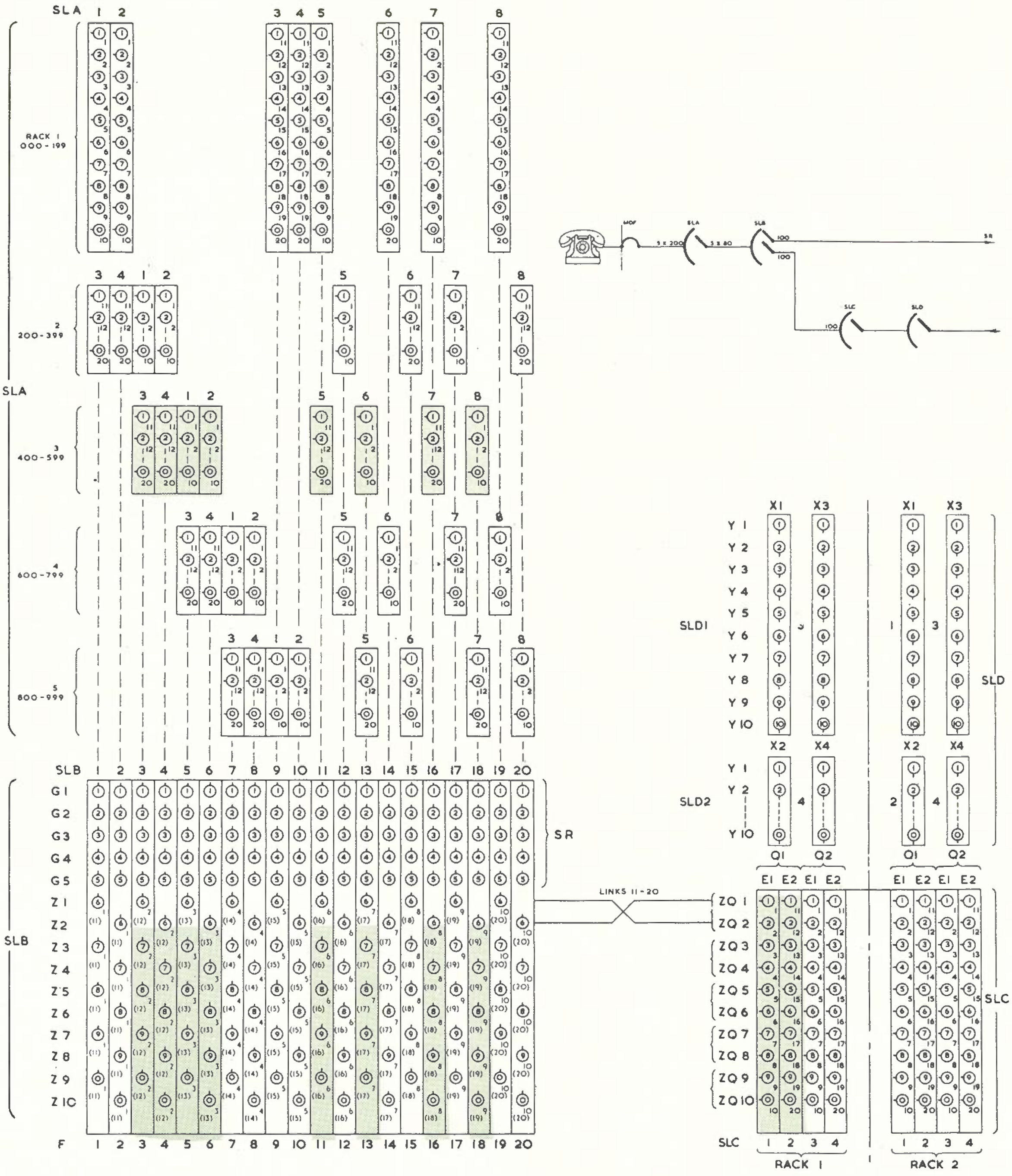


Fig. 9-14 — Complete SL Grouping Plan.

switch cannot be used if the corresponding SLA vertical is busy, this test is made conditional on the state of the SLA vertical. The marker has now identified, and pre-empted, all the SLB switches which can reach the calling subscriber via an idle SLA vertical and have not been previously pre-empted by the other marker. This test must be provided with safe-guards against simultaneous testing by both markers, but from this point on the marker has exclusive access in its defined sphere of control.

The next step tests the state of the SR relay sets which are connected to the available SLB verticals. This is a group test, (five SR's at a time) and is subject to a further condition that the SR has access to an idle register. This is done to improve the efficiency of the SR to register trunking, and does not directly involve the SL stage marker. This test shows which of the SLB switches identified in the preceding test satisfy the further condition of having at least one vertical connected in an idle SR relay set.

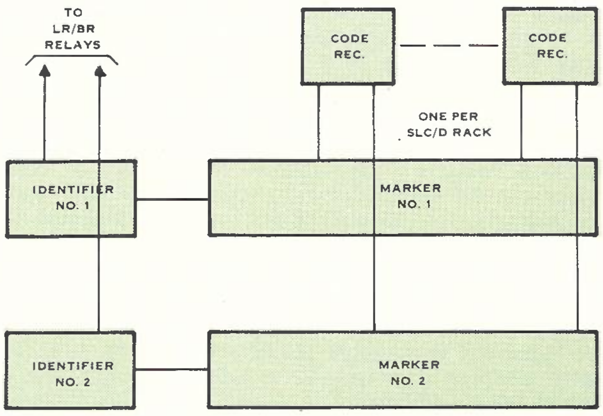


Fig. 9-15 — SL Marker Organisation.

One of the SLB switches which satisfies this test is selected, and the marker has now determined that the call will be switched via a specific SLA vertical to one of five SR relay sets connected to a specified SLB switch. The pre-empting of the other SLB switches is no longer necessary and is cancelled so that the other marker can now use them.

The final test is applied to these five SR relay sets individually, and one which is idle is selected. This completes the path selection and allows the appropriate switch magnets to be operated.

Call to Subscriber

A call to a subscriber is switched by the preceding selector to an SLD inlet. The inlet calls the code receiver, which is coupled and receives the last 3 digits of the subscribers number (say 417). The code receiver then tests the 200 group and the markers, and if the 200 line group is not being used and a marker is idle it busies the 200 line group, seizes the marker and transfers the called subscribers number to the marker.

When the marker is called the code receiver has already ensured that the appropriate 200 line group has been pre-empted for this call, and naturally only one call at a time from an SLC/D rack can be presented to a marker because of the 1/40 code receiver coupling.

The calling inlet and the called number are known, and this reduces the number of possible paths which can be used to 160. The devices which can be used for this call are shaded on Fig. 9-14. The relationship between these devices is shown in Fig. 9-16 which is a section of the whole grouping plan. It can be seen that the calling SLD inlet can reach 20 SLC verticals, all of which can be used for the call. These are in 5 sets of 4, with paralled outlets, and only 8 outlets of each SLC vertical reach SLB verticals that can be used for this call, giving access to 40 SLB verticals. These again are grouped in 8 sets of 5, with paralleled outlets, and only one outlet of each set can be used for this call. These give access to 8 SLA verticals, each of which again has one outlet to the desired line.

The marker's task is to select a path within this sub-set of the complete SL stage for which the three necessary links are idle and operate the switches so as to set up this path. The procedure can be better explained by using the diagram of Fig. 9-17, showing the links, and their connections. At each of the small circles representing an array, any link on the right can connect to any link on the left, and the conditions for using any link can be derived from this diagram.

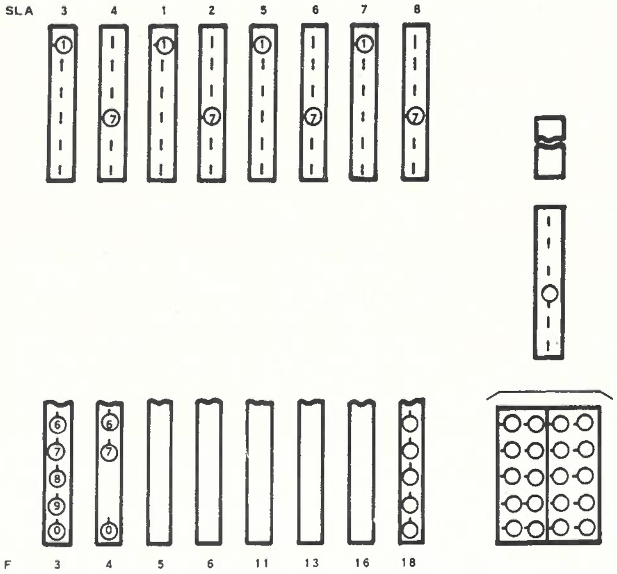


Fig. 9-16 — Portion of SL Grouping Plan.

The first step in the markers operation is to pre-empt the use of SLB switches, using the same circuit elements and the same test as for a call from the subscriber, this giving it an exclusive territory in which to work.

The next step is to identify which out of the SLA-B links and corresponding SLB switches now available to it have at least one free path to the SLD inlet. The relay contact tree involved for one SLB switch is shown in Fig. 9-18. If this switch is available to the marker, the appropriate FV(x) relay is operated, to permit the testing circuit to be extended. Five SLB-C links are connected to five verticals of this switch, and are available if the relevant vertical magnet is not operated. In turn, each of these links has access to 4 suitable

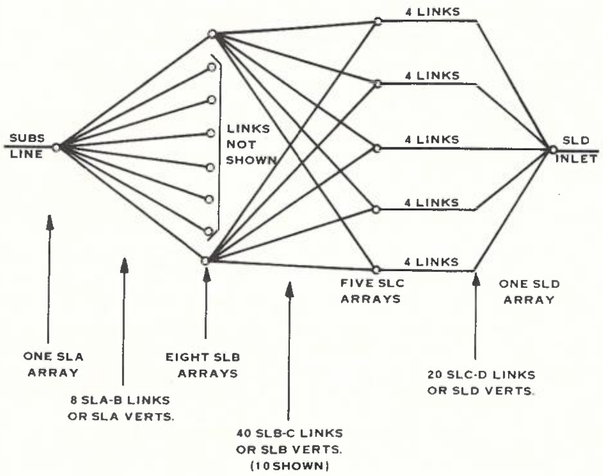


Fig. 9-17 — Paths from One Inlet to One Subscriber.

SLC-D links and the call can be connected if any one of these is idle. This is indicated by ZQG relays, each of which records the result of a test of four SLC-D links (i.e. SLC verticals) and is operated if at least one of the four is idle.

The contact tree, therefore, extends battery potential to the testing circuit if the SLB switch has at least one idle path to the calling inlet, and the testing and selecting circuit selects one of those which pass the test.

The next step is to examine individually the paths from each of the five SLB verticals in the selected switch which has been tested in parallel in the preceding test. From this test a particular SLB-C link is selected, and this link can be connected to the calling inlet over one of four SLC-D links. The final selection step chooses an idle link out of this four.

This completes the process of selecting a suitable path and the marker proceeds to operate the necessary magnets to establish the path.

Design Features

The SL Marker has several features which are the consequence of the 4 stage design or of the provision for two markers.

The need to guard against interference between the markers has already been discussed, as has the method of defining an exclusive sub-set of the total stage for each call. This has major implications for the design of the various contact trees used for testing the state of the links and operating the crossbar switch magnets. Each marker must have a full complement of these contact trees, branching out to the same speech path devices, so that the ends of the trees are joined. They do not interfere because they will only be extended to points within the territory of the particular marker.

It should be obvious that, just as the same devices are reached from the two markers, without interference, some of the contact trees can likewise be shared without interference, provided that the trees are suitably organised. This requires the sections which identify devices within (say) an SLC/D rack, as distinct from those that identify the rack, are located at the end of the tree remote from the marker and connecting to those devices.

This gives some saving, but introduces complexities in design which can be illustrated by the path which operates SLA switch horizontal magnets. There are a total of 400 of these magnets, and the correct magnet for a call is a function of the subscribers number, and the SLA switch used for the call. However, because of the way the grouping plan is organised the SLA switch can equally well be defined by the SLB switch and the 200 group, and this is what is actually done.

The relays appropriate to this selection and their functions are:

- S1 to S5 defining the 200 line group
- F1 to F20 defining the SLB switch and by implication the SLA switch
- DSI to DS10 defining the 10's digit of the subs number
- US1 to US10 defining the units digit of the subs number

The F relays are designated on the grouping plan (Fig. 9-12) and the S relays correspond to the SLA rack numbers.

The contact tree, drawn as if only one marker was present, is shown in Fig. 9-19. The earth potential required to operate the SLA horizontal magnet is controlled by relay FBU. The one wire from this relay's contact is expanded to 5 by contacts of the S relays, one of which is operated, to correspond to the 200 group.

Each of these 5 wires is expanded to 8 (giving 40 wires) by contacts of the F relay F1 to 20. Only 8 of these relays can be operated for any particular S relay and, for example, the contact of relay S3 is connected to contacts of relays F3, F4, F5, F6, F11, F13, F16 and F18. For this rack these correspond to SLA switches numbered 1 to 8 respectively.

Each of these 8 wires for switches in the SLA rack 2 are expanded to 10 wires giving a total of 80 wires by using contacts of relays US for switches 1, 3, 5 and 7 and of DS for switches 2, 4, 6 and 8. (The use of units and tens digits to identify the horizontal on different switches is a consequence of the transposed multiple.)

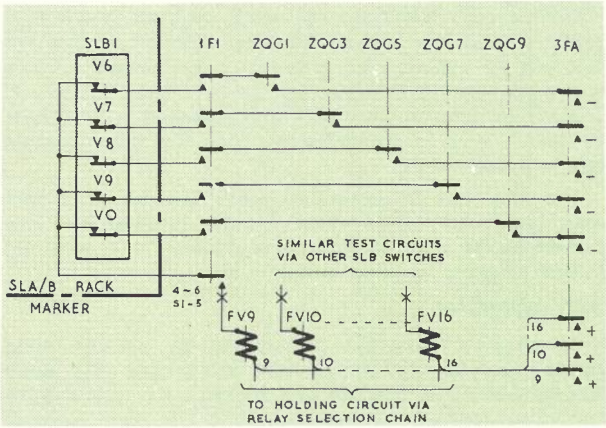


Fig. 9-18 — Testing Circuit for SLB Switches.

The same arrangements apply to the wires for the switches in the other 4 racks, so that access is possible to any one of the 400 horizontal magnets.

There are 4 DS and 4 US springsets on each relay for this contact tree in each 200 line unit and there are considerably more needed for other purposes. To provide all of these springsets there are three parallel DS relays for each ten digit in each 200 line unit and likewise three parallel US relays in each unit.

A second marker could have an identical set of contact trees, completely duplicating the one shown with its 400 wires connected to the same horizontal magnets. The circuit logic is such that each marker would extend the FBI springset to the horizontal magnet required for the call it was switching.

However, it can be seen that of the 400 DS and US springsets associated with the contact tree for one marker only 10 will be connected back to the FBI relay contact, the other 390 having an open circuit springset of an F or S relay (or both) in its path to the FBU contact. Moreover, this 10 is in the group of 80 associated with the desired 200 line unit.

The same applies to the other marker, and the 80 possible DS and US springsets to which the operate path is extended belong to a different 200 line group.

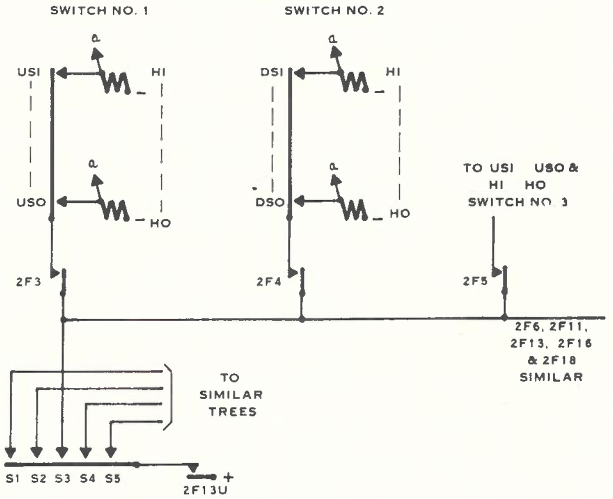
Therefore, if the marker operates only the DS and US relays of the 200 line group to which it is working there is no need to duplicate the DS and US relays for the two markers and Fig. 9-20 shows the circuit arrangement which allows two markers to share one set of these contacts. The two markers each have separate contact trees for the S and F relays, branching out to 40 wires for each marker, which are then paralleled. These 40 wires then connect to a common set of DS and US relays, which branch the trees out to the horizontal magnets. These latter relays are, naturally, on the SLA/B rack.

When a marker has reached the stage of operating the SLA horizontal magnets, one S and one F relay in the marker have been operated, as well as a DS and US in the relevant 200 line group. The FBI contact is therefore extended to one wire leading to that group and via the DS or US relay to the correct horizontal magnet. Simultaneously the second marker can be operating an SLA horizontal magnet in a different 200 line group, without interference.

In this contact tree it is possible to recognise three categories of relay contacts, based on their use. The DS and US relay contacts are shared by two markers (and in a large system by several) and the relays are located on the switch racks, to minimise wiring. Such relays are usually called rack relays, and in very large systems a contact tree may be branched via two stages of such relays.

The F relay contacts are individual to each marker, and have the distinctive property that they are the last such contacts in the tree, and that the two trees are joined beyond this point. For this reason, the relays are sometimes called rack coupling relays. In this instance they are located in the marker itself, but in other cases they are located on the switch rack. The choice is largely controlled by mechanical and wiring considerations relating to a particular switching stage and marker.

Finally, the S relay contacts in this tree are wholly within the marker.



'a' REPRESENTS WIRES FROM OTHER MARKER

Fig. 9-19 — Operation of SLA Horizontal Magnets.

In a marker system as complex as this there is a very large number of relay contacts devoted to the provision of contact trees, and considerable wiring between them. There are many alternatives open to the designer, in the sequence of the contact trees, the possibility of making some parts of the trees either individual to each marker, or shared by them and in the physical location of the relays. The designer attempts to use these options in such a way as to produce the most economical overall design and in the process an essentially straightforward concept inevitably becomes obscured by the details of its implementation.

This can be seen in Fig. 9-18 where the contact trees for testing access from SLA-SLB links are shown. In this circuit F relay springsets appear in two places, although it would appear that since they are in series the second set is redundant. However, in this instance the F relay is functioning as the marker coupling relay and springsets each side of the SLB vertical magnet springsets are needed for this purpose. If the vertical magnet were fitted with duplicate springsets the circuit could be simplified by omitting the 1F relay springs between the SLB springs and the ZQG relays. In this case an extra springset on each of 100 SLB vertical magnets would save 5 springsets on each of 40 F relays (20 relays in each marker). Whether in the long run this would save anything significant depends on the effect on wiring costs and obviously any difference is small in this instance. However, it does illustrate the principle.

When a selector has several stages so that the marker has to select the path in corresponding steps, the selection sequence can have an effect on the way the links are loaded and on the efficiency of the selector stages. Thus in the SL stage, the selection of an idle SR out of the 40 accessible takes place in the following steps:

- Each SLA-B link from the calling subscriber is tested to identify those which are idle and also have access to at least one idle SR relay set.
- One of these is chosen at random.
- The SR relay sets reached via that link are tested, and one of the idle ones chosen at random.

If, at the time of testing, one idle link has access to one idle SR relay set and another to 5 idle SR relay sets, each is equally likely to be selected. However, if the first is chosen, the 19 other SLA verticals reaching that SLB switch can no longer be used for outgoing traffic. If the second is chosen, it does not completely block any other SLA-B links.

On the other hand, if the 40 SR relay sets were tested simultaneously, conditional on the SLA-B links being idle, the SLA-B link with access to 5 idle SR relay sets would be five times as likely to be selected as one with access to only one idle SR relay set. This testing procedure therefore spreads the calls in a way which leaves a better pattern of idle links and SR relay sets. Even better is "call packing", where the call is always directed to the idle link with access to most idle SR relay sets.

In the SL marker a compromise is adopted, by arranging that the testing of one SR out of the 5 reached from any SLB switch is delayed slightly so that these SRs are only selected if there is no SLB switch with less than 4 busy SR relay sets connected to it.

PBX Operation

Many subscribers have two or more lines connected to a switchboard, and the number of only one of the lines is published in the directory.

A call to this number must be switched to any idle line of the group, and the SL stage can be fitted with "PBX equipment" to allow this function to be performed. When this facility is fitted, the called subscriber's number is transferred to the PBX equipment, which first tests to see if it is a PBX number. If it is, the PBX equipment tests the state of all lines in the group, selects one idle line, and replaces the number received and stored in the code receiver with the number of the selected line. On calls to numbers which are not PBX groups the equipment merely signals this fact to the code receiver, which connects the call to the number dialled.

Designs for Different Traffic Levels

As mentioned previously, the interconnection scheme described above is one of a range designed to cater for the wide variations in calling rate of different exchanges. The differences between them are in the size of the crosspoint arrays and particularly of the SLA and SLB stages which concentrate the subscribers' traffic.

Firstly, there are three different SLA stage sizes available, with 6, 8 and 10 SLA verticals per 20 subscribers. Each has a maximum traffic per subscriber which it can carry without generating excessive congestion in the SLA-SLB links. These cover the normal range of subscriber calling rates in rather broad stages and there is need for some variation also in the concentration ratio of the SLB stage.

The SLB stage has a problem because the method of avoiding dual seizure by markers requires the SLB arrays to be made of whole switches. Therefore the SLB arrays can only be of 20 x 10 (one switch) as already shown, or 20 x 20, using two switches. Consequently, when a concentration ratio different from 2 : 1 is needed, a mixture of 20 x 10 and 20 x 20 SLB arrays is used.

A grouping plan for the SLA and SLB stages where this has been done is shown in Fig. 9-21. It can be seen that by adding five SLB switches to Fig. 9-12, five of the arrays have been increased from 20 x 10 to 20 x 20, and there are 250 SLB verticals instead of 200. These have been used to give 125 SR relay sets and 125 SLB-SLC links.

In order to keep a balanced system, so that every subscriber has equal access, SLB switches must be added in units of 5 at a time, and can be so added until the capacity of the SLA-SLB links is exceeded.

With a mixture of 20 x 20 and 20 x 10 SLB arrays, random selection of SLA-SLB links will cause the SLB verticals on the 10 x 20 arrays to carry nearly twice the traffic of those on the 20 x 20 arrays, and the extra verticals are under-employed. More uniform loading and greater traffic capacity is achieved if the SLA-SLB verticals leading to 20 x 20 arrays are given preference over those leading to 10 x 20 arrays. The selector circuit in the marker is designed so that this is done in all cases where there is a mixture of SLB array sizes.

Variations in incoming traffic are allowed for by providing different numbers of SLC/D racks, ranging from one rack (40 inlets) to five racks (200 inlets), with their SLC-SLB link outlets paralleled. As described, the SLC/D rack had access to only 100 SLB-SLC links, and many grouping plans have more than 100. The rack is organised so that it can have either 100 SLB-SLC links with 4 parallel paths to each or 200 SLB-SLC links with 2

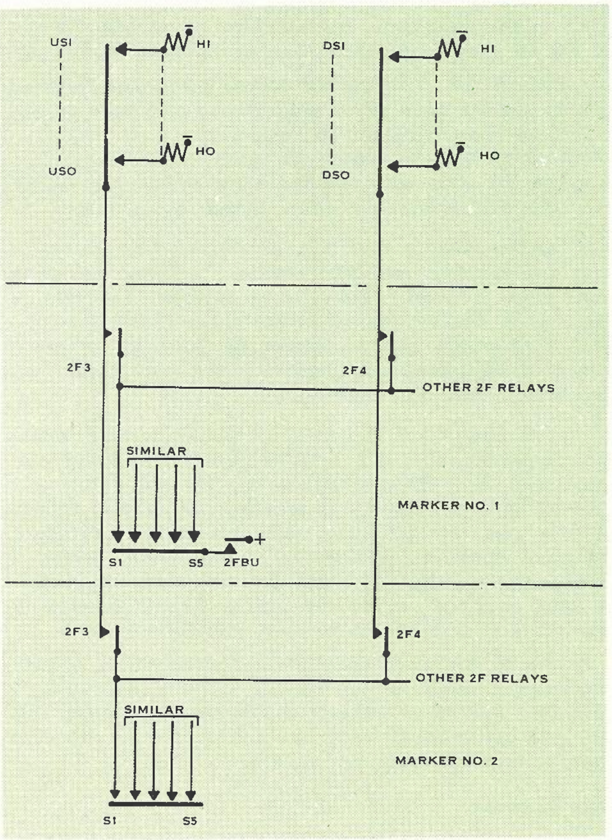


Fig. 9-20 — Operation of SLA Horizontal Magnets with Two Markers.

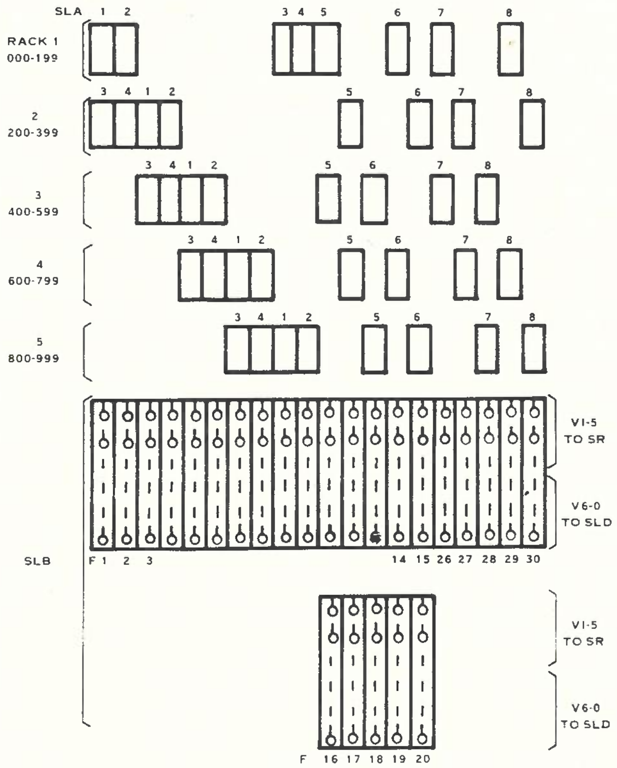


Fig. 9-21 — Grouping Plan 8D.

parallel paths to each. The second form is shown in Fig. 9-22. The change from 200 to 100 is done by parallel connection of the outlets by suitable inter-rack cabling, and involves no other change to the rack.

In the case just illustrated with 125 SLB-SLC links, the SLC/D racks are connected to give 200 links, but 75 of them are idle. It is too difficult to design the marker so that these spare SLC outlets can be used.

For the different sizes of SLA stage there are three types of SLA/B and SLA racks. The rack for 8 SLA verticals has already been described and has 8 SLA switches and 2 SLB switches on the rack. For the case with 6 SLA verticals for 20 subscribers the rack has 6 SLA switches and 3 SLB switches. Finally, for the high traffic case with 10 SLA verticals per 20 subs, the rack has 10 SLA switches and no SLB switches and is therefore called an SLA rack. Additional SLB switches to those available on SLA/B racks are provided on SLB racks, with either 5 or 10 SLB switches. The rack with 5 switches has the rest of the rack either vacant, or fitted with equipment for PBX subscribers.

TABLE 9-3 — TYPES OF SL STAGE

Type	SLB Verticals		SLD Verticals (Typical)
	Outgoing	Incoming	
6A	75	75	80
6B	100	100	120
8A	100	100	120
8B	100	150	120
8C	125	175	160
8D	125	125	120
10A	125	175	200
10B	150	200	200
10C	150	150	200

Table 9-3 shows details of all the designs available for SL stages, and their designations. These designations comprise a number, representing the type of SLA stage, i.e., 6, 8 or 10 SLA switches per 200 followed by a letter to indicate variations in the SLB stage.

Marker Modules

One basic marker design covers all the above variations of SL stage configuration, and like the switching stages is built up of modules.

The basic marker logic is identical regardless of the grouping plan, and the only difference is in the dimensions and some minor details of the contact tree, and in the number of relays in some of the selector chains. Since the marker is so big that it must be made up of a number of plug-in units, it is possible to plan its division into units so that some may be omitted for the lower traffic grouping plans. The marker rack is completely wired to suit the highest traffic requirements, so that it is merely a matter of plugging in the appropriate units and making a relatively few strapping changes in some relay sets.

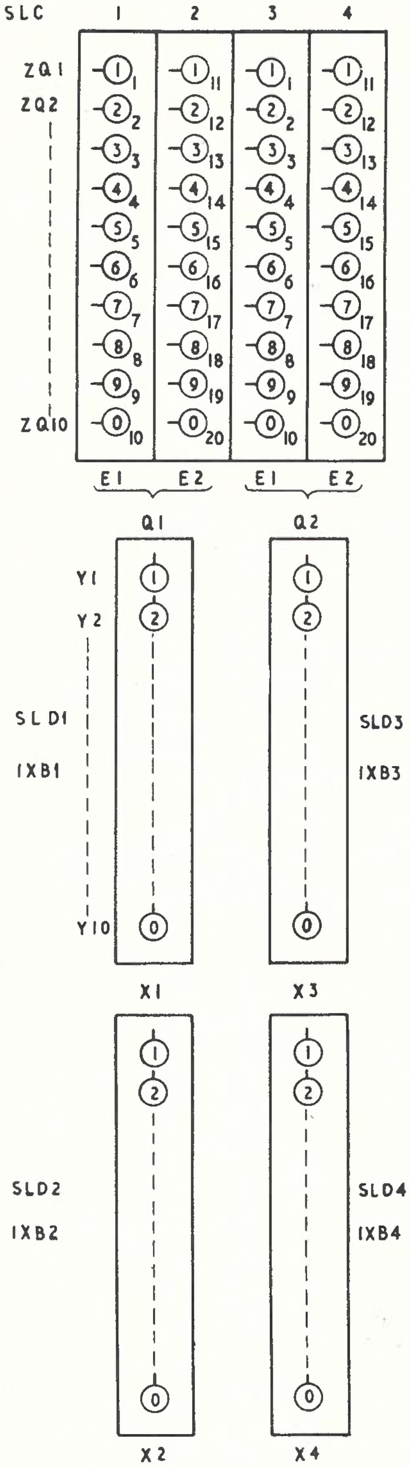


Fig. 9-22 — SLC/D Stages.

Chapter 10 – ARK and ARM Exchanges

INTRODUCTION

ARK EXCHANGES

- **External Trunking**
- **Method of Control**
- **Manual and Step-by-Step Parents**
- **Speech Path Trunking**
- **Marker Design**

ARM EXCHANGES

- **General**
- **Speech Path Trunking**
- **Registers**
- **Markers and Related Services**
    - *Route Marker*
    - *Test Blocks*
    - *Marker*
    - *Wires Between Control Services*
    - *Other Route Marker Functions*

LIMITATIONS OF RELAY MARKERS

- **Computer Controlled Exchanges**

INTRODUCTION

The descriptions of equipment have so far been concerned mainly with ARF terminal exchanges, which represent the largest part of the APO's total investment in crossbar equipment. This chapter deals with two other major types of crossbar exchange equipment.

ARF was originally intended for medium to large sized terminal exchanges ranging from about 2000 lines upward, and the cost per subscriber rises rapidly if it is used in smaller exchanges, mainly because there is a substantial "first in" cost for common equipment for even the smallest ARF exchange.

Most exchanges in Australia are in the size range where ARF is unsuitable and for these a type of exchange designated ARK is used. These are usually installed in transportable buildings up to a size of 1000 lines, allowing most of the construction to be carried out in a factory environment rather than in the field, and avoiding the costs of a permanent building.

The network also requires a variety of tandem (or trunk) switching centres to connect junctions and trunks together. As was pointed out in Chapter 2 there may be as many as seven switching centres, connecting eight trunks and junctions in tandem in order to connect two subscribers.

ARF equipment is widely used for tandem switching but has two major limitations in this application.

- Because of the internal congestion in the speech path trunking, slightly more junctions and trunks are needed than in a design with negligible internal congestion. This is most important if the trunks connected are long and expensive.
- It causes a slight impairment of speech transmission quality such that a maximum of only two ARF tandem switching centres can be allowed on a long call.

The APO switching system is therefore designed with this limitation in mind, and includes about 45 tandem centres designated as secondary, primary and main trunk switching centres where more elaborate and versatile equipment is needed.

For these centres the APO has standardised on LME ARM 20 and ITT 10C equipment.

This chapter describes the main features of ARK and ARM exchanges.

ARK EXCHANGES

External Trunking

The ARK 521 exchange is intended for low calling rate exchanges up to a maximum of 2000 lines, and uses modular techniques to provide economical designs from 100 lines upwards. It may have 2, 3 or 4 switching stages depending on the number of subscribers and the traffic requirements. For very small exchanges the ARK 511 exchange having a maximum capacity of 90 lines is used.

Australian ARK exchanges are always used as terminals and their external trunking takes the form shown in Fig. 10-1. The exchange has effectively two "sides",

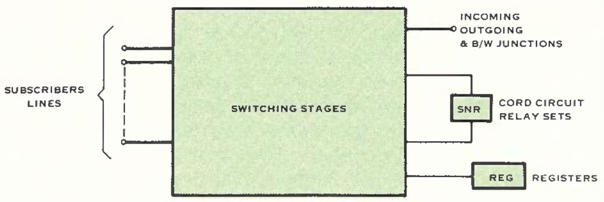


Fig. 10-1 — ARK Exchange Principle.

with subscribers' lines terminated on one (the subscribers') side and with junction and cord circuit relay sets terminated on the other (the junction) side.

On the junction side are terminated:

- Junctions to the parent switching centre — often bothway junctions, but separate in and out junctions may be used.
- Cord circuit (SNR) relay sets for local calls, with each SNR being terminated at two points, for the side connected to the A subscriber and the B subscriber respectively.
- Registers used for certain types of call as discussed later.
- Junctions for (usually) high usage routes to other exchanges if provided.

All calls are set up by a connection between a subsciber's line, on the subscriber's side, and a device on the junction side. For a local call there are two such connections, one from the A subscriber to the A side of a cord circuit and the other from the B subscriber to the B side of the same cord circuit.

The whole of the speech path trunking is designed to carry both incoming and outgoing traffic, and the marker handles both in almost the same way.

Method of Control

The design principle described earlier of using registers at the terminal exchange as buffer stores is not entirely suitable for very small exchanges. For example, with 100 lines and typical calling rates there may be 3 Erlangs of speech path traffic and 0.4 to 0.5E of register traffic, requiring 4 registers, so that the registers would be inefficiently used.

At the same time, these exchanges usually have a relatively simple network of external junctions. In most cases all the external traffic is carried over a single junction route to a tandem centre, which is classified as a minor trunk switching centre, and is often referred to as its parent. Occasionally direct routes are justified to a few nearby terminal exchanges but these are always small.

For this reason, modern ARK exchanges are designed so that they can use registers located at the "parent" minor centre. In this way, one group of registers forms a pool used by all the ARK exchanges in the minor area, and the registers are more efficiently used. Fig. 10-2 shows how this is done. When a subscriber calls, he is connected to a junction to the minor centre, and the FIR on that junction, at the minor centre, is connected to a register designated Reg-ELP. The register receives and stores digits in the normal way, but can cause the call to be switched in one of two ways:

- If the call is for a subscriber connected to the terminal exchange, the register transmits a line signal to the terminal exchange which causes the code receiver to be connected to the line. The register then transmits the B party's number to the terminal exchange. The marker is then called, and it clears down the existing connection, and sets up a new connection, via an SNR relay set between the calling subscriber and the called subscriber. This process of replacing an established connection by a new one is called "jumping".

- A very similar process can "jump" the call to a direct junction to an adjacent exchange, but two extra facilities are needed. If the direct junction route has all circuits busy, the code receiver at the terminal exchange signals this to the register at the minor centre which then sets up the call via the final route. If the call is successfully switched to the direct junction, the last 2, 3 or 4 digits must be transmitted to the destination exchange over the junction and to allow this to be done, a by-path circuit is set up between the code receiver connected to the junction to the minor centre and the junction to the adjacent exchange. This by-path uses a relay set known as a KFID and only one is provided for all such calls in an exchange. The amount of signalling traffic on the by-path is seldom, if ever, great enough to cause overloading. The ARK design is not meant for use in a network where a large number of direct routes is justified and in such situations ARF must be used.

  On all outgoing calls other than local traffic, or traffic switched over direct junctions, the register at the minor centre sets up the call via the minor centre in the normal manner. However, in order to avoid line signalling problems the register even on these calls is still required to call the code receiver at the terminal exchange. In such cases the code receiver merely signals that it cannot make the connection requested. If the register is aware from its own analysis that the call cannot be set up that way, it sends a digit "11" so that the terminal exchange does not have to again analyse the code.

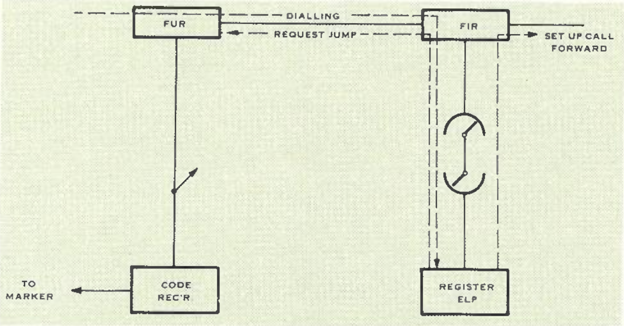


Fig. 10-2 — Use of Reg-ELP.

The reason for calling the terminal exchange code receiver on all codes is that the line signalling system is limited and has to use a sequence of identical signals to mean, in turn, "call code receiver", "B party answer" and "metering", and the "call code receiver" signal must always be sent to establish the sequence.

The same code receiver is accessible to FIRs and is used for incoming calls, under which conditions it expects to receive only the last two, three or four digits of the called number, depending on the size of the exchange. On a both-way junction the relay set must be able to use the code receiver in both ways.

Manual and Step-by-Step Parents

The above design can only be used with a crossbar minor centre equipped with the necessary registers. Where it is necessary to instal an ARK exchange with either a step by step or a manual parent, some kind of local register is needed in the ARK.

For a step by step parent the register is called a Reg-D, and the configuration of the exchange is shown in Fig. 10-3. The register is coupled to junction relay sets via a register finder, and is used for both outgoing and incoming calls.

On outgoing calls a junction to the parent exchange is seized and a register is coupled to the junction relay set. The digits dialled by the subscriber are repeated both to the register and the parent exchange, so that the call is set up stage by stage at the parent at the

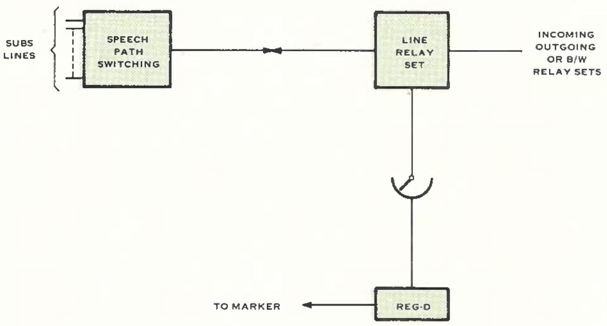


Fig. 10-3 — Use of Reg-D.

same time as the digits are stored in the register. As each digit is stored, the code is examined in the register until it has determined that the call is either a local call, or one for which a direct route exists, or one which can only be connected via the parent. If it is a call which must be connected via the parent the register disconnects and allows the call to proceed. If it is one which can be switched by the ARK exchange the call to the parent is released, and the local register controls the subsequent action.

For a local call, it waits till the full B party's number has been dialled, and then transfers the last 2, 3 or 4 digits to the marker, which jumps the call to an SNR relay set. For a direct junction, it calls the marker immediately, and causes the call to be jumped to the junction route. Because the "jump" cannot be completed in the normal interdigital pause, direct junctions to automatic exchanges require the subscriber to pause between digits and wait for second dial tone and hence this arrangement is not used if any alternative is possible. For incoming calls, the same register is used as a code receiver, receiving the last digits of the B party's number as decadic signals, and calls the marker.

ARK exchanges with a manual parent use a different configuration, with a register designated Reg-LK. The structure of an exchange using Reg-LK is shown in Fig. 10-4. The registers are connected to the junction side of the speech path switching, and take the place of a junction to a crossbar parent.

On outgoing calls, the subscriber is connected first to a Reg-LK, which returns dial tone. The digits dialled by the subscriber are stored and analysed in the register, until a complete and valid code is stored. It then calls the marker, and the call is jumped appropriately. In general, there are only two types of calls, local calls and calls to the parent manual exchange, and the register is therefore quite simple.

For incoming calls, the junction appears both on the subscribers' side and the junction side. When the junction is seized for an incoming call it is connected from the subscriber's side to a Reg-LK. When the number is stored in the register, the call is jumped to connect the junction side termination of the junction to the B party.

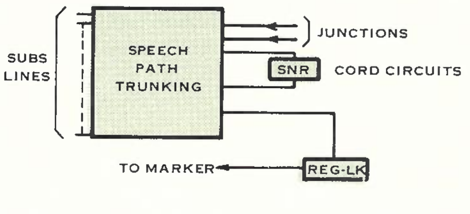


Fig. 10-4 — Use of Reg-LK.

A very useful feature of this design is that when the parent is converted to crossbar very little change is needed to make it work with the new parent. The Reg-LK gives almost identical conditions to the marker and the rest of the exchange as does a junction to a crossbar parent. This also makes it possible to use the Reg-LK in an ARK exchange with a crossbar parent as an "overflow" register. In this application it is connected and trunked so that it is seized if all junctions to the parent are busy.

It then allows local calls to be switched even if there are no idle junctions to the parent.

Speech Path Trunking

There are two types of ARK exchange, with different speech path trunking, the ARK 511 for the very smallest exchanges, up to 90 lines, and the ARK 521 for exchanges of 100 lines up to a maximum of 2000 lines.

The ARK 511 uses a single stage switching scheme, and is available in three sizes as in Table 10-1.

TABLE 10-1 — ARK 511 EXCHANGE SIZES

No. of Subs	No. of Junction Terminations	No. of SL Switches
30	10	1
60	15	3
90	15	5 (4½ used)

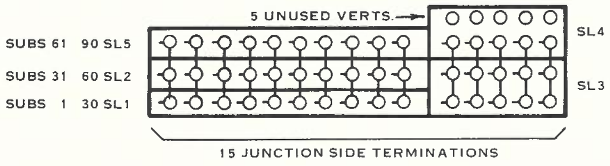


Fig. 10-5 — Grouping Plan of ARK 511.

A grouping plan is shown in Fig. 10-5, and is self-explanatory. A special crossbar switch is used in which each vertical gives access to 30 outlets. This is done by a special arrangement of the switching magnets, whereby if neither is operated, access is given to a third group of outlets. When this is done, only 3 wires can be provided for each crosspoint, but this is adequate for this application although it creates a difficulty with the larger ARK exchanges.

The smallest size of the ARK 521 serves 100 subscribers and has 2 switching stages designated SLA and SLB connected as shown in Fig. 10-6. The SLA stage connects 90 subscribers to 20 links with each subscriber having access to 6 or 7 links. The SLB stage is a 30 x 20 crosspoint array, one side of which is connected to the 20 links from the SLA stage, and 10 more subscribers lines, to give a total of 100 subscribers. The other side provides 20 terminations for junctions, SNR relay sets and registers.

This is not a link trunked system but a stage by stage system, and a simple version of it was described in Chapter 3. Because it is a stage by stage system, any idle link between SLA and SLB which serves a particular subscriber can be used unconditionally for a call to or from that subscriber.

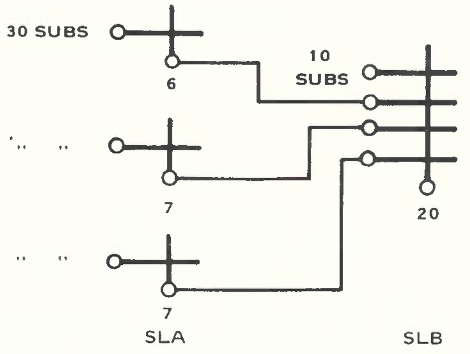


Fig. 10-6—Crosspoint Arrays 100 Line ARK 521 Exchange.

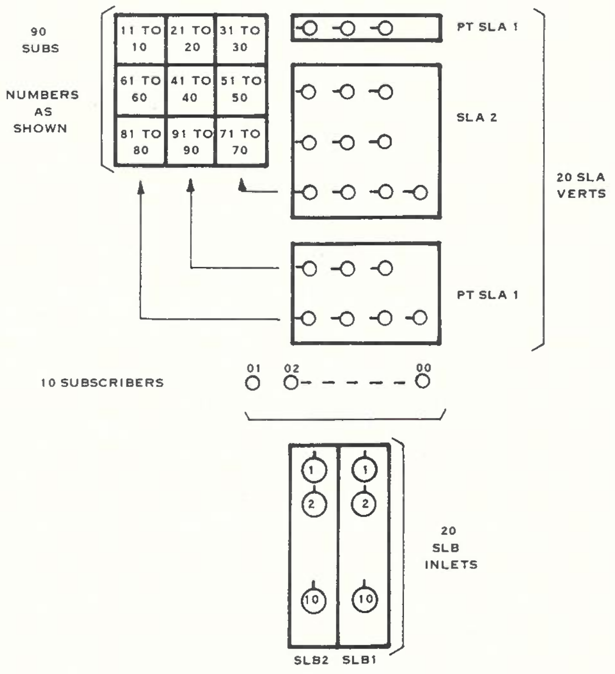


Fig. 10-7 — Grouping Plan 100 Line ARK 521 Exchange.

The SLA and SLB stages use crossbar switches with 30 outlets per vertical, and in order to increase the traffic capacity of the SLA-SLB links the SLA stage has a transposed multiple. Details of the connections from the SLA stage to subscribers and between the SLA and SLB stage are shown as a simplified grouping plan in Fig. 10-7. The SLA verticals, and SLA-SLB links which can be used for a call are specified by the tens digit of the subscriber's number, and subscribers with the tens digit "0" are connected directly to the SLB switch. As far as possible these numbers should be allocated to high calling rate subscribers, such as PBX lines or busy public telephones.

Exchanges of more than 100 lines are constructed using 100 line units as a basic building block, but almost invariably with one or two additional switching stages.

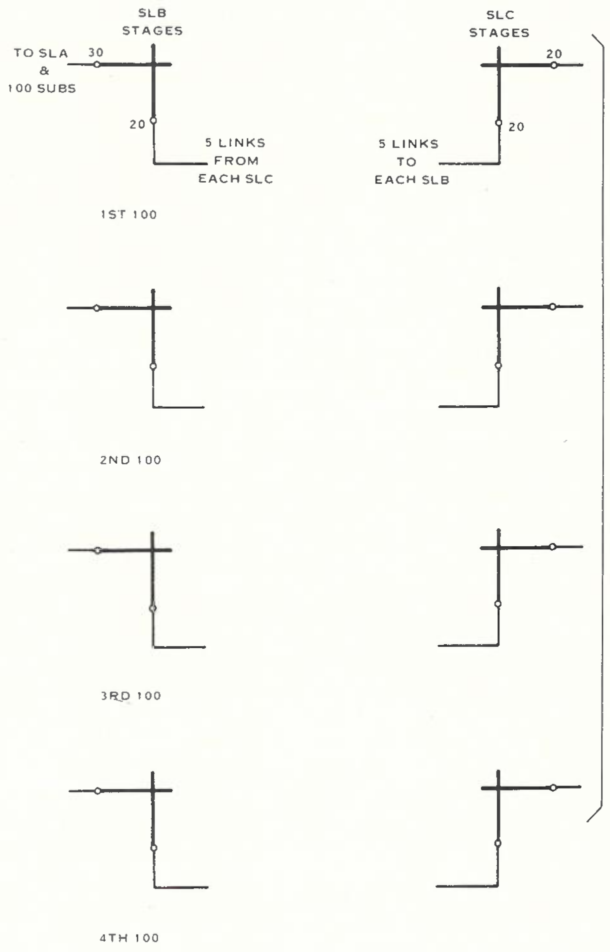


Fig. 10-8 — 400 Line ARK 521 Exchange.

The only exception is that where an exchange of 200 lines requires not more than 20 devices connected to the junction side, two 100 line units can have their SLB inlets multiplied together. For this to be possible the calling rate must be extremely low, and consequently this design has very little application in Australia.

A three stage design is used for exchanges between 200 and 500 lines, and the arrangement for 400 lines is shown in Fig. 10-8. The third stage is designated SLC, and consists of four arrays each 20 x 20. Each array has five links to each 100 line group, and is effectively a group selector. On incoming calls, the call enters at a specific SLC inlet from the incoming junction and must be switched to a particular subscriber. Depending on the hundreds digit a specific set of five links must be used, and selection of an idle link out of this five can be made unconditionally, since each link terminates on an SLB vertical with access to all free paths to the called subscriber. The loading of the links must be such that a call incoming to the exchange has less than 0.002 probability of encountering congestion in either the SLC-SLB links or the SLB-SLA links.

For outgoing calls the calling subscriber can be connected to any one of several junctions. However, since the SLC inlets are all suitable for terminating incoming junctions, the marker is designed to select any idle outgoing junction, and select a path to it as if it were an incoming call. Consequently, the 3 stage ARK exchange is effectively a stage by stage design, rather than link trunked.

There are two other 3 stage designs, one with 200 lines, and 10 links between each SLB and SLC array, and each 100 line group, and the other for 500 lines, and 4 links in each link route. The 500 line 3 stage design is suitable only for very low traffic subscribers and is seldom used, and a 500 line design with four stages is also available. Its arrangement in the form of crosspoint arrays is shown in Fig. 10-9. The SLC stage is of the same form as Fig. 10-8, but for 500 instead of 400 lines. However, 16 of the 20 inlets of each SLC array are combined with SLD arrays to form a 2 stage link trunked group selector. There are 80 inlets to the SLD arrays, and any one of these has access over 4 different SLD-SLC links to any SLC-SLB link. It is thus a group selector, giving access from the SLD inlets to the 5 routes to 100 line groups. An incoming call from a junction connected to an SLD inlet can therefore reach a particular subscriber via any of the 20 SLC-SLB links, and there are 4 different paths by which it can be reached. Obviously the traffic capacity of this design is much higher than the 3 stage design.

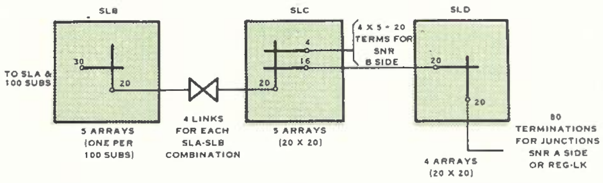


Fig. 10-9 — 500 Line ARK 521 Exchange.

On local calls it is necessary to set up a call from one subscriber to one side of an SNR, and from the other side of the SNR to the other subscriber. Each of the four SLC inlets on each array not used for SLC-SLD links is connected to the B subscriber's side of an SNR, while the A subscriber's side of each SNR is connected to an SLD inlet. In all ARK exchanges, local calls are set up by firstly connecting the B subscriber to any idle SNR B side, and then connecting the A side of the SNR to the A subscriber. For the first step the SLB and SLC stages form a link trunked selector, and an SNR is chosen which is idle and for which at least one suitable SLB-SLC link is also idle. By inspection, each SNR B side can be reached via 4 different SLB-SLC links, and every such link could be used for access to SNR B sides. This ensures reasonably efficient usage of SNR relay sets. For the second step, of switching to the A subscriber, the SNR is in the same position as an incoming junction.

If desired, fewer than five 100 line units can be connected, and this arrangement is used in high traffic cases for as few as 300 lines. It is also possible to reduce the SLC and SLD switches if the traffic is low enough.

Two similar designs are used for 1000 and 2000 lines maximum capacity, with the SLC and SLD stages organised as group selectors with access to 200 and 400 SLC-SLB links respectively.

Marker Design

The marker design follows standard principles, and since most of the selection is stage by stage it is relatively simple. Only the following few special features are worthy of comment.

Provision is made for two markers, both to provide sufficient switching capacity for very large exchanges, and to improve security. The use of duplicate markers for security is considered justified for exchanges over about 400 lines, if very remote from the maintenance headquarters.

The arrangement for avoiding interference is that two markers cannot work in the same 100 line group, or the same SLC or SLD switch.

When a call is to be jumped, the code receiver places a special condition on the c wire of the subscriber which causes it to call the marker. The marker recognises the special c wire condition and connects this subscriber to the device or routes indicated by the code receiver. Only one code receiver at a time is allowed to order a jump, so there is no ambiguity.

On a local call, to avoid the marker getting in its own way, the code receiver first calls the marker, requesting a connection from the B party to the SNR B side, and when this is complete calls for a jump of the A party to the A side of the same SNR.

The SLB switch has only 3 wires through the crosspoints, used for a, b and c wires, and the d wire to hold the vertical magnet cannot be extended to the SLA switch. SLA verticals are therefore held by a local circuit. Every time a marker has to make a connection in a 100 line group it carries out a preliminary test to detect any operated SLA verticals for which the SLB switch has released and releases them.

ARM EXCHANGES

General

As discussed, ARM 20 exchanges are used where a versatile and flexible design is needed and some of its features are:

- It can be built as a single switching entity up to a size of 4000 inlets and 4000 outlets.
- Internal congestion is very low, and normally is such that if two outlets on a route are idle, the probability of being unable to switch to at least one is less than 0.002.
- Outlets can be allocated to routes in any manner desired.
- It can use different forms of information and line signalling on different trunks and provide the necessary interfacing.
- By providing 4 speech wires through the exchange used as one pair in each direction of speech it gives improved speech transmission.

The first four of these requirements have a major influence on the design of the speech path trunking and of the common control equipment.

Speech Path Trunking

The speech path trunking of an ARM 20 exchange is organised in line groups, usually with capacity for 200 trunk line terminations. Each line group has two switching stages and Fig. 10-10 shows the crosspoint pattern for an incoming and an outgoing line group. The incoming line group terminates the lines on ten first stage (GIA) arrays, each 20 x 20, which are link trunked to ten second stage (GIB) arrays, each 20 x 30. The far side of the switching stage from the inlets has 300 terminations and any inlet can reach a termination via two paths.

The outgoing line group is shown as a mirror image of the incoming line group and has two identical stages designated GUA and GUB, with the GUB array providing 300 terminations.

In an ARM exchange there is a number of incoming and outgoing line groups, up to a maximum of 20 of

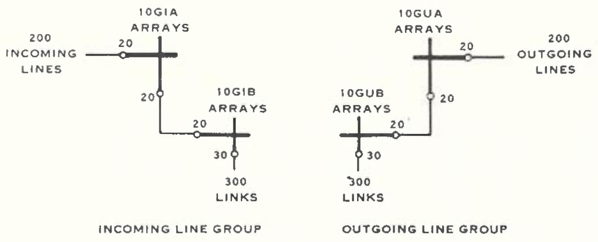


Fig. 10-10 — ARM Crosspoint Arrays.

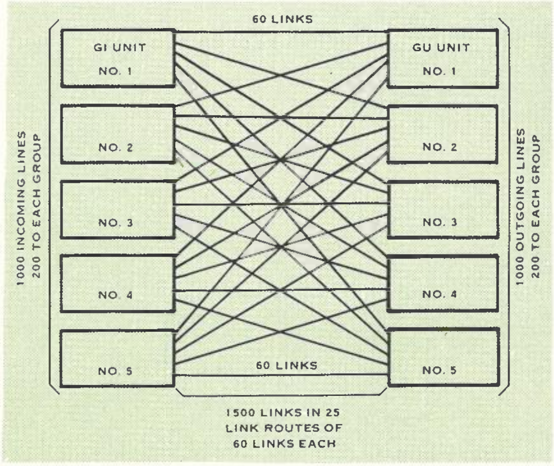


Fig. 10-11 — Interconnection of Line Groups.

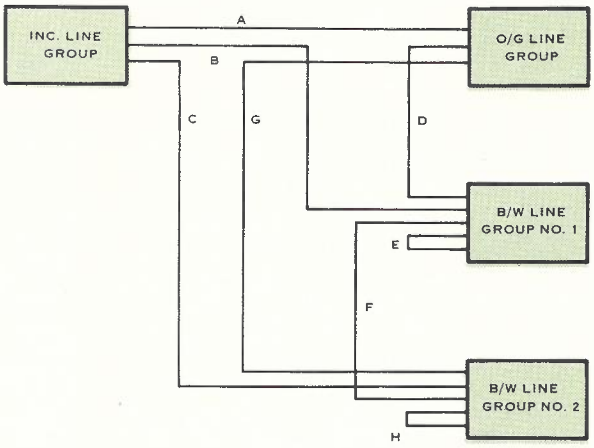
each. The 300 GIB terminations of one incoming line group are connected to the GUB terminations of the outgoing line groups by links, and a typical configuration is shown in Fig. 10-11. In this illustration there are 5 incoming groups and 5 outgoing groups, and the links are so arranged that each incoming group has 60 links to each outgoing line group.

A call from (say) an inlet or incoming line group 2 to an outlet on outgoing line group 3 can use any one of the 60 links between them (provided it is free and one of the two suitable paths through the incoming and one of the two suitable paths through the outgoing line group are all simultaneously idle). Note that this set of links can only be used for a call between these two line groups.

The set of links between an incoming and an outgoing line group is known as a link route. Link routes can be of any size from a minimum of 5 to a maximum of 80, in steps of 5 links and, although they often are, they need not be the same size for all link routes in an exchange.

For a maximum size exchange with 20 incoming and 20 outgoing line groups each link route contains 15 links, and under these conditions the internal congestion condition referred to earlier can be met with about 0.6 E per inlet or 2400 E of through traffic.

In the trunk network considerable use is made of bothway trunks. These can be connected to an ARM exchange by terminating them on both an incoming and an outgoing line group. Alternatively, on a small ARM exchange a bothway line group can be provided. A bothway line group is identical in structure to the incoming or outgoing line groups previously described, but is provided with link routes both from incoming line groups for traffic using trunks terminated on it for outgoing calls, and to



LINK ROUTE	FOR TRAFFIC	
	INC. FROM LINE GRP.	O/G TO LINE GRP.
A	INC	O/G
B	INC	B/W 1
C	INC	B/W 2
D	B/W 1	O/G
E	B/W 1	B/W 1
F	B/W 1	B/W 2
	B/W 2	B/W 1
G	B/W 2	O/G
H	B/W 2	B/W 2

Fig. 10-12 — Use of Bothway Line Groups.

outgoing line groups for the reverse direction. In addition, of course, it must have a link route from itself to itself for a call between two lines in that line group, and a link route to any other bothway line group.

Fig. 10-12 shows an exchange with one incoming, one outgoing and two bothway line groups, showing the link routes involved. Each bothway line group has its links divided into 5 link routes, allowing for the need for the link carrying traffic within a line group to appear twice, once for each end. The relatively large number of link routes in an ARM with bothway line units restricts their use to relatively small exchanges, but in such cases they are useful and can readily be converted to incoming or outgoing when the exchange grows.

The interconnections of a line group are shown in the form of a grouping plan in Fig. 10-13, and is self-explanatory, being a typical four partial stage construction. Ten racks are needed for a fully equipped line group, four for the A stage and six for the B stage. If desired, complete racks may be omitted, giving the partly equipped line groups shown in Table 10-2.

The links which would be chosen for a typical link route of 20 links, are indicated on the grouping plan. Other sizes of link routes are selected in a similar manner.

Registers

Many calls through an ARM exchange require the provision of a buffer store and/or some degree of translation of information signalling between the incoming and

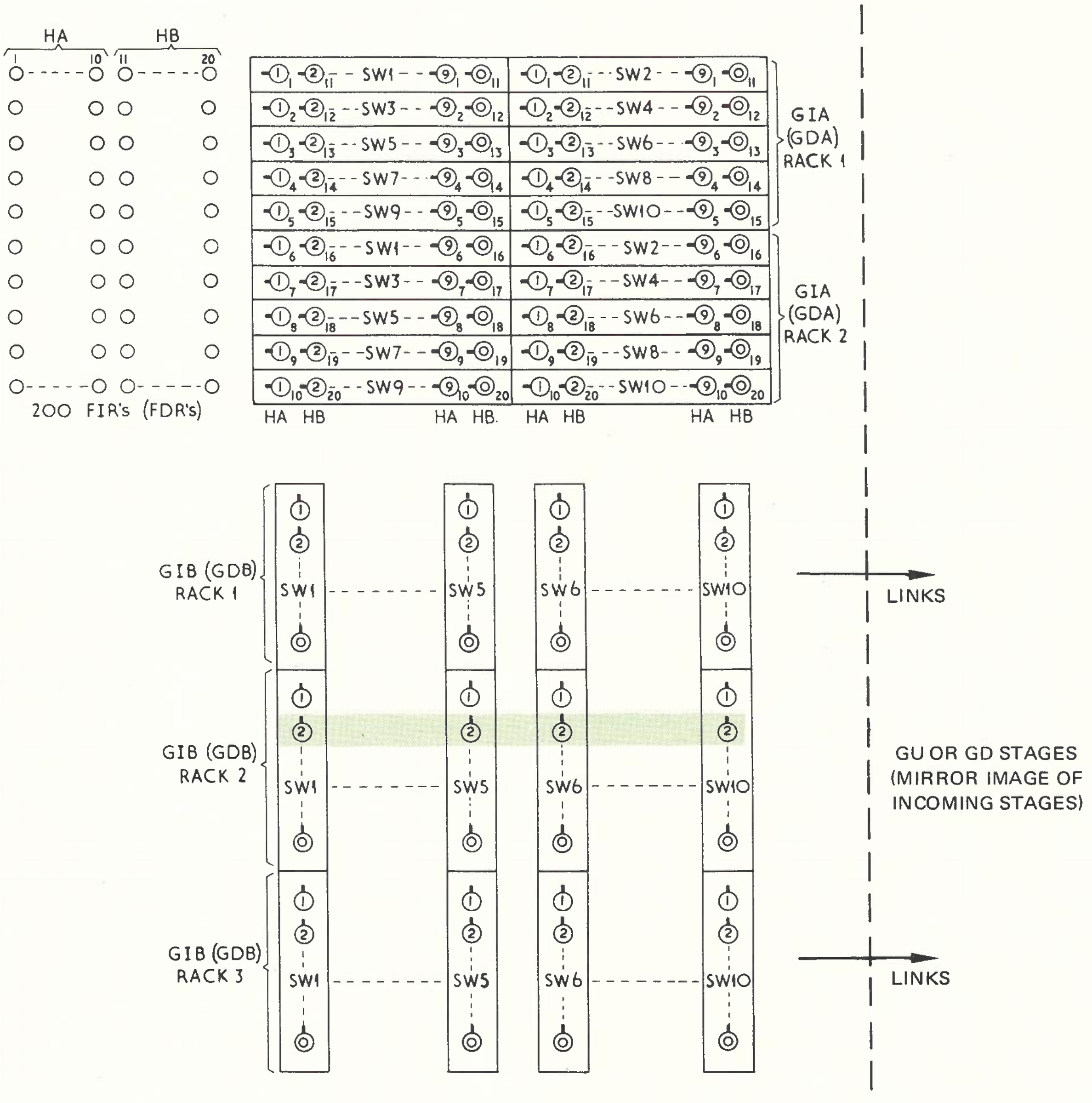


Fig. 10-13 — Grouping Plan — Incoming GI or Outgoing GU or GD Stages.

TABLE 10-2 — ARM LINE GROUPS

GIA, GUA or GDA Racks	GIB, GUB or GDB Racks	Trunk Line Terminations	Link Route Terminations
2	3	200	300
2	2	200	200
1	2	100	200
1	1	100	100

outgoing circuits. For these and other reasons, incoming trunk circuits are given access to a register, which is retained as long as it is needed to perform any such function. In addition, this register performs the function of a code receiver in obtaining address information from the originating register, and passing this to the marker complex of the exchange.

Fig. 10-14 shows this portion of an ARM exchange and illustrates the register's function. An incoming call seizes the line relay set, which is then connected to a register via a register finder. The register finder stage and its marker are similar to those in an ARF exchange, but 20 wires are provided between FIR and register, because of additional signalling needs.

The register contains a signalling receiver, suitable for the type of incoming information signals received on path A and a digit store, to store them.

When sufficient address digits are stored for its subsequent functions, it calls the common control equipment via path B, and transfers address digits.

When the call is switched through the exchange, the common control equipment signals the register to indicate the type of action appropriate to the outgoing circuit which has been selected. It may:

- Signal to the preceding register to set it so that it is sending the digit needed by the next switching point, and disconnect from the circuit; i.e. act as a code receiver only for this call, or

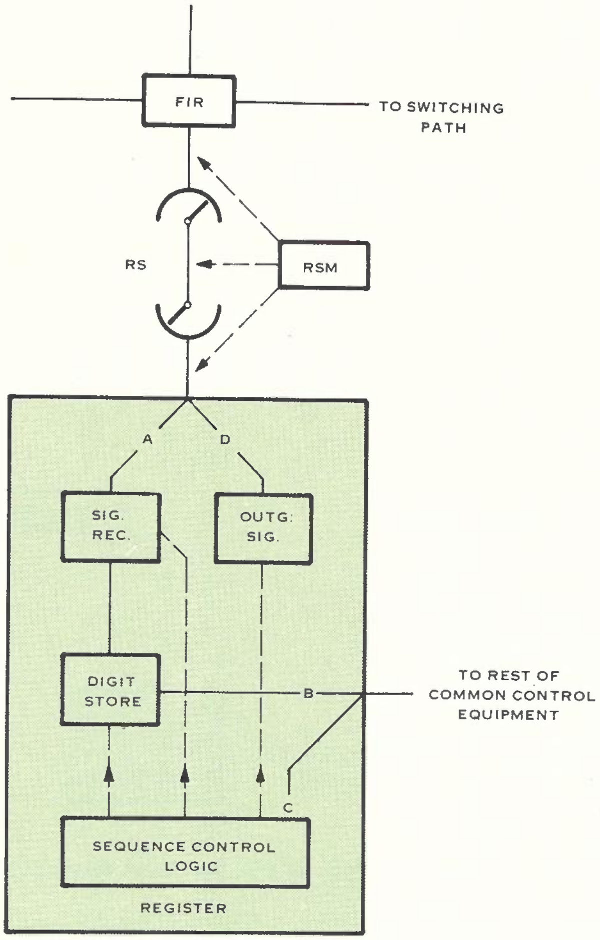


Fig. 10-14 — Register Organisation.

- Remain connected to the line relay sets and control the setting up of the call from this point to finality via path C and as necessary signalling to the preceding register over path A and finally disconnecting when the call is established.

The register is often used in the second mode as a terminating register and has to provide an auxilliary buffering function. In this application it must not call the common control equipment until enough digits are stored to complete the call. This requires "starting point" analysis of the address digits and is usually performed in a set of register analysers common to all registers and reached by a register analyser finder stage.

Markers and Related Services

In a maximum size ARM exchange, with 2400 Erlangs of through traffic, it is necessary to connect 20 to 30 calls a second, which is far beyond the capacity of a single marker with relay technology. The common control system is therefore designed to have as many as 20 markers, depending on the traffic. In addition some of the marker functions are dispersed into other common control devices.

Provision for prevention of interference between markers is necessary and this is achieved by allowing only one marker at a time to work in any line group. In the discussion of the grouping plan it was shown that the equipment used for a call for a particular inlet to a particular outlet is confined to the specific line groups in which the inlet and outlet are located. The above limitation therefore is sufficient to avoid interference between markers.

The probability of congestion on a call between a specific inlet and a specific outlet is very low, and seldom exceeds 0.03, so that a "screening" test to select a free outlet without reference to the availability of a path is a sound strategy. The common control equipment is therefore designed to operate as follows:

- Select any free outlet on the route.
- Attempt to connect the calling inlet to this outlet.
- If unsuccessful, select a different free outlet on the route.
- Attempt to connect the calling inlet to this outlet.
- If again unsuccessful, return congestion signal to the subscriber.

This procedure, incidentally accounts for the form of the specification of internal congestion quoted earlier.

The three major items of the common control equipment are the "Route Marker", "Test Block" and "Marker", and are shown in Fig. 10-15.

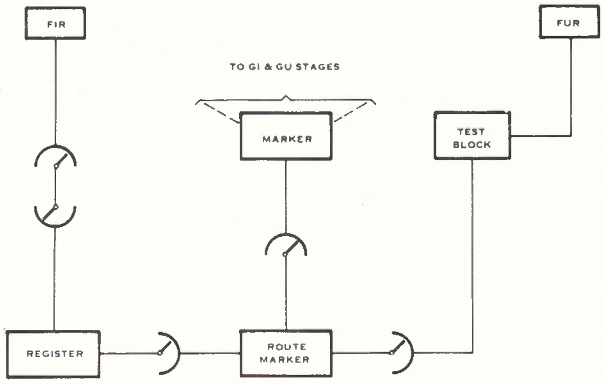


Fig. 10-15 — Common Control Organisation.

Route Marker

The designation "Route Marker" is an unfortunate translation from the Swedish, and it is better described as a code analyser.

It is the first major item of common control equipment seized by the register and calls in the other devices as necessary. Its first function is to receive address digits from the register. It then determines which routes can be used for the call, and the order in which they should be tested. Up to five alternative routes can be specified in the analysis part of the route marker.

In the exchange, each outgoing route is subdivided into two or three "route parts", as nearly equal in size as possible. For each route part there is a free marking (VL) relay which remains operated as long as at least one outgoing trunk in the route part is idle, and thus provides a "free marking" signal to the route marker.

The route marker tests to these free marking signals and selects a route part in the earliest choice route which has a free outlet. For example, consider a case where there is a direct route, a first alternative and a second alternative route each of which has three route parts. If there are two or three route parts in the direct route which are free marked, the route marker chooses one at random. If only one route part is free marked in the direct route that route part will be chosen. Only if none of the route parts in the direct route are free marked will the route marker select from the first alternative route, when the same rules, of course apply.

Test Blocks

The selection of a specific outlet in the selected free marked route is a function of a further item of control equipment, known as a "Test Block". A test block consists of testing relays and selection chains to choose a particular outlet. Each test block has facilities for testing and selecting from a maximum of 150 outlets, organised into 30 route parts. The route parts are of varying size, up to a maximum of 30 outgoing trunks, and the two or three route parts of any one route must be located on different test blocks. Each outlet from the ARM appears on one test block only so there is no competition in selecting an outlet.

Only one route marker at a time can make use of a specific test block, which becomes for the time being an extension of the route marker.

When the test block has selected a specific outgoing trunk, it transfers to the route marker the identity of the outgoing line group in which the selected outlet is located.

Marker

The marker's function is limited to selecting a path between specified inlet and outlet, and establishing the connection — the preliminary work having been performed in the Register, Route Marker and Test Block.

When the route marker receives an indication that the test block has selected an outlet, it seizes an idle marker, and transfers to it the identity of the incoming and outgoing line groups.

After waiting, if necessary for other markers working in these line groups to complete their functions, the marker extends testing leads to the line groups and selects a free path through the four partial stages. This is a fairly conventional procedure, testing from the two ends towards the centre. Having selected the path, the marker operates the necessary magnets and establishes the connection.

Wires Between Control Services

The contact trees from the marker must extend to various devices and some of the information which identifies the device is available in other common control devices. It is therefore convenient to extend some contact trees through these devices.

For example, the horizontal magnet in the GIA stage can be wired directly to the FIR relay set — as shown in Fig. 10-16 and this magnet is operated over a contact tree which passes from the marker, via the route marker, and register, and register finder to the FIR. In the reverse direction, the identity of the incoming line group is transferred from the FIR via the same devices to the marker. Obviously these paths require additional wires between the various devices, so that these interconnections involve numerous wires, as follows:

FIR to Register	20 wires
Register to Route Marker	48 wires
Route Marker to Test Block	48 wires
Route Marker to Marker	72 wires
Marker to GI Stages	168 wires
Marker to GU Stages	96 wires

to make a reasonable compromise between traffic efficiency and cost of interconnection. A good example is the connection from registers to route markers. There may be up to 400 registers and 40 route markers in a fully equipped ARM, but these are segregated into 8 groups of 50 registers in which each register has access to a maximum of 5 route markers. The interconnection is shown in Fig. 10-17. It will be seen that the registers are grouped in sets of 5, and only one at a time in that 5 can be connected to a route marker. A maximum of 50 registers, in 10 such sets of 5 have access to up to 5 route markers. A register may therefore be delayed in reaching a route marker either because one of the other four registers in the same group is already connected, or because all five route markers are in use. This design

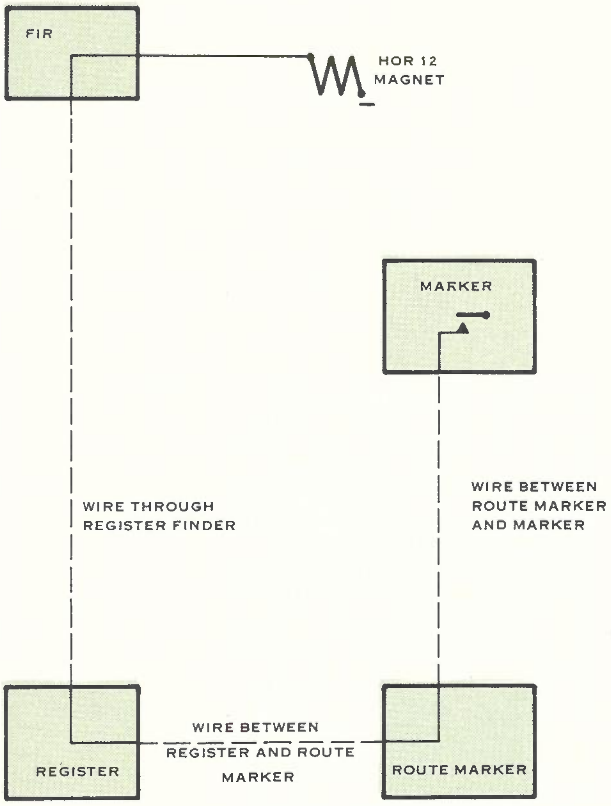


Fig. 10-16 — Operation of GIA Horizontal Magnet.

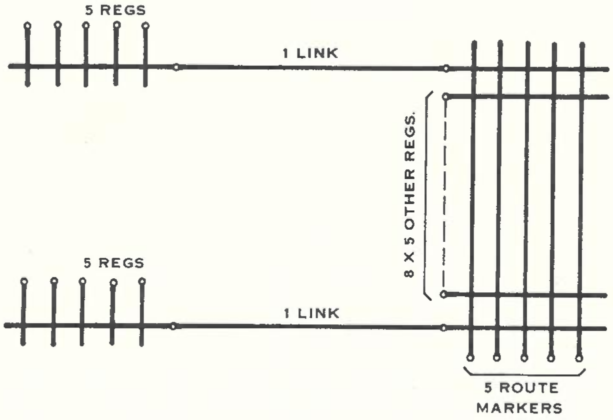


Fig. 10-17 — Register to Route Marker Coupling.

gives satisfactory performance, and is a compromise between the cost of the connecting circuits, the efficiency of use of the route markers, and the overall delay. Depending on traffic the number of registers or of route markers may be reduced.

Other Route Marker Functions

The route marker has some subsidiary functions, in addition to these already described. It controls the overall strategy of the common control in such action as reselection, a function which is appropriate since it is the only item other than the register which is held for the whole of the switching and charging operation.

A number of provisions are made for selecting a new outlet if the switching sequence fails for some reason. The actual arrangement depends on the sequence which led to the failure; and may involve the use of different items of common control equipment.

LIMITATIONS OF RELAY TYPE MARKERS

In the preceding accounts of different crossbar markers it has been shown how various additional features are needed for markers controlling progressively larger and more complex switchblocks. It is convenient at this point to summarise the various methods employed and the compromises involved in adopting them.

The simplest and most economical marker organisation exists when a single marker has exclusive control of a specific block of equipment, as in the register finder stage. In this type of organisation the major limitation is the number of calls that can be switched in a given time with acceptable delays, which is a function of the "operating time" of the marker.

By subdividing the marker into a "code receiver" portion and a "marker" portion and arranging that 2 code receivers can share the use of one marker, the advantages of single marker control can be retained for a group selector stage with 160 inlets and about 110 Erlangs. In the 1/80 group selector this is more a matter of economy of markers than the need to control a large switching block as a unit, since the 160 inlets are effectively two separate units of 80 sharing only the marker. With longer signalling times in a mixed step by step and crossbar network, the 2/160 group selector was developed. This still has two code receivers and one marker for 160 inlets, but the two code receivers were no longer dedicated to serve any inlet in the 160. This gave reduced queueing times in reaching an idle code receiver, but involved a more costly access between code receivers and selector inlets.

The above two group selector stages are two partial stage designs, with relatively high internal congestion, but being considerably more powerful and versatile than a typical step by step group selector, represent a useful compromise between complexity and cost. The internal congestion is acceptable in most local network situations and more powerful designs can only be justified if they give access to fairly long and expensive trunks and junctions.

The 3 partial stage group selector is an extension of the above design to the limit of a single marker control structure. The selector must have a grouping plan which retains a subdivision into units of 160 inlets because of the marker limitation. A result of this is that speech path switching configurations must be accepted which are less than ideal and in some cases use very low loading on GUB-GVC links. Thus in the maximum size of 1600 outlets, these links carry 0.25 Erlangs each and 100 crosspoints are needed per inlet. This is the same as the number in ARM 20 exchanges where by using a 4 stage configuration access to 4000 outlets is possible, so that a large price is paid in inefficient speech path trunking to allow 1 to N marker connection. In practice, the upper limit of economical use of the 3 stage group selector is usually 1000 or 1300 outlets for this reason.

The next step in increased complexity is the 2 marker design used in the ARF subscribers stage, partly as a means of handling more traffic and partly as a security measure. In the early days of common control systems there was a reluctance on the part of many telephone administrations to have the services of 1000 subscribers dependent on a complex and at that time relatively untried marker. The subscribers stage was therefore always designed so that two markers could be used, and they were often fitted purely for security. The APO still equips the first 1000 line unit with 2 markers, but this is largely to ensure that spares are available for replacement of faulty items, and that these spares are known to be in working order.

Only in the very highest calling rate situations are two SL stage markers needed because of the traffic and in these situations a moderate increase in capacity is adequate. Therefore the design is one which does not achieve the maximum potential of duplicate markers. The markers will wait on each other relatively frequently, but as a consequence the design is little more complicated than a single marker design. In this case, the speech path inter-connections do not involve any compromises due to marker limitations.

In the ARM the aim was to produce a means of controlling a very large and efficient switch block, to which expensive trunk lines would be connected. The resulting marker organisation is extremely complex, and expensive, and the overall design extends the potential of relay marker technology to its limits in more than one direction.

The basic organisation of the speech path trunking into line groups and link routes between them is employed in all large exchanges. Ideally each line group should be organised with only one link between any pair of arrays within the line group. With the array sizes used in the ARM this would give the structure of Fig. 10-18. Each line group then has 400 inlets and 600 link terminations and for 4000 lines there are 10 line groups and 60 links between every pair of line groups. In this way the 60 possible paths between one inlet and one outlet each use a different link between line groups. In the actual ARM design, the line groups have 200 inlets and 300 link terminations. There are still 60 different paths, but only 15 of the links between line groups are involved. This change causes a fairly large increase in internal congestion, but is done in the interests of marker organisation.

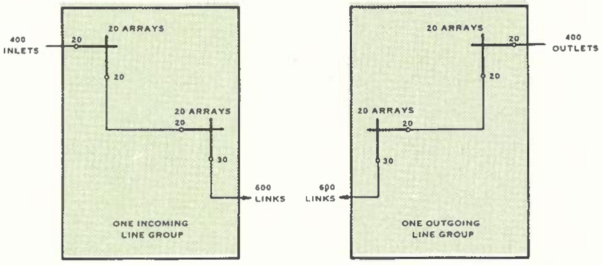


Fig. 10-18 — Alternative ARM Design.

A line group of 200 inlets and about 140 Erlangs is the largest for which it is possible to adopt the restriction of allowing only one marker to operate at a time in a line group. For a 400 inlet line group some much more complex organisation allowing simultaneous operation of 2 or more markers per line group would be needed, and the improvement in efficiency would not be sufficient to justify the additional cost.

A second limitation lies in the process of reselecting an outlet when the first selection cannot be reached. Ideally the reselection should involve entirely new paths, but the circuit logic cannot remember the previous choice, and the reselected outlet may be in the same line group, or even the same set of 20 outlets.

Reselection is therefore not as effective as it could be, and a theoretical study has shown that the internal congestion is appreciably greater than it could be if it was possible to ensure that reselection took place in a different line group. Moreover a third or fourth reselection cannot be allowed because of additional marker loading.

The above considerations are of little significance in an ARM exchange of 2000 outlets, but cause a substantial reduction in the traffic capacity at 4000 outlets. Larger crossbar exchanges have been built, notably the Bell No. 4A toll crossbar, but the price in extra crosspoints is very high.

In any case, other factors also limit the size of a crossbar exchange with relay logic. One problem is that the speed of operation needed in certain key areas is close to the limit of the technique. One such area controls the access between markers and line groups. In a maximum size ARM exchange 20 markers may be switching between them an average of 30 calls a second, and for each call the marker must test that the necessary line groups are idle and mark them busy against intrusion. This is no mean task with relays having operate times around 10 milliseconds.

Equally important are the physical problems of providing and maintaining various strapping fields in which the allocations of outlets to routes, the interconnections of speech path switches, and the structure of the network outside the exchange are mapped. This problem is compounded by the need to repeat the same information in many places. For example, if a new outgoing route is established, the analysis trees in every route marker (perhaps 40) must be altered to give access to the route. A change in the terminating network, such as the conversion of an exchange from step by step to crossbar requires the register analysers (up to 10 or 12) to be restrapped to indicate the digit at which seizing the route marker takes place. Even the addition of one outgoing circuit to an established route requires jumpers and straps in several places. The GUA outlet is connected to the relay set for the speech path, a separate jumper must be provided to the appropriate terminal on the test block, and a strapping provided in the test block to indicate to the marker (via the route marker) which outgoing line group it is connected to.

Stored Program Control Changes

The above problems can be greatly minimised by the use of computer techniques. The most important gain is that a computer can perform the marker functions so rapidly that a single marker structure is feasible for the largest size of exchange, with all the savings in complexity implied in this change. In practice and in the interests of reliability, such exchanges have two or more independent computers, each forming part of a processor performing marker functions. Processors may be synchronised, performing the same tasks and comparing results, or may share the load. If one fails, the remainder can carry the traffic load.

Also, the various analysis functions and such information as the allocation of outlets to routes are recorded in the form of "translation tables" in the core storage memory of the computer. Modification of this storage is comparatively easy and freer from error than the changing of wire strapping in a relay marker exchange. Particularly since the computer program will perform any "bookkeeping" needed to ensure that all records agree.

Of course, in a SPC exchange, the improvement in the organisation of the marker function is only one of the features. However, it is in this and similar areas that computer technology allows things to be done which simply are not possible with relays and crossbar switches.

Appendix – Graphic Symbols

INTRODUCTION

CROSSBAR SYMBOLS

GROUPING PLANS

INTRODUCTION

The following details have been extracted from several APO Technical Training Publications, to assist in understanding the text. Further reference to such publications may be useful. A complete listing of available literature is contained in APO Engineering Instruction, GENERAL, Publications, C0100.

CROSSBAR SYMBOLS

The introduction of crossbar automatic switching systems made it necessary to introduce symbols for devices not previously encountered. In addition, many devices such as relays are represented on crossbar circuits by symbols which differ from APO standard symbols. The following chart of relay symbols does not include all types, but includes those in general use.

Crossbar circuits are drawn using a "semi-detached method" in which the contacts are shown with their associated relay, but not necessarily in the same order that they are mounted on the relay. The relay coil and associated contacts are arranged in a line either vertically or horizontally, being linked together by a broken line as shown in the example in Fig. 1. When a contact is detached, it is also drawn in its usual position associated

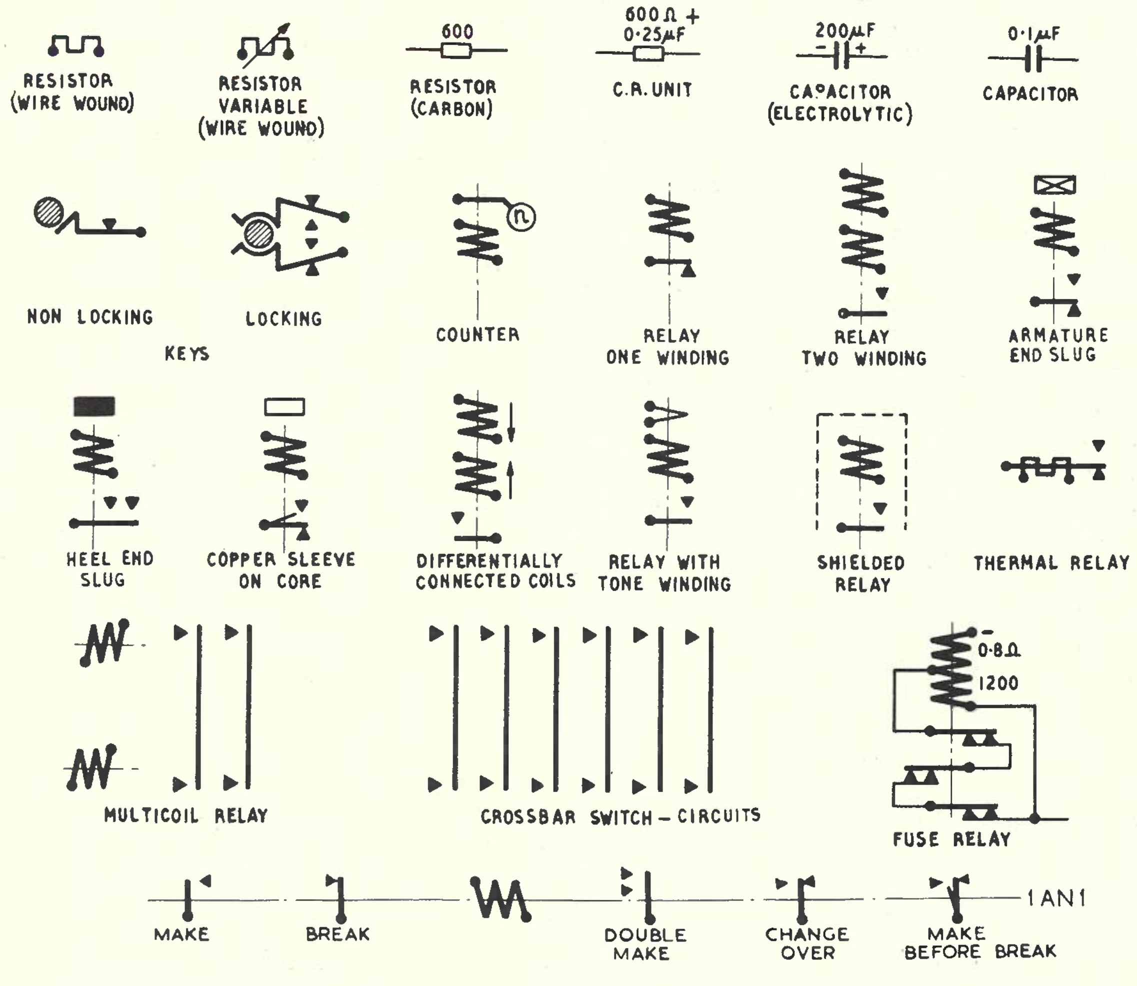


Fig. 1 — Crossbar Symbols.

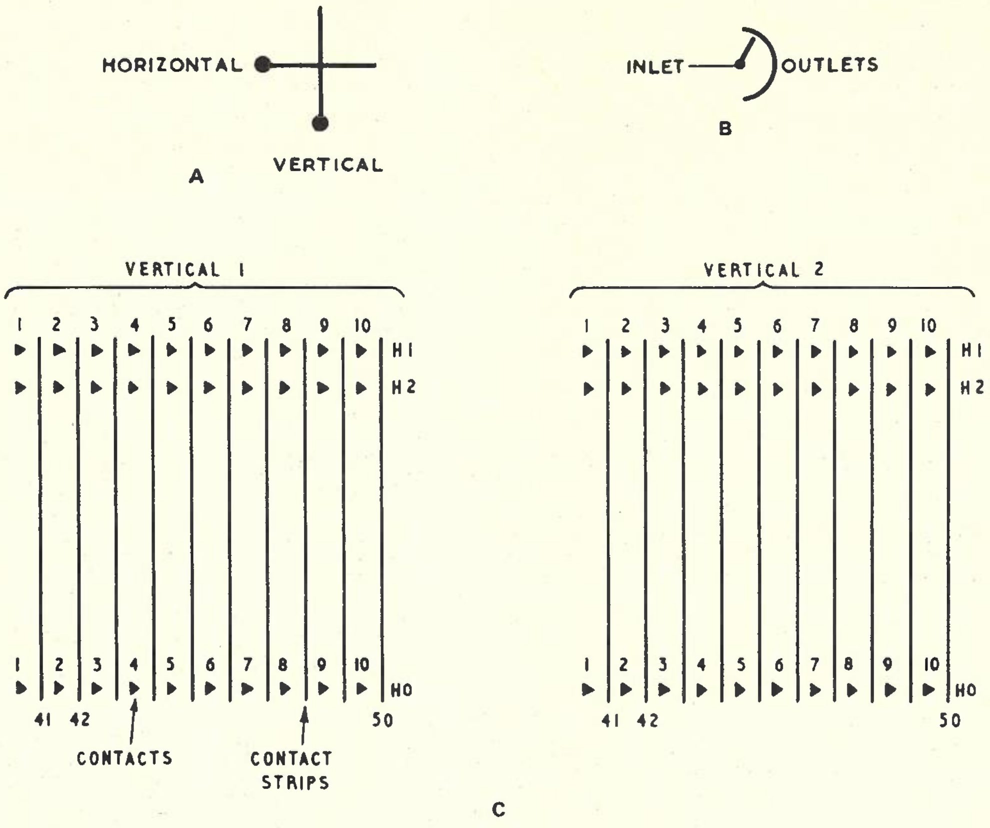


Fig. 2 — Crossbar Switch Symbols.

with the relay, and a reference written beside this normal appearance indicates the position on the circuit where the detached contact appears.

The crossbar switch may be represented by three different symbols as shown in Fig. 2. The symbol shown in Fig. 2(a) is used only on block diagrams, that shown in Fig. 2(b) is mainly associated with trunking diagrams, while the symbol shown in Fig. 2(c) is used to represent a switch or part of a switch in a schematic circuit.

GROUPING PLANS

In crossbar grouping plans, which are a special type of trunking diagram designed to show the connections between partial switching stages, special grouping plan symbols are used. Fig. 3(a) represents a crossbar vertical, with the number of the vertical shown inside the circle and the line connected to the circle pointing to the available outlets. These are often represented by a circle, with the number of the outlet shown beside the symbol as in Fig. 3(b). As the vertical symbol resembles a chicken's head, it is often referred to as a "chicken" symbol, while the grouping plans containing these symbols are referred to as "chicken" diagrams.

In grouping plans chicken symbols are arranged in varying group combinations according to the type of exchange and the switching stage concerned. Therefore, in the maintenance of crossbar exchanges, it is essential to understand the meaning of these symbols in the grouping plans.

Fig. 3 — Vertical and Outlet Symbols.

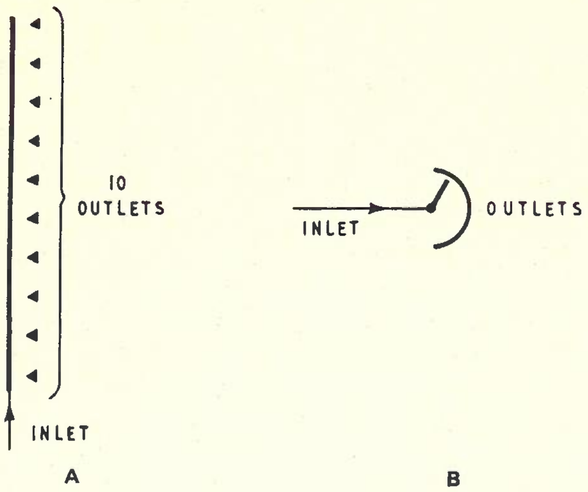


Fig. 4 — Symbols of a 10 Outlet Crossbar Vertical.

Figs. 4(a) and 4(b) show common methods of representing a crossbar vertical having 10 outlets. Fig. 4(a) is the mechanical symbol of the vertical, and Fig. 4(b) is the standard trunking symbol.

In Fig. 5(a) the same vertical is represented using the chicken symbol, showing that vertical 1 has access to 10 outlets. Fig. 5(b) shows a method of simplifying the drawing. Where a number of outlets are available from the same vertical, only the first and last outlets need to be drawn, the intermediate ones being shown by a broken line.

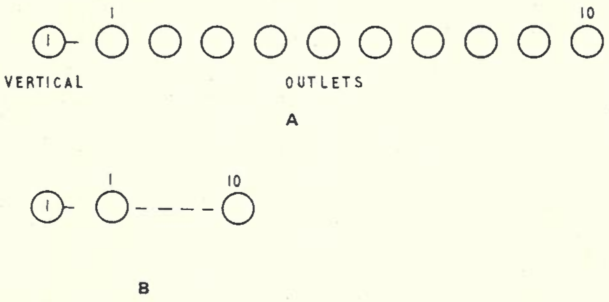


Fig. 5 — Chicken Symbol of 10 Outlet Vertical.

Fig. 6—Two Verticals with Access to the Same 10 Outlets.

In many of the practical applications of the grouping plan, two or more verticals have access to the same group of outlets. To illustrate this condition using chicken symbols, the symbols representing the verticals are placed so that their "beaks" point *in a line* towards the group of common outlets. Fig. 6 shows a condition in which either of two verticals may be switched to any one of ten outlets.

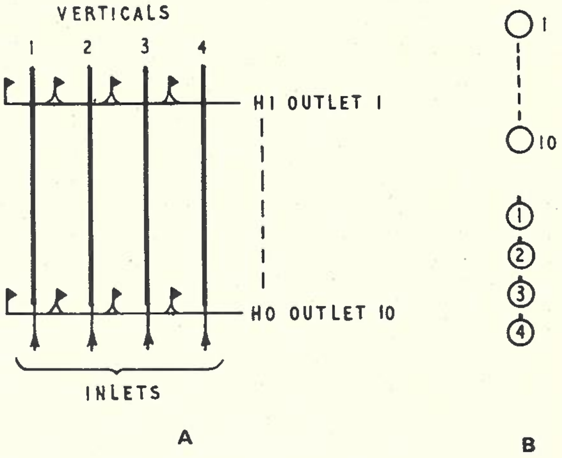


Fig. 7 — Verticals with Access to Common Outlets.

To give a number of verticals access to the same group of outlets, the *outlets* are commoned together with a multiple wiring form. For example, when four verticals are to be given access to the same outlets, the outlets are commoned together as shown in Fig. 7(a). The 1st horizontal springset on the 1st vertical is connected to the 1st horizontal springset on each of the other verticals. The other horizontal springsets are multiplied in a similar manner. Fig. 7(b) shows the equivalent chicken diagram.

About the Author

A. H. FREEMAN, who is a member of the Institution of Engineers, Australia, joined the A.P.O. in 1938 as a cadet draftsman in Sydney and was promoted to engineer in 1946. Until 1956 he was employed in the Radio Section, mainly on the installation and operation of broadcasting transmitters.

He then transferred to the Transmission Planning Section, at the time when the basic plans for introducing common control switching systems, and for a fully automatic trunk network were evolving, and participated extensively in the work which produced the "Community Telephone Plan 1960". During this period he was in charge of the "COMET" project which was the first application of electronic computers to Telephone network design in Australia. He was chosen as an APO representative at the fourth "International Teletraffic Congress" in London in 1964 where he presented a paper on the results of this Study.

From 1966 to 1972 he was Supervising Engineer, Trunk Service and Telegraphs, responsible for oversight of equipment maintenance in country areas of New South Wales and for installation and maintenance of Telegraph and Data facilities. Since 1972 he has been Supervising Engineer, Fundamental Planning, responsible for long term development plans in NSW.

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