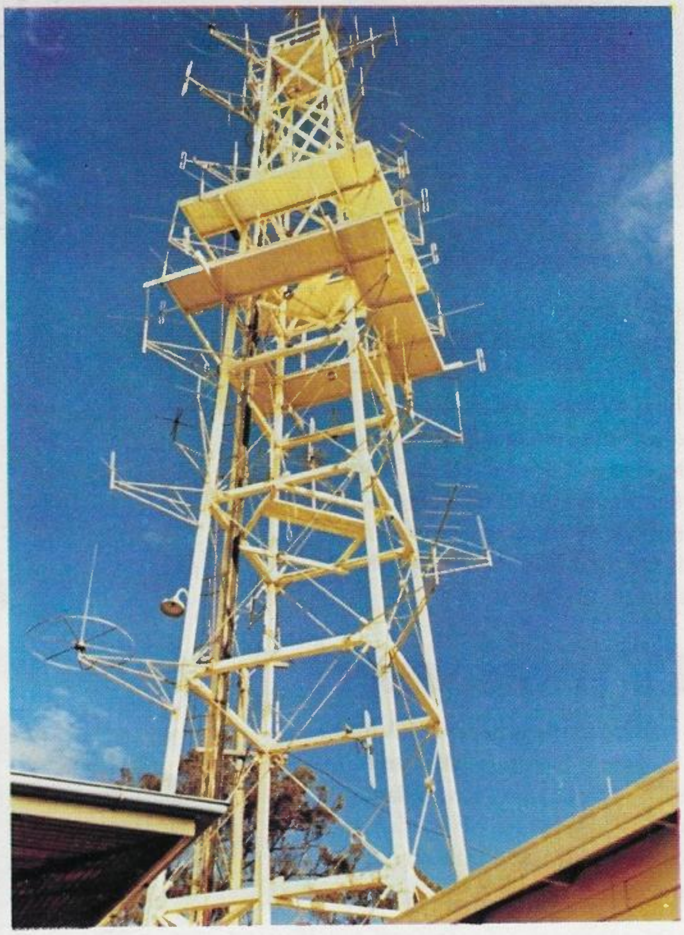
Volume 28, No. 2, 1978

the telecommunication journal of Australia



IN THIS ISSUE

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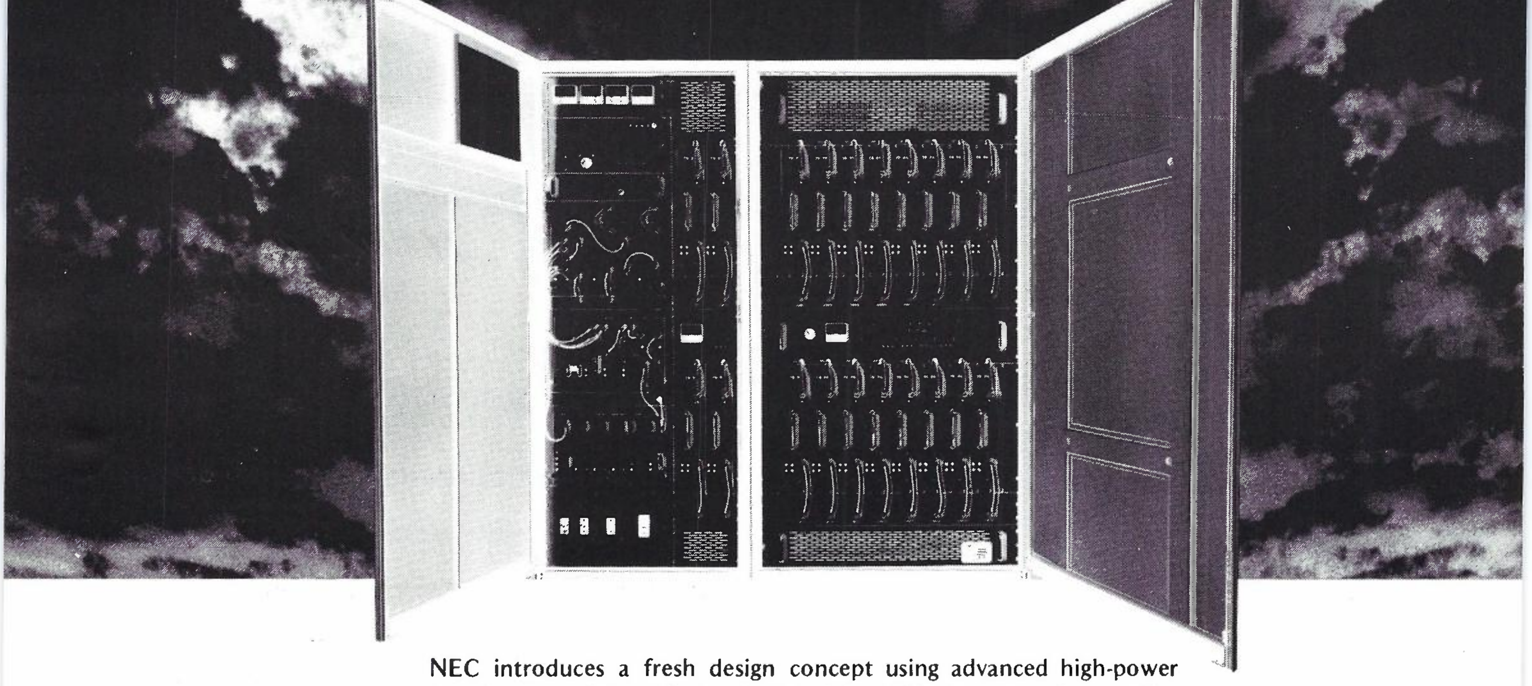

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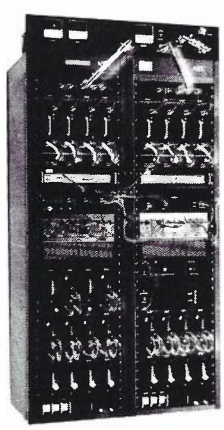

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THE TELECOMMUNICATION JOURNAL OF AUSTRALIA

Volume 28, No. 2, 1978

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COVER

MULTICOUPLERS CAN REDUCE THE PROBLEMS ARISING FROM CO-LOCATING SEVERAL SEPARATE ANTENNAS.

The Telecommunication Journal of Australia

The Journal is issued three times a year (February, June and October) by the Telecommunication Society of Australia. The object of the Society is to promote the diffusion of knowledge of the telecommunications, broadcasting and television services of Australia by means of lectures, discussions, publication of the Telecommunication Journal of Australia and Australian Telecommunication Research, and by any other means.

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Antenna Multicouplers at VHF and UHF

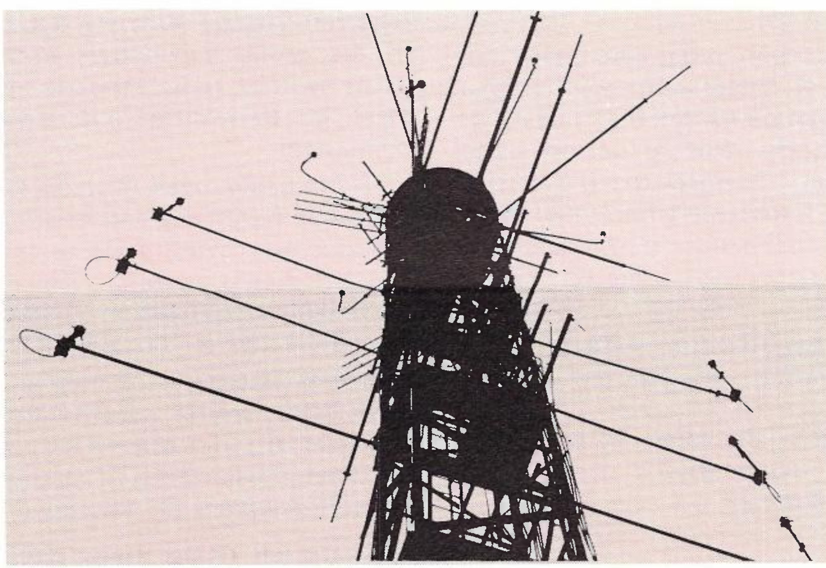
FOREWORD

The following three papers were presented at a Colloquium held in Melbourne on 23rd of February 1977. The Colloquium was organized by Telecom Australia, and dealt with the increasingly pressing problem of how to couple many radio services into a small number of antennae without intolerable interaction.

The papers have been revised somewhat to make the material more suitable for written presentation, but the content is much the same as presented at the Colloquium.

The first paper outlines how some of the specifications on antenna couplers are obtained. The second paper treats the antenna coupler design problem from a building block viewpoint, outlines the available devices and demonstrates how they are used in practice. The third paper deals with possibly the most complex network the manufacturer may need to design — the filter. This paper serves to show that there are gains to be made in size, cost and performance by mastering the art of filter design.

The attendance and discussion at the Colloquium showed that there is a high degree of interest in antenna coupler design.



The situation which can arise when a number of VHF transmitters or receivers use separate antennas on the one tower. Antenna Multicouplers, as described here, enable a single antenna to do the same job.

Multicoupler Performance Specifications

L. J. DERRICK, B.E.

This paper reviews the Telecom Australia requirements for antenna multicouplers in the VHF and UHF frequency range and shows how some of the important performance specifications are set. Some of the circumstances in which it would be advantageous to use such devices with single antennas rather than the use of separate antennas for each transmitter or receiver are also discussed.

INTRODUCTION

As greater numbers of radio systems are required to operate satisfactorily on individual sites, it often becomes necessary to have available devices which enable the numbers of transmitters and/or receivers to share common antenna systems.

The devices or circuits under discussion can broadly be defined as systems for combining a number of radio equipments into the one antenna. This paper restricts itself to narrow band devices and does not consider the broadband devices such as TV filterplexers and multi-band microwave transmitter/receiver combiners. The devices are commonly known under one of the following titles:

- Duplexer, (specifically refers to a transmitter-receiver coupler for duplex operation)
- Diplexer, (specifically refers to a coupler for two radio equipments)
- Transmitter combiner
- Multicoupler
- Multiplexer
- Transmitter-receiver combiner
- Receiving antenna splitter

Telecom Applications

The main requirements for the multiple use of antenna systems exist in the mobile, group subscribers, and small capacity radio services. At this stage the main frequency bands of interest are the 160 MHz (VHF) and 450 MHz (UHF) nominal bands. Some requirements also exist in the 80 MHz (VHF) band. In the mobile service, base transmitter combiners, base transmitter-receiver combiners and mobile transmitter-receiver combiners are employed. Base station receiving antenna splitters are also sometimes required where a number of receivers are fed from the one antenna system. In the group subscribers and small capacity point to point radio services requirements also exist for transmitter and transmitter-receiver combiners.

Three basic types of radio systems are used i.e. single frequency and two frequency simplex systems employing press to talk arrangements and full duplex systems. The simplex systems are mainly employed in mobile radio systems not connected to the telephone network.

Future operation of mobile systems in the 900 MHz region where the use of large numbers of radio channels in radio systems is anticipated will no doubt require the availability of multi-couplers for this band.

Reasons for using these devices

The situation often occurs where an existing antenna structure is required to accommodate additional radio services but there is insufficient physical space available or the structure cannot be safely subjected to any additional wind load. Multiplexing of additional services into existing or replacement antenna systems is therefore a useful technique to avoid the cost and disruption involved in the erection of an additional structure. Further, there are sometimes aesthetic reasons for limiting the number of antennas on a structure. Accommodation for antennas on buildings is sometimes allowable only on the basis of a small number of unobtrusive antennas being installed.

Another reason for sharing antennas is the predictability of the isolation between transmitters and/or receivers using this technique, and therefore, the level of unwanted intermodulation products is known. If single antennas are installed on a structure, the isolation between them is not always predictable in the practical case because of proximity to structural elements and other objects. The siting of antennas is often decided on site and the system designer's assumed isolation between antennas may not always be realised.

There are also some situations where there may be suitable space available for additional antennas, however, because of a long run of feeder cable required, expensive large diameter low loss cable is used. The most economic solution in these cases may be to use shared antennas rather than multiple runs of feeders to individual antennas.

Horizontal radiation patterns can also be disturbed by the proximity of antennas mounted at about the same level on a structure. Sharing of antennas once again can avoid this problem.

In the mobile situation using a duplex service (such as the public automatic mobile service) the use of a transmitter-Receiver combiner (duplexer) is necessary to avoid the use of more than one antenna on the mobile and to control the transmitter receiver isolation.

THE SETTING OF PERFORMANCE SPECIFICATIONS

Transmitter Combiners

When transmitters are combined into the one antenna system, intermodulation products are produced in the output stage of each transmitter due to mixing of each transmitter's output with signals from all other transmitters in the relatively non-linear power amplifier stage. The most significant products are the third order 2A−B ones. It is of course necessary to limit the level of these products to reduce interference to other channels. The Postal and Telecommunications Department specifications generally require the level of any intermodulation product to be less than 2.5 micro watts at the antenna terminal (−56 d Bw).

To illustrate this requirement an example of a two transmitter combiner is shown in **Fig 1**

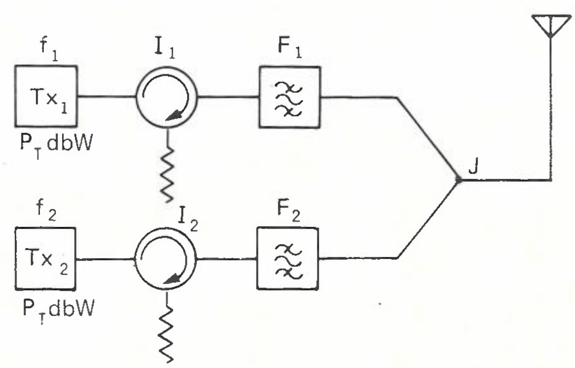
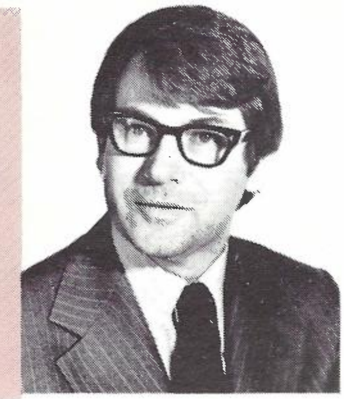


Fig. 1 — Example of a Two Transmitter Combiner

L.J. DERRICK is a Class 4 Engineer in the Customer Section of the Radiocommunications Construction Branch, Headquarters. In 1961 he completed a Bachelor of Engineering (electrical) degree at Melbourne University and joined the Radio Section of the Australian Post Office as an Engineer Class 1 in 1962. Since that time he has occupied a number of positions in the Broadcasting and Radiocommunications areas in the APO/Telecom Australia and was associated with projects such as the Darwin HF Broadcasting station and the Black Mountain Canberra Tower.

He is currently the Project Engineer for the proposed public automatic mobile telephone service.



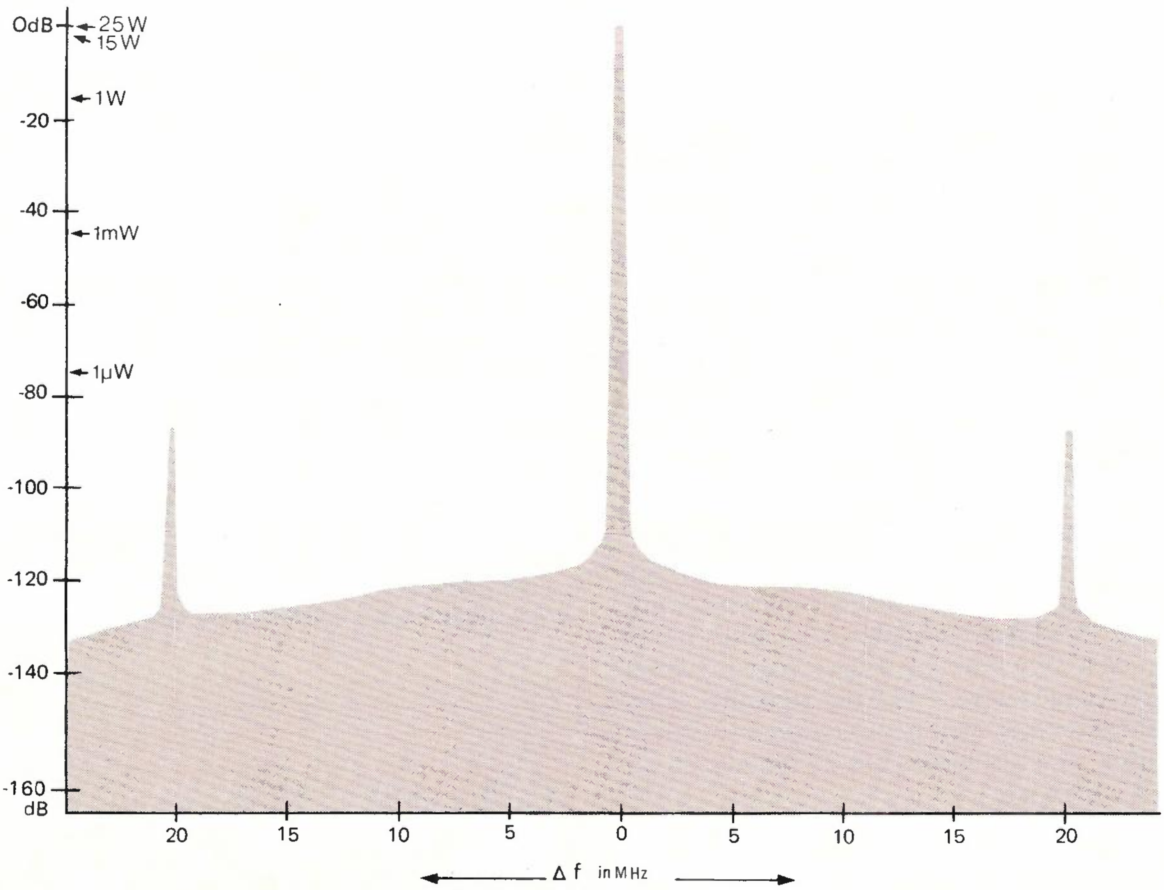


Fig. 2 — Transmitter Noise Spectrum

which consists of isolators and filters. A calculation of the system loss to intermodulation product formation is shown below to illustrate the level of rejection required in the individual components to meet the above specification. This system might be used in a mobile base station transmitter combiner with typically 50 watt transmitters.

I_2 loss	= 1 dB
F_2 loss at f_2	= 1 dB
F_1 loss at f_2	= 14 dB
I_1 isolation	= 30 dB
T_1 conversion attenuation for 2A−B products	= 14 dB
I_1 loss at $2f_1 - f_2$	= 1 dB
F_1 loss at $2f_1 - f_2$	= 14 dB
Total Cable Loss	= 1 dB
Therefore, Total system loss L_S	= 76 dB

(the loss due to any mismatch at junction J has been ignored)

For T_1 and T_2 power of 50 watts (+17 dBw)

Intermodulation product level IMP

$= P_T - L_S$

$= 17 - 76$

$= -59$ dBw

(target−56 dBw)

the minimum system loss to meet the specification is 73 dB. This calculation is for one of the intermodulation products. Similar calculations would of course apply to the other main product.

To maintain sufficient effective radiated power, the loss in these combining systems should be kept to a minimum. Due to unavoidable losses in these systems, particularly

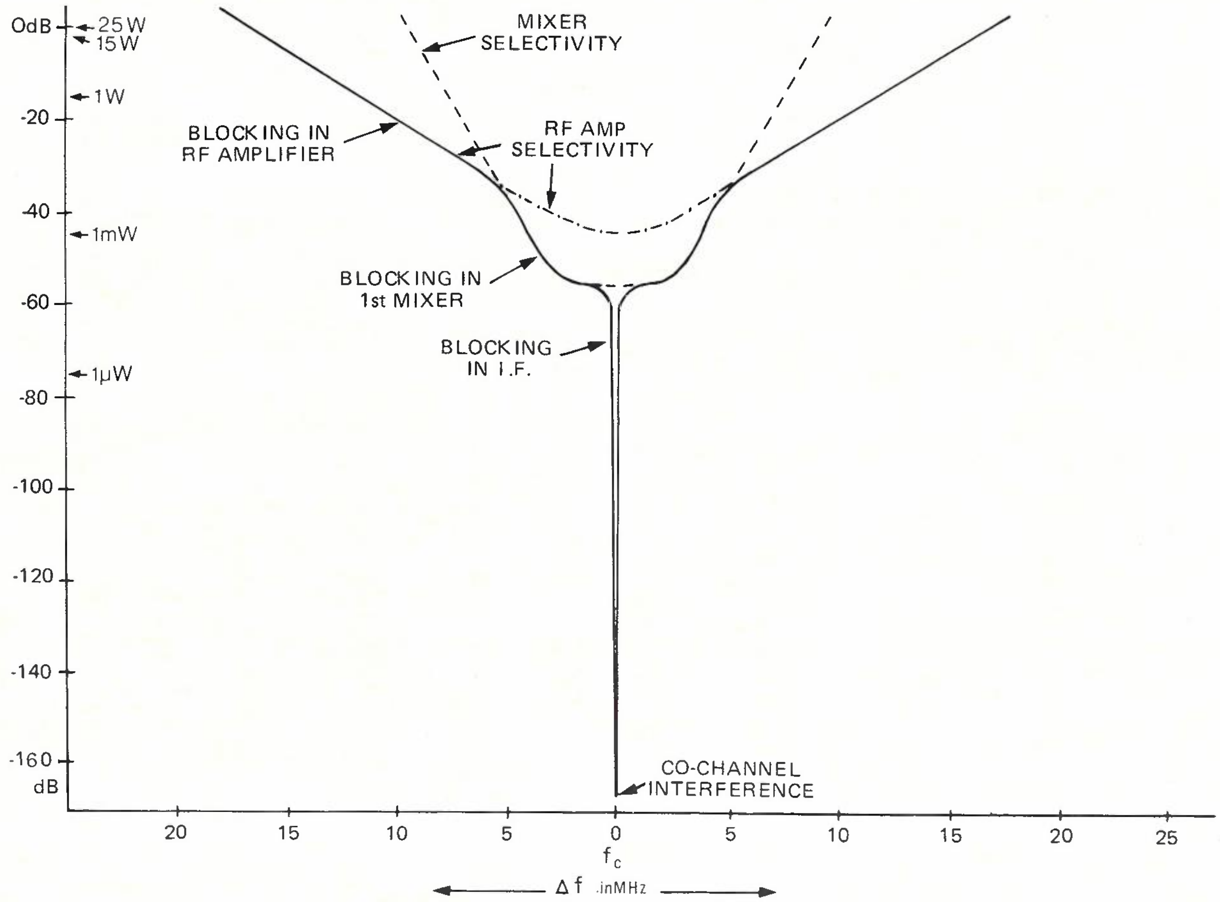


Fig. 3 — Receiver Desensitization Curve

where close frequencies spacings exist, high transmitter powers and/or antenna gains are sometimes required. The higher power solution however further aggravates the intermodulation problem.

Transmitter-Receiver Combiners

The main requirement of the transmitter receiver combiner in a duplex system is to provide sufficient isolation between the transmitter and the receiver to prevent blocking or desensitization of the receiver. Transmitters produce a noise spectrum as well as the wanted output signal, and noise will exist on the receiver frequency. The receiver will also have a response off its tuned frequency and on the transmitter frequency. Therefore isolation at both the transmitter frequency and the receiver frequency is required. To illustrate this requirement, an example of a transmitter noise spectrum is shown in **Fig. 2** and a receiver desensitization curve is shown in **Fig. 3**. The desensitization curve shown is for a reduction of the 20 dB Signal/Interference Noise and Distortion (SINAD) ratio of 3 dB (0.5 micro volts, 5 KHz deviation wanted signal). The isolation requirement can be illustrated by superimposing the two curves at the transmitter-receiver frequency spacing. An example of 5 MHz spacing is shown in **Fig. 4.** From this figure it is seen that a transmitter noise reduction of 47 dB is required at the receiver frequency and a 35 dB reduction of the transmitter at the carrier frequency is required.

To allow for tolerance on individual units and to reduce the desensitization to a negligible amount an additional margin of about 10 dB on

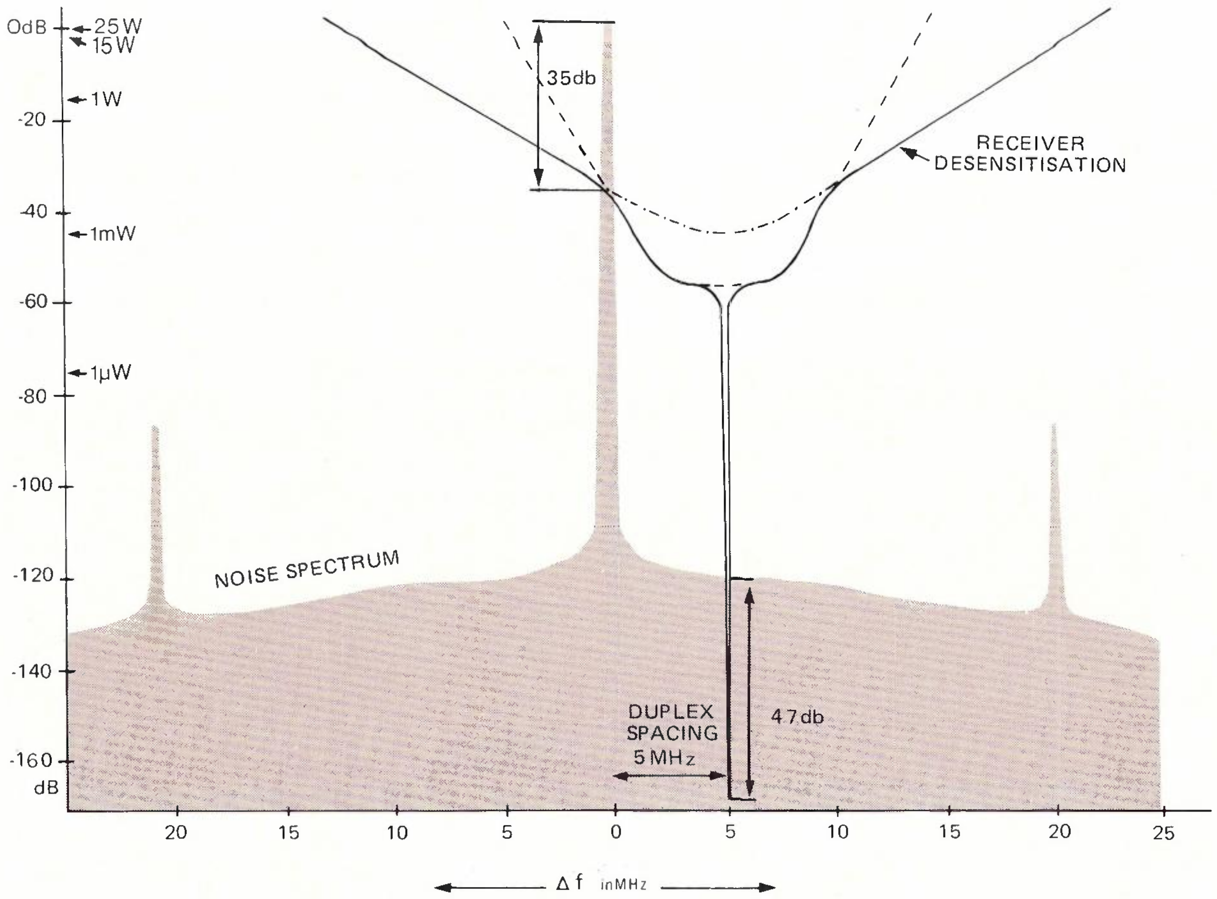


Fig. 4 — Transmitter Noise Spectrum and Receiver Desensitization Superimposed.

the above isolation figures would be required. The above isolation figures assume that any discrete frequency spurious signal from the transmitter is stable and would not drift into the receiver pass band.

The loss to the wanted signals in both the receiver and transmitter paths should be low. In the transmitter case this is required to maintain the effective radiated power particularly in the mobile case where there is a practical limit to the transmitter power and antenna gain. Loss in the receiver path effectively increases the noise figure of the receiver. Where the limitation to reception is external noise pick up, the loss figure can be relaxed as the external noise becomes the limitation. In electrically quiet environments however the loss is more important. Typically a loss of 1 dB is tolerable in most cases.

General

The isolation of these combining systems sometimes depends on suitable matching to the antenna. With balance type devices such as hybrids the isolation produced will vary with the VSWR of the load. Because of this the VSWR reference the nominal impedance (often 50 ohms) of the system is specified to be approximately less than 1.2.

Systems for mobile applications must allow for the environmental situation encountered. Specifications in this instance are often required to be met under the vibration conditions existing in this application and over a temperature range of $-10^{\circ}C$ to $+60^{\circ}C$. For fixed installations in untreated environmental conditions the temperature range may be $0^{\circ}C$ to $50^{\circ}C$. For mobile use physical size of transmitter-receiver combiners must be small in view of the typical physical size of the transmitter-receiver which may have dimensions such as 365 by 270 by 125 mm. The frequency bandwidth required will depend on the particular requirement and the transmitter receiver frequency spacing will be set by the standard duplex channel allocations. For the proposed automatic mobile service a bandwidth of between 2 and 3 MHz will be required for the transmitter-receiver combiner to accomodate about 100 channels.

CONCLUSION

As indicated above, to make maximum use of existing radio sites it is often of advantage to employ combining devices to enable single antennas to be shared by a number of transmitters and/or receivers. These combining devices must enable transmitters to operate into single antennas while attenuating intermodulation products, formed in the output of the transmitters, to a tolerable level. The devices must also provide sufficient isolation between transmitters and receivers to prevent receiver blocking and desensitization. Other parameters of the devices such as temperature stability and impedance are shown to be important in maintaining the required performance under all expected environmental and antenna matching conditions.

A DIFFERENT TYPE FACE

Readers will notice a change of type-face in some of the articles in this issue of the Journal.

When the type, with which you have become familiar in the main body of the text of most articles, was introduced in Volume 23, No. 2, a note inside the front cover invited readers' views on the large type-face as compared with the smaller one used in the last artiicle in that issue.

There has been little or no comment from readers on the subject but a viewpoint from the editorial ranks favoured the neat style of the small type with the qualification that possibly a little larger size would make for easier reading.

While the Editor in Chief was considering means of securing the best features of both types it transpired that our printer also had reasons to consider changes.

In line with modern trends in the printing industry, Standard Newspapers Ltd. is transferring as much typesetting work as possible from linotype to phototype setting; in general terms, from hot setting to cold setting.

Advantages are better, uniform quality work since the type itself is not subject to wear, faster setting, simpler correction procedure; the equipment is more compact, quieter and cleaner in operation.

Photon is the trade name of the system used in this instance. The articles with the different look about them in this issue use type from the Photon series of fonts.

Although the lino type has been an effective type-setting medium for some 80 years and is not yet obsolete, it seems inevitable that more and more of the printed matter which comes before us in the future will have been put together by one of the more modern cold setting processes.

Your Journal will adapt to and take advantage of these technological changes as appropriate.

Editor in Chief

A Building Block Approach to Multicoupler Fundamentals

N.A. McDONALD, Ph. D.

This paper is an introduction to the techniques used in the design and construction of aerial couplers. It introduces first the components commonly used in multicouplers and then describes how these components may be assembled to make a variety of configurations to suit given requirements. The configurations described are encountered in VHF and UHF mobile radio systems.

INTRODUCTION

The preceding paper by L.J. Derrick has outlined the applications of multicouplers in VHF and UHF radio communications systems, and has shown how the necessary performance specifications are determined. This paper will provide an introduction to the techniques used in the design and construction of such multicouplers. The first section will deal with components used in multicouplers, and the second section will deal with assemblies of these components to make various multicoupler configurations.

The building block viewpoint in this paper provides a good introduction to multicoupler techniques. It is also a common approach to multicoupler construction, especially where only a small quantity of a particular multicoupler type is required. For larger quantity production, the combining of more than one building block function in one physical element is sometimes possible.

BUILDING BLOCKS IN MULTICOUPLERS

Bandpass Filters

The first building block element to be considered will be the bandpass filter as represented in **Fig. 1.** On the transmission response diagram there is a peak at the pass frequency f1 and reduced transmission at all other frequencies. Bandpass filters are commonly made from one or more coaxial line resonators, although other forms such as combline and interdigital filters are sometimes used. Refer to the coaxial line resonator in **Fig. 2(a).** The centre conductor is one quarter wavelength electrical, and slightly shorter than one quarter wavelength physical because of the end effect. Coupling into and out of the resonator is commonly achieved with magnetic field loops placed up towards the short circuit end of the resonator, although electric field probes placed

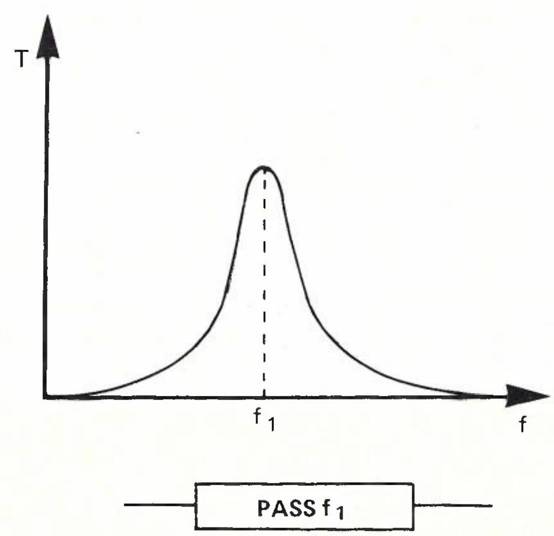


Fig. 1-Bandpass Filters

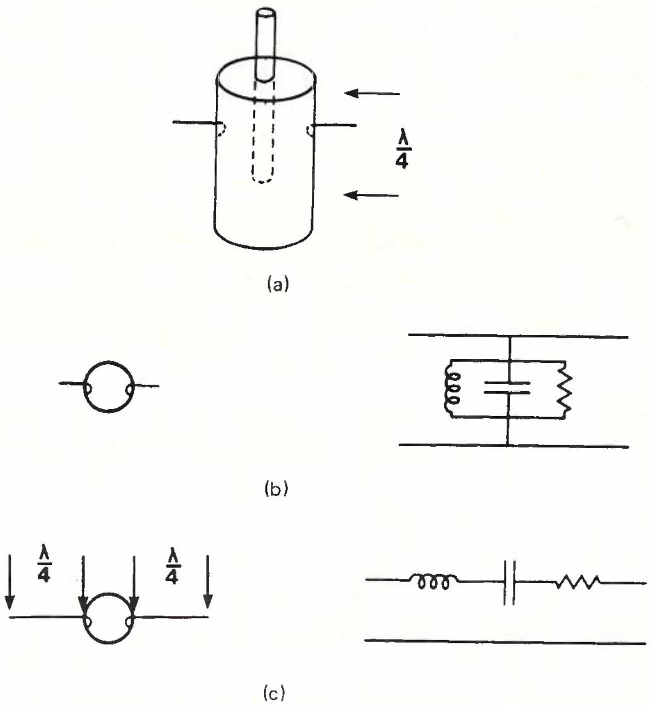


Fig. 2-Resonator Construction, Symbols and Equivalent Circuits

towards the open circuit end are sometimes used. With very short lead lengths the equivalent circuit is that of a parallel resonant circuit as shown in **Fig. 2(b).** If, however, the loops are extended out with quarter wavelength transmission lines on each side of the resonator, these transmission lines act as impedance inverters and the equivalent circuit is that of a series resonant circuit as in **Fig. 2(c).** The unloaded Q of such a resonator is typically in the range of 3000 to 8000.

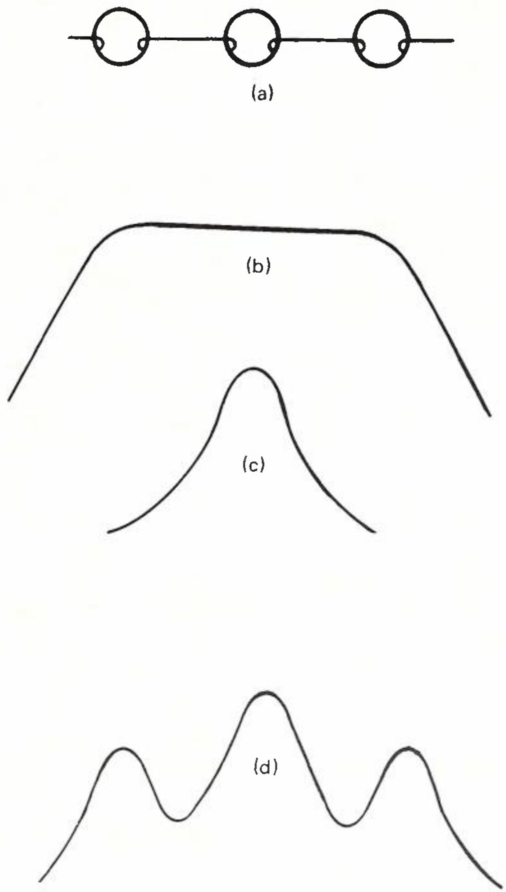
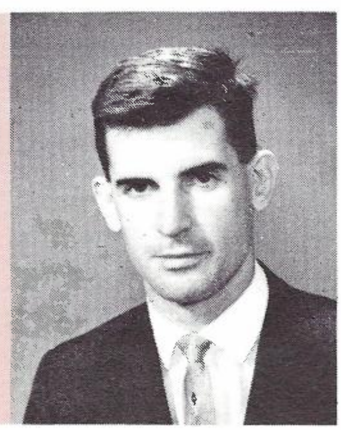


Fig. 3-Cascade Connection and Passband Shapes

A number of resonators can be connected in cascade as in **Fig. 3(a).** In this way the off-frequency rejections are additive, but if arbitrary interconnections are used between the cavities, then an arbitrary passband shape will be obtained. However, with proper design of the interconnections between the resonators, the

NOEL A. McDONALD received the B.E. degree from the University of Auckland, New Zealand, in 1961 and the M.A.Sc. and Ph.D. degrees from the University of Toronto, Canada, in 1963 and 1971, respectively. In 1961 and from 1963 to 1968, he was a Radio Systems Engineer with the New Zealand Post Office. From 1961 to 1963 and from 1968 to 1971 he was with the Department of Electrical Engineering, University of Toronto. From 1971 to 1975 he designed antennas and antenna coupling devices with Antenna Engineering Australia Pty. Ltd., Melbourne. He is now with the Department of Communication and Electronic Engineering at the Royal Melbourne Institute of Technology.



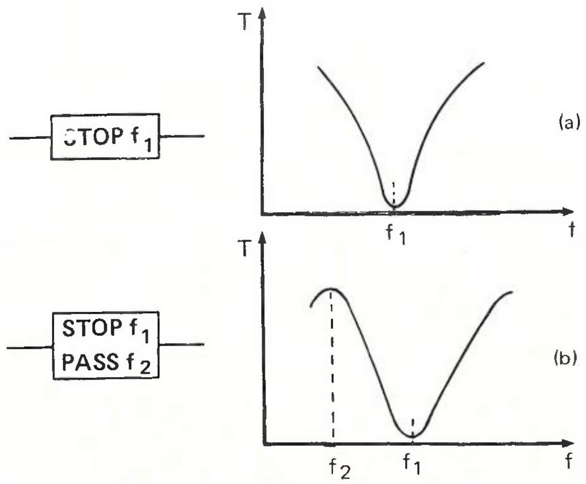


Fig. 4-Bandstop Filters

passband shape can be wide and flat topped as in **Fig. 3 (b)** or rounded and narrow as in **Fig. 3 (c)**. The passband shape shown in **Fig. 3 (d)** is that of a typical arbitrary interconnection between the resonators.

Many bandpass filters use quarter wave coaxial line resonators as they are tunable over a wide range and various passband shapes are available. For narrowband multicouplers a particular response shape, namely the "minimum loss characteristic", is most desirable. Many bandpass filters are made from assemblies of individual resonators because of the economics of manufacture, by comparison with the costs of making interdigital and combline filters.

Bandstop Filters

The second building block element to be considered is the bandstop filter as shown in **Fig. 4 (a)**. The transmission is almost zero at frequency f1. It is very simple in practice to convert the symmetric bandstop response of **Fig. 4 (a)** into an asymmetric shape such as in **Fig. 4 (b)**, which shows a stop f1 pass f2 response. A single resonator can be used as a bandstop element by using only one coupling loop and a quarter wavelength line which bridges across the main transmission line as in **Fig. 5 (a)**. At resonance, the input impedance of the resonator is very high and resistive, so that at the other end of the transmission line the impedance is very low and resistive, and therefore the equivalent circuit is that of a series resonant circuit bridging across the main transmission line as in **Fig. 5 (a)**. If the transmission line length is slightly different from one quarter

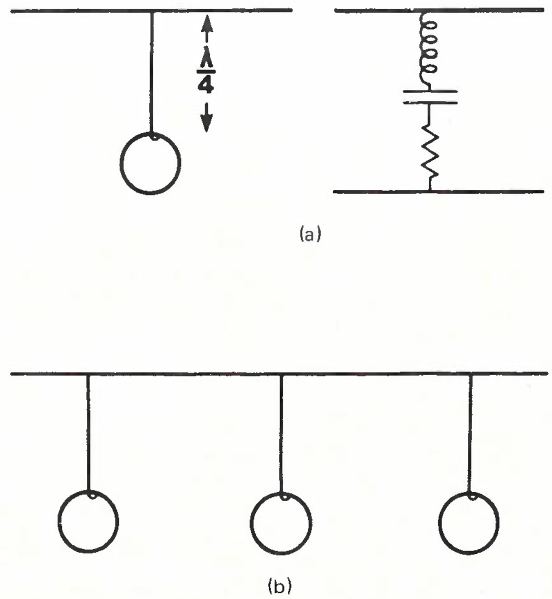


Fig. 5-Resonators used as Bandstop Filters

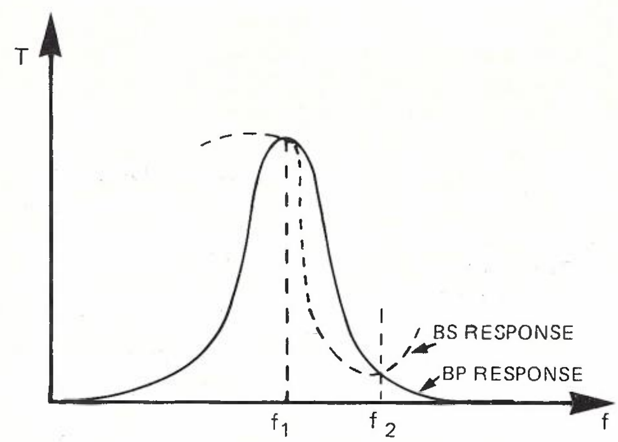


Fig. 6-Transmission of Filters

wavelength, then this introduces the asymmetric response of **Fig. 4 (b)** and the peak can be made on either side of the rejection notch according to whether the transmission line length is longer or shorter than one quarter wavelength. A simple analysis of such elements can be carried out by use of the Smith Chart.

A number of bandstop elements can be connected in cascade as in **Fig. 5 (b)** to give any predetermined bandstop filter response. The resonators used in such bandstop filters are either the coaxial line resonators referred to earlier, or helical resonators. The reason for using helical resonators can be seen by inspection of **Fig. 6** which shows a requirement where two different frequencies f1 and f2 are to be isolated or separated by a particular attenuation. The solid curve gives a typical bandpass response to fulfill the isolation requirement and the dotted curve shows a typical asymmetric bandstop response to meet the same requirement. For a given number of resonator elements and a given allowable insertion loss at the pass frequency f1, the required unloaded Q of the bandpass filter elements is higher than the required unloaded Q of the bandstop filter elements. Accordingly, more helical resonators, which have a lower Q than coaxial line resonators, are used in bandstop filters than are used in bandpass filters.

Bridge Filters

The filters considered above all have in their physical realisations a finite attenuation at the stop frequency. The question arises whether it is possible to construct a filtering device in practice which has in principle an infinite attenuation at the stop frequency. It will be recognised that various bridge configurations such as the bridged T network are capable of infinite attenuation in their physical realisations. Accordingly it should prove possible to make a stop filter based on a bridge configuration and one such form is shown in **Fig. 7**. To consider the operation of this bridge filter, first eliminate the network shown dotted on the left side and the resonator and quarter wave transmission line shown on the right side. The upper and lower transmission lines represent the input and output. The two can be interchanged as the network is completely reciprocal. A signal entering the bridge configuration from the top travels one half wavelength through the two left transmission lines to the bottom and one full wavelength through the two right hand transmission lines, and therefore the total signal at the bottom transmission line is zero.

Such a network will give a very deep rejection but this rejection will occur over quite a wide bandwidth. The next problem is to obtain at the same time a pass response and this is achieved by connecting to the right hand corner of the bridge what we would normally regard as a bandstop element, but in this case it is used as a switch to switch the bridge. The resonator is tuned to the pass frequency and the input impedance at the bridge end of the quarter wave

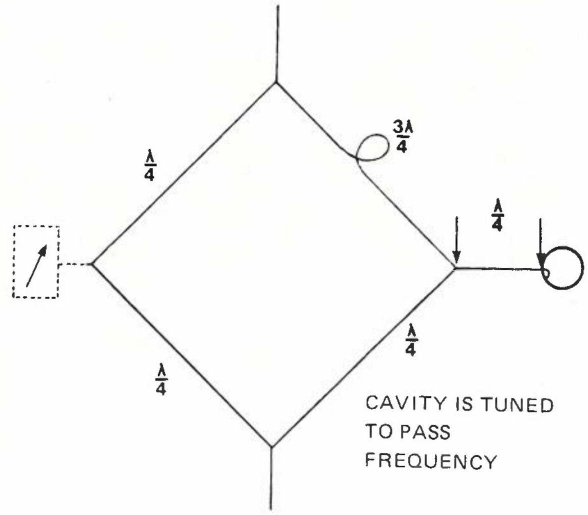


Fig. 7-Bridge Filter

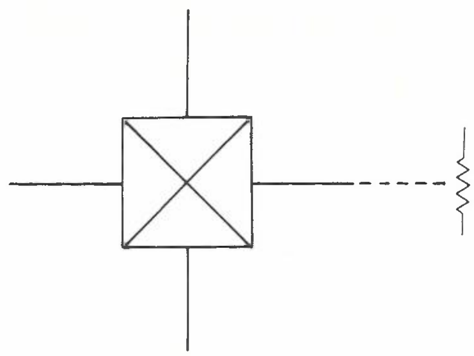


Fig. 8-Hybrid Power Divider

line is therefore very low and resistive at this frequency. Consider an ideal case in which this resistance is zero. This short circuit will transform to an open circuit at the upper and lower transmission lines and the signal path is therefore from the upper to the lower transmission line via the left hand pair of quarter wave lines. At the stop frequency there may well be some residual effect due to connecting the bandstop element to the bridge, but such a residual effect can be balanced out by connecting a compensating network on the opposite side of the bridge.

Hybrid Power Dividers

The next building block element to consider is the Hybrid Power Divider as represented in **Fig. 8**. This is a 4 port network of which 1 port is often terminated. The emphasis in the title Hybrid Power Divider is on the Hybrid term which has an analogy with the hybrid transformer of telephony practice. An input into one port appears with equal signal levels at the two adjacent ports and zero signal appears at the opposite port. It should be noted that there are many other power dividers such as the power dividers used in transmitting antenna arrays which are not hybrid power dividers in the sense of having isolated outputs. A property therefore of a hybrid power divider is that there is equal power division, and in principle complete isolation between the input and the opposite ports. In practice with matched terminations an isolation of approximately 30 dB is achieved. The hybrid power dividers used in multicouplers are commonly constructed either in the form of hybrid rings or as 3 dB directional couplers, or as the class of transmission line networks known specifically as hybrid power dividers.

One property of hybrid power dividers which will be made use of later is shown diagrammatically in **Fig. 9 (a)**. If there is an input to the left port then two equal level signals will appear at the adjacent ports and zero level at the opposite port. It will be assumed that the two outputs are in phase. Some hybrid power dividers do not instrinsically have in phase outputs but with narrow band devices it is possible to bring the two outputs in phase by adding a length of transmission line to one of the outputs. By reciprocity if two in phase signals are applied to the two outputs they will combine at the port which was previously the input but if instead two out of phase signals are applied as in **Fig. 9 (b)** then the output appears at the 4th port and there is no signal appearing at the original input port. Hybrid power dividers are physically small devices by comparison with coaxial line resonators.

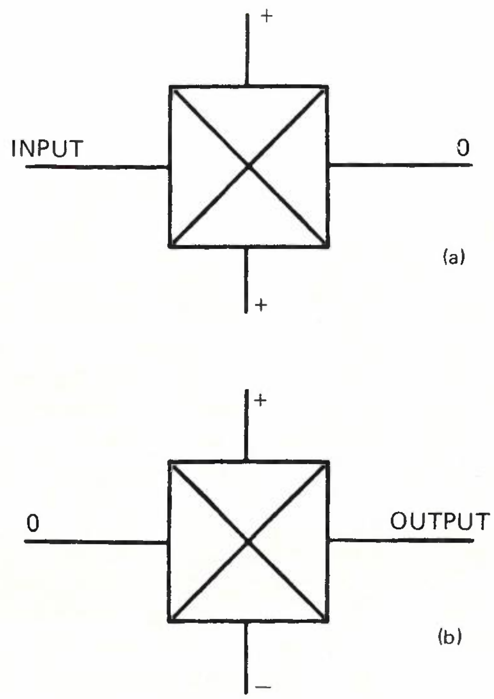


Fig. 9-Phase Relations in Hybrid Power Dividers

Fig.10-Circulator and Isolator Symbols

Circulators and Isolators

The next items to consider as building blocks in multicouplers are circulators and isolators as depicted in **Fig. 10**. A circulator is a 3 port device having a particular direction of signal rotation as shown in **Fig. 10 (a)**. This is the first non-reciprocal device encountered in this summary of multicoupler elements. A signal entering the left port of **Fig. 10 (a)** rotates clockwise to the right port, a signal entering at the right port rotates clockwise to the lower port, and a signal entering the lower port rotates clockwise to the left port. If the lower port is terminated with a matched load as in **Fig. 10 (b)**, then the circulator becomes an isolator and a signal will travel from the left port to the right port with very small attenuation but a signal entering at the right port does not appear at the left port as it is dissipated in the load. Typical electrical characteristics of an isolator are 25-30 dB reverse isolation for a forward insertion loss of 0.5 to 1 dB. They also are physically small devices by comparison with coaxial line resonators.

Other Components

For completeness, the following devices should also be included in any summary of building blocks for VHF and UHF multicouplers. These devices are:

(i) Transmission line sections, which are often more than simply devices to interconnect equipment items, insofar as they are frequently used as impedance matching or impedance inverting devices.

(ii) Amplifiers, for the reason that there are some multicouplers known as active receiving multicouplers, in which amplifiers are used.

(iii) Low pass filters and high pass filters which are sometimes incorporated in multicouplers.

MULTICOUPLER CONFIGURATIONS

The next part of this review is an outline of some of the various common multicoupler configurations. Because of the considerable number of building blocks that have been considered above, it will be recognised that there will be a very large number of ways in which these building blocks can be interconnected and only the more common resultant multicoupler configurations will be dealt with here. The first multicoupler configurations to be considered will be those which use as their basis frequency selective filters, as these are by far the most common multicouplers encountered in practice.

Parallel Coupled Bandpass Filters

Fig. 11 (a) shows an interconnection of two bandpass filters fulfilling a multicoupling or diplexing function for frequencies f1 and f2. It is apparent that isolation will be provided between the equipments on frequencies f1 and f2 as a consequence of the selectivities of the two bandpass filters. However there is an additional requirement to be met, and that is impedance matching at the junction between the two bandpass filters and the main transmission line. Consider, for example, a signal travelling from the main transmission line to the equipment item operating on the frequency f1. To provide satisfactory impedance matching at the junction, it is apparent that the pass f2 filter must present a very high impedance at the junction at frequency f1, and likewise the pass f1 filter must present a high impedance at the junction at the frequency f2.

It is not difficult in practice to achieve this impedance requirement particularly over the small bandwidths of VHF and UHF multicouplers used for mobile radio systems. However, there are other multicouplers such as military multicouplers which are required to tune over typically one octave and the impedance matching requirement in such situations is more difficult to achieve. In **Fig. 11 (b)** there is an extension of the parallel coupled bandpass filter configuration to a case where there are four channels operating on separate frequencies, and it is seen that by appropriate connection of four bandpass filters the multicoupling requirement of physical combining and electrical isolation can be achieved.

Parallel Coupled Bandstop Filters

The question arises whether a combining function can be achieved by use of bandstop elements only, and a bandstop diplexer is shown in **Fig. 12.** The isolation between the f1 and f2 equipment items is provided by stop filters in this case, and where there are only 2 channels as shown in **Fig. 12** it would be common to make the stop filters asymmetric so that

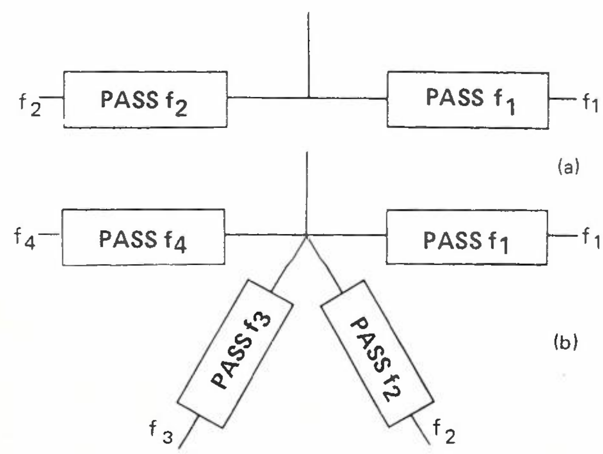


Fig.11-Parallel Coupled Bandpass Filters

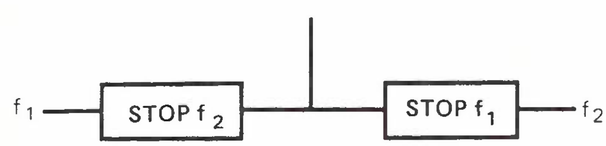


Fig.12-Parallel Coupled Bandstop Filter

they have a combined pass and stop response. The outline of **Fig. 12** is the very common bandstop diplexer configuration which is frequently constructed using helical resonators. If it is desired to extend a bandstop diplexer beyond two channels, to make a bandstop multicoupler, then the number of elements required increases considerably, as illustrated by the example in **Fig. 13** which shows a three channel multicoupler comprised only of bandstop filters. Each frequency has to be protected against the other two frequencies so that in principle there are six elements involved. However it is possible to combine two of the stop f3 filters shown in **Fig. 13 (a)** into the form of **Fig. 13 (b)** which gives a minimum element configuration for a three channel multicoupler using only bandstop filters. The transition from the bandstop diplexer of **Fig. 12** to the bandstop multicoupler of **Fig. 13 (b)** is a transition from devices which are encountered very commonly in practice, to devices which are hardly ever encountered. There are two reasons for this. One is the added complexity of the bandstop multicoupler by comparison with its bandpass counterpart, as seen above for three channels, and the other factor is one of multicoupling philosophy.

If there is a number of allocated frequencies it is in principle best to make a multicoupler which passes only the frequencies that are regarded as desirable, and this multicoupler will then provide some attenuation at other frequencies such as those of intermodulation products and harmonics. On the other hand, if only bandstop devices are used, then attenuation is usually only large at the operating frequencies, and spurious frequencies such as those of intermodulation products are not reduced to a large or significant extent. It is therefore very common for multicouplers with more than two channels to incorporate bandpass filters where frequency separations and physical space permit.

Sequentially Connected Bandpass Filters

It would be extremely convenient if a number of bandpass filters could be sequentially connected to a transmission line as shown in **Fig. 14**. While such an arrangement does indeed provide isolation between the various radio frequency equipment items operating on the different frequencies, the configuration is not satisfactory as shown because of the lack of impedance matching at the junctions between the bandpass filters and the main transmission line.

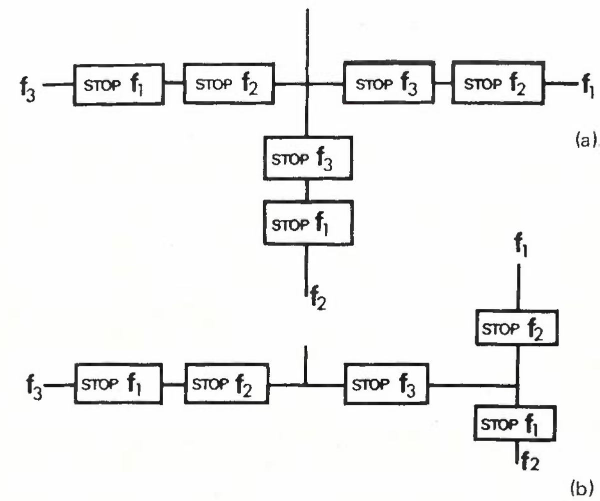


Fig.13-Three-way Multicoupler from Bandstop Filters

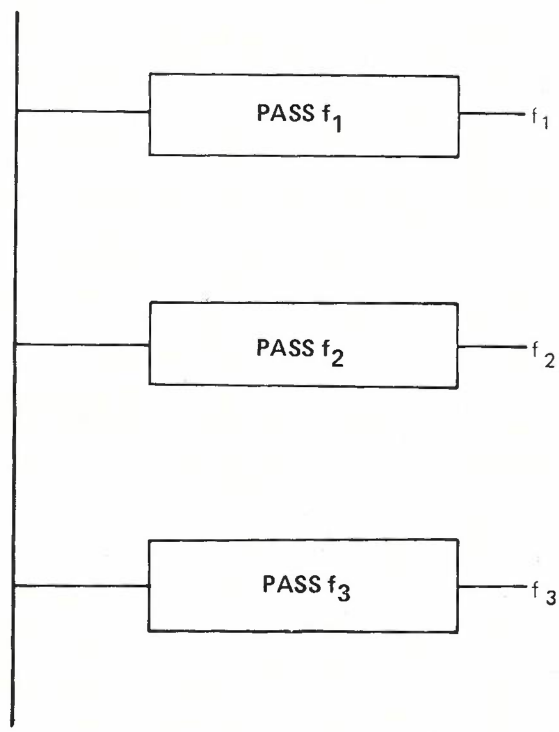


Fig.14-Sequentially Connected Bandpass Filters

There are two common ways of obtaining correct impedance matching at these junctions. The first, which is quite common in broadband microwave bearer systems, is to terminate the lower end of the main transmission line with a reactive load (normally a short circuit) and then to place a phase shifter below each junction of a bandpass filter with the main transmission line.

The phase shifters are then adjusted from the bottom in turn so that the correct impedance is presented at the transmission line junctions.

An alternative technique which is more common in VHF and UHF multicouplers is to place a bandstop filter below each junction as shown in **Fig. 15.** A bandpass filter and bandstop filter can be manufactured as a combined package, and a system can be extended in the number of channels that it operates by adding such a package at the end of the main transmission line. The bandstop filter is located so that it presents an effective open circuit at the corresponding junction between bandpass filter and main transmission line.

Hybrid/Filter Combinations

The next multicoupler configuration to be considered is the Hybrid/Filter combination. Although a hybrid power divider used alone has an inherent 3 dB power division loss, this does not mean that all devices using hybrid power dividers are lossy. In the configuration shown in **Fig. 16,** two hybrid power dividers are used together with two band-pass filters. For a simple explanation of how this configuration operates, consider a frequency f1 applied to the lower port. This signal will divide equally in the lower hybrid power divider and pass through the bandpass filters for combining at the upper hybrid power divider. The f1 signal therefore appears at the main transmission line at the top of the diagram. Consider now a frequency f2 applied to the 4th port of the upper hybrid power divider. This signal will divide equally in the upper hybrid power divider, and the two component signals will travel towards the two bandpass filters. However the bandpass filters do not transmit frequency f2 which is therefore reflected. The two reflected components arriving back at the upper hybrid power divider are now out of phase because of the quarter wave difference in the two transmission line lengths. The two components of f2 therefore recombine in the upper hybrid power divider to give an f2 output on the main transmission line. This approach can be extended to more than two frequencies when it is recognised that there is no unique feature which determines the frequency f2. Therefore if frequencies 2, 3, 4 and 5 are applied to the upper hybrid power divider and frequency f1 to the lower hybrid power divider, then all frequencies f1 to f5 will appear at the main transmission line. This configuration therefore provides a method for extracting a particular frequency out of a large number of frequencies. When hybrid power dividers are used without frequency selective elements, then the 3 dB power division loss must be accepted.

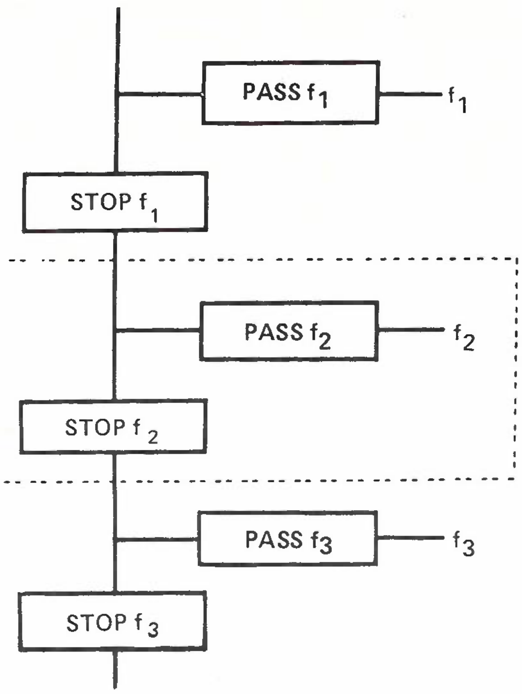


Fig.15-Sequentially Connected Bandpass/Bandstop Filters

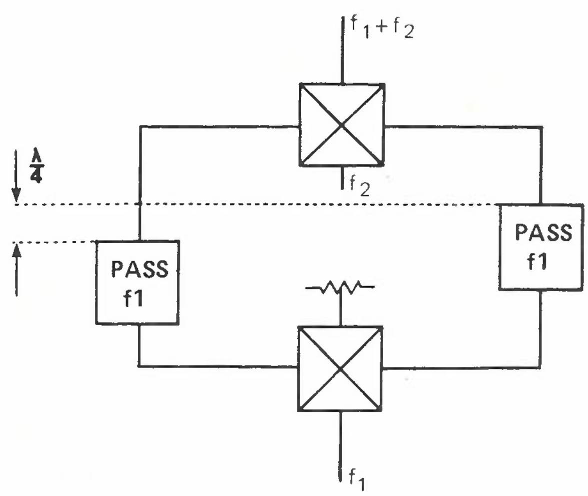


Fig.16-Hybrid and Filter Combination

Hybrid/Isolator Combinations

The next configuration to be considered is the hybrid/isolator combination. In the above, it has not been important whether the radio equipment items in the multicoupler configurations have been transmitters or receivers, as only reciprocal devices have been considered, and it is only in the amounts of isolation required that the two cases are different. However when non-reciprocal elements are incorporated into multicouplers, it is necessary to know whether transmitters or receivers are being used. **Fig. 17 (a)** shows a combining network for two transmitters. This combiner would be used where the frequencies of the two transmitters are so close that frequency selective filters cannot be used. The combining function in **Fig. 17 (a)** is provided by the hybrid and additional isolation between the two transmitters is provided by one or more isolators in each transmitter path. From each transmitter to the transmission line there would be approximately 4 dB attenuation. Of this, 3 dB would be power division loss in the hybrid, and the other 1 dB would be dissipative loss in the isolator and hybrid. Whereas the hybrid on matched loads would have an isolation of approximately 30 dB or more, the isolation obtained in the configuration of **Fig. 17 (a)** will be dependent on the impedance of the antenna connected at the end of the main transmission line. If the antenna has a VSWR of 1.5, this corresponds with a return loss of 14 dB. A signal entering the hybrid from one transmitter is therefore reduced initially by 3 dB due to power division. It leaves on the antenna transmission line and returns from that line reduced by another 14 dB. That returning signal is further reduced by 3 dB before leaving in the direction of the other transmitter. The isolation provided by the hybrid is therefore 20 dB as against its rather higher value obtained with two matched loads. It is not desirable practice to over design the antenna system for very low VSWR, as if circumstances such as icing are encountered, then this will affect the antenna VSWR in any case.

It may be considered that one method of improving the isolation provided by the hybrid power divider would be to insert an isolator in the main antenna transmission line as shown in **Fig. 17 (b)**. This should eliminate any reflected signal from the antenna and therefore enable a higher isolation to be achieved across the hybrid. However placing an isolator in such a location is not good practice, because isolators have a finite range of linearity and can generate intermodulation products and harmonics. In the location in **Fig. 17 (b)**, the isolator is subject to strong levels from both transmitters and this is the worst situation for the generation of intermodulation products. In addition, any such products generated have unimpeded access to the antenna.

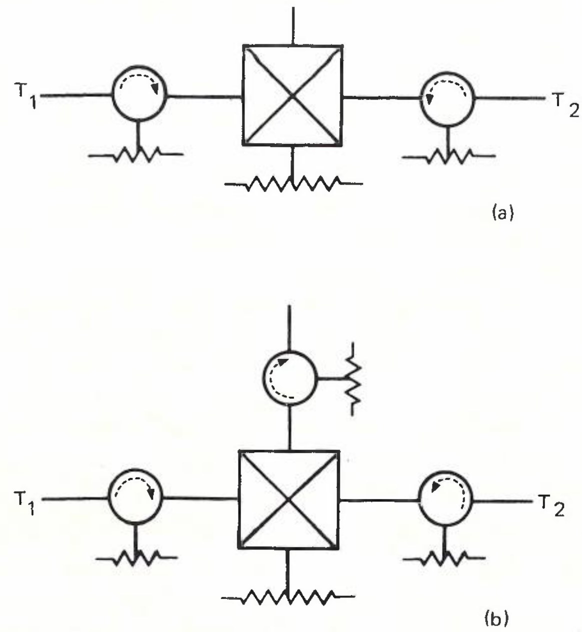


Fig.17-Hybrid and Isolator Combinations

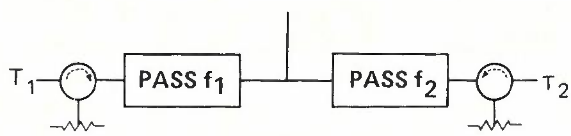


Fig.18-Filter and Isolator Combination

Filter/Isolator Combinations

When transmitters, having a significant frequency separation, are to be combined but there is insufficient physical space to allow a multicoupler constructed only of bandpass filters to be used, the filter/isolator combination shown in **Fig. 18** is useful. The configuration in **Fig. 18** is suitable for two transmitters, but the technique is also applicable for larger numbers. The two bandpass filters are simple and provide the multicoupler combining function. The additional isolation required between the transmitters is provided by the isolators. By comparison with the configuration shown in **Fig. 17**, the configuration shown in **Fig. 18** has the advantages that there is no 3 dB power division loss in a hybrid, and that any intermodulation products or harmonics generated in the isolators have to pass through frequency selective filters before reaching the antenna.

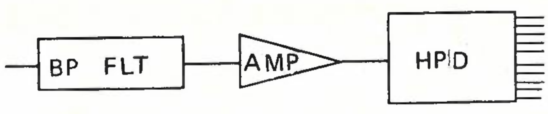


Fig.19-Active Multicouplers (Receiving)

Active Multicouplers (Receiving)

The final multicoupler configuration to be considered in this review is the active receiving multicoupler. In this configuration, shown in **Fig. 19**, an amplifier is used to amplify the received signal before it is divided between the receivers with a hybrid power divider. The hybrid power divider can have many outputs, and numbers up to 32 are common. To prevent blocking of the sensitive main receiving amplifier by nearby transmitters, the amplifier is preceded by a bandpass filter, of bandwidth appropriate to the channels being received. This configuration is most useful in two-frequency plan situations, where the transmitters at the base station occupy one segment of the allocated frequency band, and the receivers occupy another segment. This configuration is at present used only for receiving situations because of the difficulty in obtaining the linearity that would be necessary for it to be used in a transmitting case. For example, consider the case of ten, 50-watt outputs. Fifty watt is a convenient power level to consider as it is not uncommon and it corresponds with 50 volts on a 50 ohm transmission line. If ten signals are to be combined so that the total output power is 50 watts on each of ten different frequencies, the average output power requirement of the amplifier is 500 watts. However because the ten signals are not related in any way, there will be times when the ten signals combine in phase to give a voltage of 500 volts, which on a 50 ohm transmission line corresponds with a power of 5 kilowatts. Therefore the linearity must be that of a 5 kilowatt amplififer, although the average output power is only 500 watts.

CONCLUSION

The above are the more common multicoupler configurations in use for VHF and UHF mobile radio systems. Many other configurations are of course possible. Some are patented and some physical realisations of the multicouplers shown above are patented. Other multicouplers, such as in military communications systems, need different approaches, to satisfy such requirements as rapid retuning, often over a wide frequency range. The optimum multicoupler configuration for a particular application is determined largely by the frequency plan. It is at the time when the frequencies are allocated that the difficulty of the subsequent multicoupler design is established. In addition, the frequency plan will determine the maximum number of radio frequency channels or equipment items that can be accommodated on one site.

Meeting Specifications with Practical Filters

R. L. GRAY, B.E. (Hon.) M.E., Ph.D.

An essential element of the better couplers is the frequency-selective filter. The following paper sets out some principles in a quantitative way for the assistance of radio system designers who may wish to examine the cost or feasibility of various coupler proposals. It discusses a theoretical relation between stopband rejection, frequency separation and loss for a given choice of elements and complexity and suggests an optimum trade-off. This theme is further developed to show the extent to which performance can be improved, or complexity reduced, by matching the filter stopband response more closely to the requirement.

INTRODUCTION

The couplers discussed here owe their directional or signal-separating property to their frequency selectivity. That is, they are filters which have a common input or output. Such multiplexers are sometimes called "filterplexers".

The problem most frequently discussed in the technical literature about the design of these devices is the minimising of interaction between the filters at their common input (Ref. 1). This interaction is apparent to the user as reflection from the common input and consequent loss through the filters and standing wave on the feeder. However, at VHF and UHF several factors combine to make the problem of resistive transmission loss of even greater importance. These are:

- the need to separate signals which are close in frequency and consequently
- the need for stable, low loss resonators in the filters, and
- the necessity of making resonators large to achieve these high Q factors.

The result is frequently either a large filter, or a lossy one; both undesirable properties, particularly for mobile applications.

The aim of this paper is to show how to make the best use of lossy resonators in filters which meet desired attenuation requirements. Although the examples are directed to VHF and UHF, the principles outlined are applicable to any filter which consists of resonators coupled together, be they waveguide, electro-mechanical, TEM coaxial or lumped LC.

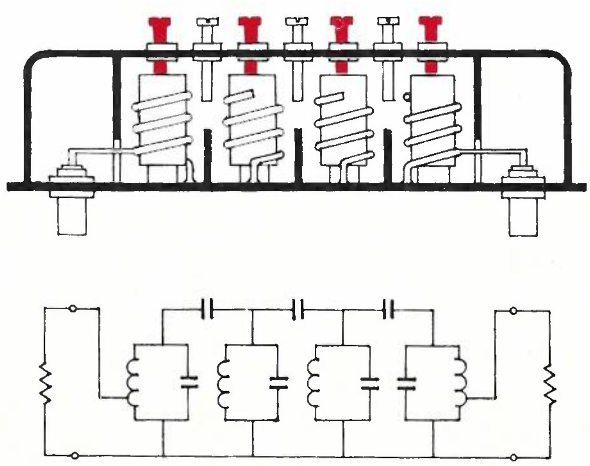


Fig. 1 — Coupled Helical Resonator Filter Cross-sectional View and Circuit Diagram.

COUPLED RESONATOR BANDPASS FILTERS

Suppose we are given a number of lossy resonators and some means, which can be adjusted, of coupling them together and to the resistive terminations. The requirement is to reject unwanted frequency bands while passing a wanted signal through the filter with the least attenuation possible from the given elements. A schematic of such a circuit is shown in **Fig. 1**, together with a cross-section view of a coupled helical resonator filter (Ref. 2) where the coupling of the helical resonators is via apertures in the separating walls. The screws shown are for opening and closing the apertures. Screws for tuning each resonator are shown coloured.

The Effect on Loss of Narrower Bandwidth

As the unwanted frequency bands are pushed closer to the wanted frequency, the filter is compelled to be narrower and narrower in order to provide the required rejection at the stop band edges. To achieve this narrowing of response, the coupling between resonators of the filter in **Fig. 1** is being reduced by closing up the apertures. The effect on loss at the wanted frequency is illustrated in **Figs. 2 and 3.** Note that not only does the narrower filter have more loss at the wanted frequency, but the edges of the filter passband become more rounded.

Other Filter Types. The Minimum Loss Filter.

The responses shown in **Fig. 2** are for a Tchebycheff filter type for which the coupling coefficients are computed assuming lossless resonators. The effect of resonator losses is to

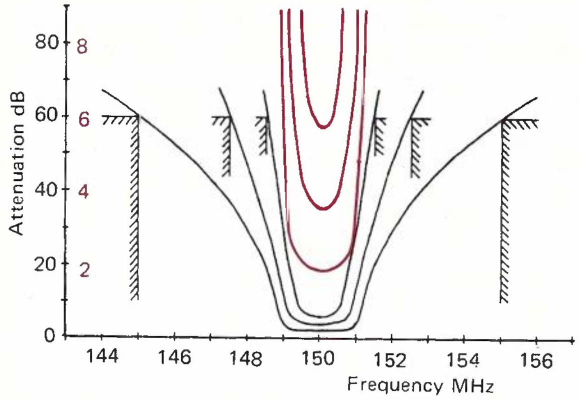


Fig. 2 — Effect of 60 dB Bandwidth on Mid-band Loss. F_o = 150 MHz, n = 4, Q = 1000, A_r = 60 dB.

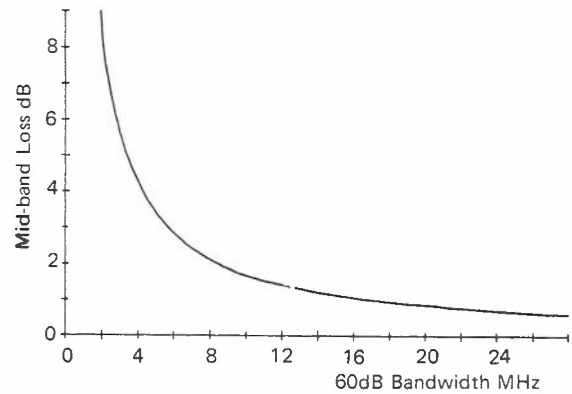
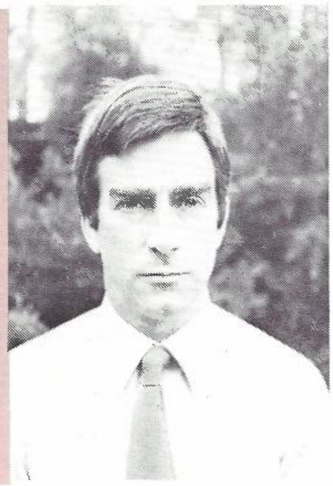


Fig. 3 — Effect of 60 dB Bandwidth on Mid-band Loss. F_o = 150 MHz, n = 4, Q = 1000, A_r = 60 dB.

Rod GRAY received the Bachelor and Master of Engineering degrees from the University of Adelaide in 1962 and 1964 and a Ph.D. from the University of Newcastle, U.K. in 1969. Both higher degrees were awarded for research achievements in circuit theory — the M.E. for a thesis on time domain synthesis and the Ph.D. for techniques of crystal filter design.

Between periods of research, he has been a filter designer for manufacturers of communications equipment. During 1964 and 1965 he worked for Philips, Clayton and from 1969 until 1972 he was employed by I.T.T., U.K. with a design team developing monolithic quartz crystal, LC and electromechanical filters.

Since joining Telecom in 1972, he has contibuted to new methods of design for equalisers, VHF and UHF filters as well as helped provide the Network Theory Section consultant service to Telecom. At present he is developing a design method for new filter structures.



smooth out the ripples which are characteristic of the Tchebycheff passband response as well as cause an increase in insertion loss. Since the Tchebycheff behaviour is so utterly destroyed by resonator losses, there would seem to be little value in using a lossless design. The question then arises: can a different type of filter response be chosen so that the effect of losses is reduced? Some other common types are illustrated in **Fig. 4** where the couplings have been computed to give Butterworth, Tchebycheff (as in **Fig. 2**) and the "equal element" responses. The last type has been shown by Cohn (Ref. 3) to be the optimum in terms of mid-band loss. Also shown in **Fig. 4** is a predistorted or "loss-compensated" filter. This is included to emphasise that, although it is possible to achieve a Tchebycheff response in the presence of losses, this can be done only at the expense of a large increase in insertion loss. It does produce a flat passband but at the expense of an increased insertion loss.

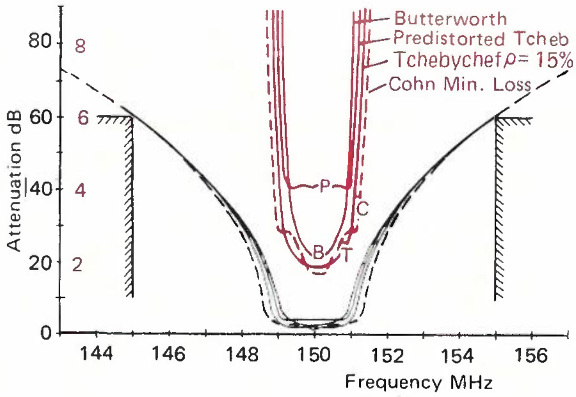


Fig. 4 — Effect of Filter Type on Mid-band Loss. F_o = 150 MHz, n = 4, Q = 1000, A_r = 60 dB, B_r = 10 MHz.

Increasing the Number of Resonators. The Effect on Loss.

So far, it has been shown that making a filter narrower increases the insertion loss and that the best filter type to use to minimise insertion loss is the equal-element filter. The examples chosen to illustrate these points all used four resonators. What about changing the number of resonators? Might we expect fewer resonators to give a lower insertion loss? The answer to this question is surprising at first sight. It can be illustrated with a numerical example of a filtering problem stated in the following way. Suppose the given resonators have a Q factor of 1000. A number of these resonators are to be coupled together to form a filter which has at least 60 dB rejection of all frequencies above 155MHz, and below 145 MHz while passing the wanted frequency, 150MHz, with the least attenuation possible. The minimum loss or equal-element filter is used to illustrate the effect of number of resonators on the attenuation at 150MHz and the responses are shown in **Fig. 5** for two, three, four and five resonators.

It can be seen that an increase, not a decrease, in the number of resonators is needed to reduce the loss. Notice that because the various filters have been chosen for the same 60 dB bandwidth, the pass bandwidth of the higher order filters is greater than for the lesser orders. The wider pass band filter has lower insertion loss. Note also that, while the improvement gained by using more than four resonators is only slight, the insertion loss of a two resonator filter is very poor.

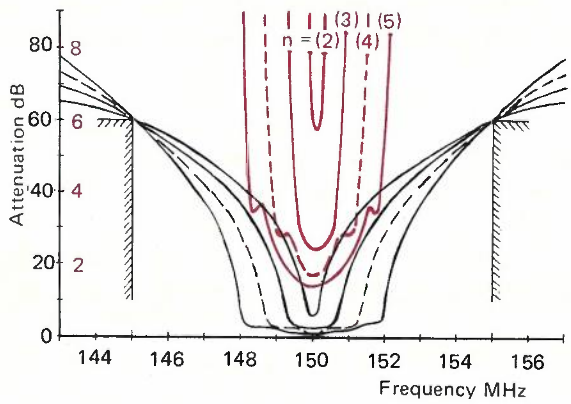


Fig. 5 — Effect of Number of Resonators on Mid-band Loss. F_o = 150 MHz, Q = 1000, A_r = 60 dB, B_r = 10 MHz.

Shown in **Fig. 6** is a graph of insertion loss against number of resonators. The ordinates for this graph are the minima of the responses shown in **Fig. 5,** but the number of resonators is extended out to twelve. It can be seen that there is a shallow minimum at about seven resonators and a steep rise below three resonators.

The expression for mid-band loss of minimum-loss filters has been shown (Ref. 4) to be approximately

$$L_o = \frac{4.34\, n\, F_o}{B_r\, Q} \exp\left(\frac{A_r + 6}{8.7n}\right) \quad .....(1)$$

where F_o is the pass frequency in MHz

L_o is the pass frequency loss in dB

B_r is the stopband width in MHz

A_r is the stopband attenuation in dB

Q is the resonator Q factor

n is the number of resonators.

The graph of **Fig. 6** is a plot of this expression for L_o with F_o = 150, Br = 155 — 145 = 10, A_r = 60 and Q = 1000. Differentiation of equation (1) with respect to n shows that the minimum L_o occurs for

$$n = \frac{A_r + 6}{8.7} \quad .....(2)$$

Note that this is independent of all parameters except stopband rejection. Although approximate, the two formulae (1) and (2) are sufficiently accurate for most purposes when A_r exceeds 20 dB.

The Effect of Number of Resonators on Q and Volume for a Given Requirement.

The graph of **Fig. 6** and the expression for loss in equation (1) can equally well be used as the expression for the Q factor which is necessary to meet a given requirement. For example, if the Q specification of 1000 is removed and an insertion loss requirement is substituted, say L_o = 1 dB, in its place, then a graph for Q against n can be plotted. This curve has the same shape as **Fig. 6.** However, writing the expression in this form presents an opportunity for other quantities, related to Q, to be assessed. For example, if helical resonators are used, the filter volume may be calculated from the number of resonators and the knowledge that the volume of a helical resonator is proportional to the cube of Q. It can be shown, in a similar way to the derivation of equation (2), that the optimum number of resonators for minimum volume is three quarters of the number giving minimum Q. Another quantity which may also be evaluated in this way is filter cost, for which it might be expected that a somewhat lower number of resonators is the optimum.

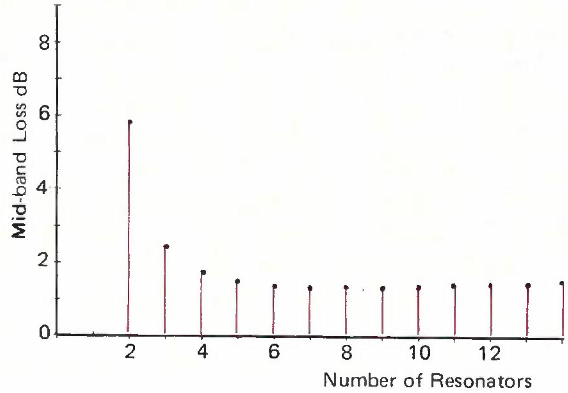


Fig. 6 — Effect of Number of Resonators on Mid-band Loss. F_o = 150 MHz, Q = 1000, A_r = 60 dB, B_r = 10 MHz.

Notice that the optimum number of resonators depends only on the stopband attenuation. For example, if 30 dB of attenuation is required to isolate, for example, two co-sited transmitters, then four resonators should be used for minimum Q and three for minimum volume. If 70 dB of rejection is needed say, to separate transmitter and receiver, then nine resonators give the minimum Q and minimum volume is achieved with seven. These formulae make it a simple matter to determine, at least approximately, the consequences of setting a particular specification for the frequency separation, isolation and insertion loss for a transmitter-transmitter or transmitter-receiver combination.

Stopband Attenuation Peaks

The attenuation of the ideal filters discussed so far rises to the desired stopband level and then continues to rise without limit. In practice, it is usually sufficient for the attenuation to rise to the desired level and then not fall below this level anywhere in the stopband. The question then arises of what can be gained by designing a filter which achieves the stopband rejection desired and no more. That is, can some of the unnecessary attenuation be "given away" in return for, say, a lower insertion loss? The answer is that it can, and the means for achieving this is to introduce finite peaks of attenuation (Ref. 8). This can usually be done without increasing the complexity of the filter significantly.

Double Sided Attenuation Peaks

To illustrate this, **Fig. 7** shows the response of a four resonator minimum loss filter having a 60 dB bandwidth of 10 MHz at 150 MHz centre frequency. The Q factor of the resonators in this filter is 1000 and the passband loss (shown on the ten times expanded dotted inner curve) about 1.7 dB. Superimposed on these curves, is the response of a filter having the same number of resonators with the same Q factor as before, but modified so that a pair of attenuation peaks is introduced. The locations of these peaks are controlled so that the filter has the same 60 dB bandwidth as before and so that the attenuation minima ensure that the minimum requirement is achieved everywhere in the stopband. It can be seen that the insertion loss of this filter is reduced to about 1.2 dB; that is, two thirds of the "unpeaked" value.

Both of these structures are equal element or minimum loss designs in which each resonator is coupled to its neighbour in the manner shown earlier in **Fig. 1**. However, in the second case an additional coupling path is introduced between the input and output resonators (Refs. 6, 7), (one-to-four coupling). If this crosscoupling is opposite in sign to the main coupling path, it produces a pair of attenuation peaks symmetrically disposed about the centre frequency and has very little effect on the pass frequency loss. The effect of the attenuation peaks is to reduce the stopband width, which, when the filter is rescaled to the original stopband requirement, results in a reduced pass frequency loss. Put another way: the second filter is created by cross-coupling an unpeaked filter which has a wider stopband and therefore lower insertion loss.

Single Sided Attenuation Peaks

Attenuation peaks can be used to obtain even less pass frequency loss when the stopband attenuation is required on only one side of the wanted frequency. In this case, all the peaks can be concentrated on this one side to maximise the attenuation here at the expense of the other side.

A simple way of designing such filters is to apply a frequency transformation to the minimum loss filter (Ref. 5) to create multiple, coincident peaks of attenuation in the stopband. This technique simplifies calculation of the response of the one-sided filter by relating it directly to the two-sided response. The transformation may also be applied directly to the circuit elements of the filter as well as in the calculation of response. The effect on the minimum loss filter of **Fig. 2** is to transform each parallel resonant branch into a branch which has both series and parallel resonances. The resonators are identical, as before, but each one is now series resonant in the stopband in addition to being parallel resonant near the pass frequency. It can be shown that the optimum number of resonators is the same as for the previous cases, but the pass frequency loss is reduced to half.

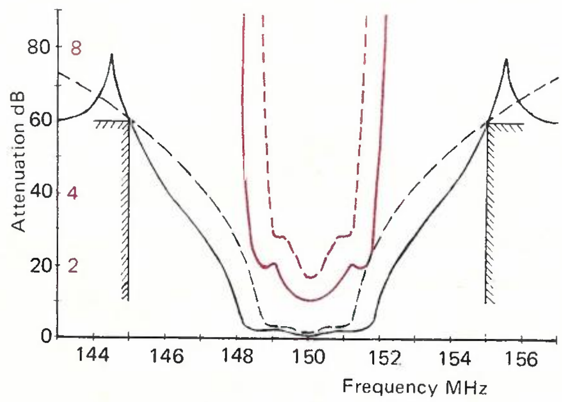


Fig. 7 — Effect of Double-sided Attenuation Peaks on Mid-band Loss. F_o = 150 MHz, n = 4, Q = 1000, A_r = 60 dB, B_r = 10 MHz.

The previous example is used in **Fig. 8** to illustrate the response obtained when the stop attenuation is required only on the upper side of the wanted frequency. Note that the attenuation on the lower side slowly approaches 60 dB.

This circuit configuration has two disadvantages which tend to reduce its practical value. Firstly, the more complicated resonator tends to have a lower Q factor than the simple one and secondly, it is no longer feasible to use apertures to provide coupling. Filters using helical resonators may, however, be coupled with cables which, although solving the coupling problem, also add to the filter insertion loss.

It is also possible to apply this transformation to the cross-coupled filter configuration and thereby reduce the insertion loss to one third. The stopband response in this case will have attenuation peaks which are not coincident, but distributed through the stopband. This produces a circuit configuration which has both cross coupling and modified resonators. However, the additional complexity is usually not warranted because an equivalent performance can be obtained by making the resonators different. The change necessary is a retuning of each resonator so that its series resonance corresponds to one of the desired attenuation peaks while its parallel resonance is maintained near the passband. The design of this type of filter will not be considered here.

It should be pointed out that it is also possible to use generalised cross-coupling arrangements between simple resonators to give this type of response. These possibilities would normally only be considered when a particularly difficult filtering requirement was encountered: for example, where a wide, flat passband and sharp transition to stopband, or where a controlled phase response were required.

The "Bandstop" Case

In the cases discussed so far, the stopband has extended to zero and/or infinite frequency. The greatest improvement in performance is possible when the stopband, in addition to being single-sided, is confined to a finite frequency band. As this band becomes narrower, the improvement in performance increases. Such a case may occur, for example, in an aerial diplexer where a transmit frequency is to be excluded from a receiver input while an adjacent frequency is to be admitted at that receiver input. The design of diplexers having this type of specification is discussed in reference 5. These filters have the same type of asymmetric response as discussed in the previous section and are similarly based on transformation of the minimum loss filter. It can be shown that, if the width of the desired reject band is W MHz, and the separation of the pass and stop centre frequencies is S MHz, as shown in **Fig. 9,** then the insertion loss at the pass frequency is reduced by the factor W/2S. Since this factor is commonly less than 0.1, the practical difficulties brought about by using complicated resonators may be easily out-weighted by the savings in overall complexity possible through reducing the number of resonators required.

Conclusion

In this paper, the use of frequency difference to separate signals is discussed. The filters which do the separation are inevitably made from lossy components, but it is possible to minimise the undesirable effects of loss by properly proportioning the filters.

Some of the principles to be followed in filter design are somewhat surprising at first look. For example, to diminish the insertion loss of a filter, it may be advantageous to increase, rather than decrease, the number of resonators (Cohn's principle).

The trade-off between stopband rejection and insertion loss at the pass frequency is dis-

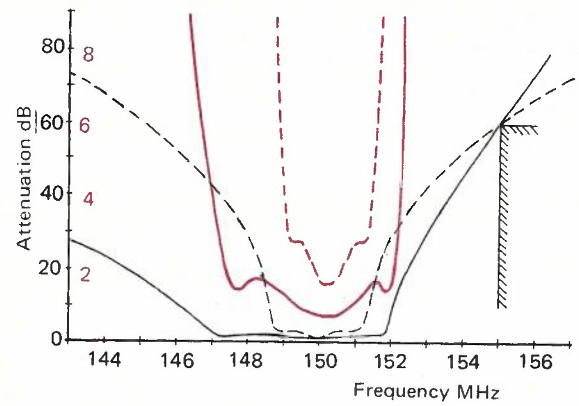


Fig. 8 — Effect of Single-sided Attenuation Peaks on Mid-band Loss. F_o = 150 MHz, n = 4, Q = 1000, A_r = 60 dB, s= 5 MHz.

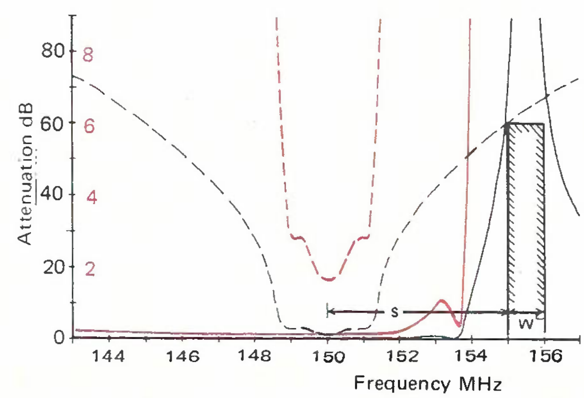


Fig. 9 — Effect of Narrow Band-stop on Mid-band Loss. F_o = 150 MHz, n = 4, Q = 1000, A_r = 60 dB, s = 5 MHz, w = 1 MHz.

cussed for bandpass, single-sided and bandstop specifications. It is shown that the following improvements in performance are possible over the simple coupled-resonator filter

- the use of attenuation peaks in the filter stopband may reduce the insertion loss to two thirds
- a single sided stopband response may reduce the insertion loss to one half
- a narrow stopband or "Bandstop" filter may reduce the insertion loss by half the ratio of the stopband width to the frequency spacing.

It is hoped that an awareness of these principles will contribute to better multicoupler design and more efficient use of our spectrum resources.

References

1. Matthaei G. L., Young L. and Jones E. M. T.: "Microwave Filters, Impedance - Matching Networks and Coupling Structures," McGraw-Hill, 1964, pp 965-1000.
2. Zverev A. I.: "Handbook of Filter Synthesis", John Wiley and Sons, 1967, p. 500.
3. Cohn S. B.: "Dissipation Loss in Multiple-Coupled Resonator Filters"; Proc. IRE vol. 47, pp 1342-1348; August 1959.
4. Taub J. J.: "Design of Minimum Loss Band-Pass Filters"; The Microwave Journal, pp 67-76, November 1963.
5. Gray R. L.: "Asymmetric Bandpass Filter and Aerial Diplexer Design"; A.T.R. vol 8, No. 2, pp 53-58, 1974.
6. Gray R. L. and Holt A. G. J.: "Bandpass Crystal Filters by Transformation of a Low Pass Ladder"; IEEE Transactions on Circuit Theory, vol. CT-15 No. 4 pp 492-494, December 1968.
7. Gray R.L.: "Multi-coupled Resonator Bandpass Filters"; IREE Australia Convention Digest, pp. 274-276; Melbourne 1977.
8. Taub J. J.: "Equal-Element Elliptic-Function Filters"; IEEE Transactions on Circuit Theory, Vol. CT-15, No. 4, pp. 478-481, December 1968.

The Telecom "Telefinder" Radio Paging Service

B. E. ROBINSON, B.E., M.I.E. Aust

Since its introduction in 1973 in Sydney and Melbourne the Telecom Telefinder radio paging service has been in high demand and has been expanded to include Canberra and all State capital cities. The service will be extended to serve many of the larger regional cities and will be improved to offer additional facilities.

INTRODUCTION

The Telecom "Telefinder" radio paging service is a one-way communication system which provides a means of contacting each customer of the service individually, at any time, while allowing him freedom to move about within the service area. The method used to contact a paging customer is to call his number from any telephone connected to the Telecom telephone network. Telephone calls to a paging customer are directed to a paging terminal which encodes the calls and transmits them through a number of radio transmitters located throughout the required service area. Each paging customer carries a pocket-sized radio receiver which receives and decodes all of the transmitted calls, but responds only to its own exclusive code, by generating an audible, visual, or tactile alerting signal. The alerted paging customer then takes some pre-arranged course of action, which might be, for example, to telephone his secretary to obtain a message. The Telefinder system is capable of serving up to 100,000 subscribers over a single, voice frequency bandwidth radio channel.

THE RADIO PAGING SERVICE

The service, first commissioned in Sydney and Melbourne in December 1973 with equipment of 3,600 customer capacity in each city, was highly successful and achieved a high growth rate in the number of customers connected, so that within 2 years, replacement of the switching terminals with terminals of 10,000 customer capacity was necessary to meet demand. Within a further 2 years, expansion to 20,000 customer capacity was required in each city. In 1976, the service was extended to include Canberra and Brisbane and in 1977, Adelaide, Perth and Hobart were served. A functional illustration of the system is given in **Fig. 1** and **Table 1** gives information on the equipment locations and transmitter powers. **Fig. 2** shows the growth in the number of paging customers connected to the services. Each area served includes a major city and the telephone network unit fee call area associated with the city.

THE NETWORK CONFIGURATION

The equipment used in the Telefinder network comprises a paging switching terminal which interfaces with the telephone network, a number of circuits carrying paging calls and control and supervisory signals between the terminal and the paging transmitters and a number of paging transmitters.

The Telephone Network Interface

The paging switching terminal is designed to connect into the telephone network, via a number of circuits, at Group Selector stage level and to use decadic signalling. Future systems will be required to operate with multi-frequency code (MFC) signalling.

The Paging Switching Terminal

The Telefinder system requires equipment known as a paging switching terminal, to accept paging calls from the National Telephone Network and to generate paging codes. A modern paging switching terminal comprising one 1930mm height by 533mm width rack of

TABLE 1 — EQUIPMENT

SYSTEM	TERMINALS		TRANSMITTERS	
	LOCATION	SIZE (CUSTOMERS)	LOCATION	POWER (WATTS)
SYDNEY	HAYMARKET EXCH.	2 × 10,000	PARK REGIS WAVERLEY MT ELLIOT DURAL CECIL PARK	150 150 150 150 150
CANBERRA	SYDNEY	1 × 10,10,000	BLACK MOUNTAIN	200
MELBOURNE	LONSDALE EXCH.	2 × 10,000	LONSDALE EXCH. MT. DANDENONG ARTHURS SEAT PRETTY SALLY	150* 150 150 150
BRISBANE	EDISON EXCH.	1 × 10,000	COMMUNICATION HOUSE MT. COTHA EAGLE HEIGHTS	80 80* 80
ADELAIDE	WAYMOUTH EXCH.	1 × 10,000	WAYMOUTH EXCH. MT LOFTY MT RONYTHON	80 80 80
PERTH	PIER EXCH.	1 × 10,000	PIER EXCH MT BICKLEY FREMANTLE	80 80* 80
HOBART	MELBOURNE	2 × 10,000	MT WELLINGTON	80*

* A COLD STANDBY TRANSMITTER IS PROVIDED

B. E. ROBINSON graduated from Sydney University in 1957 and was appointed to a position in the Australian Post Office in Queensland, where he worked in the Long Line Equipment Installation and Radio Sections. In 1966 he was promoted to a position in the Radio Section of Headquarters where he was involved with mobile radiotelephone, tropospheric scatter and radio paging equipment.

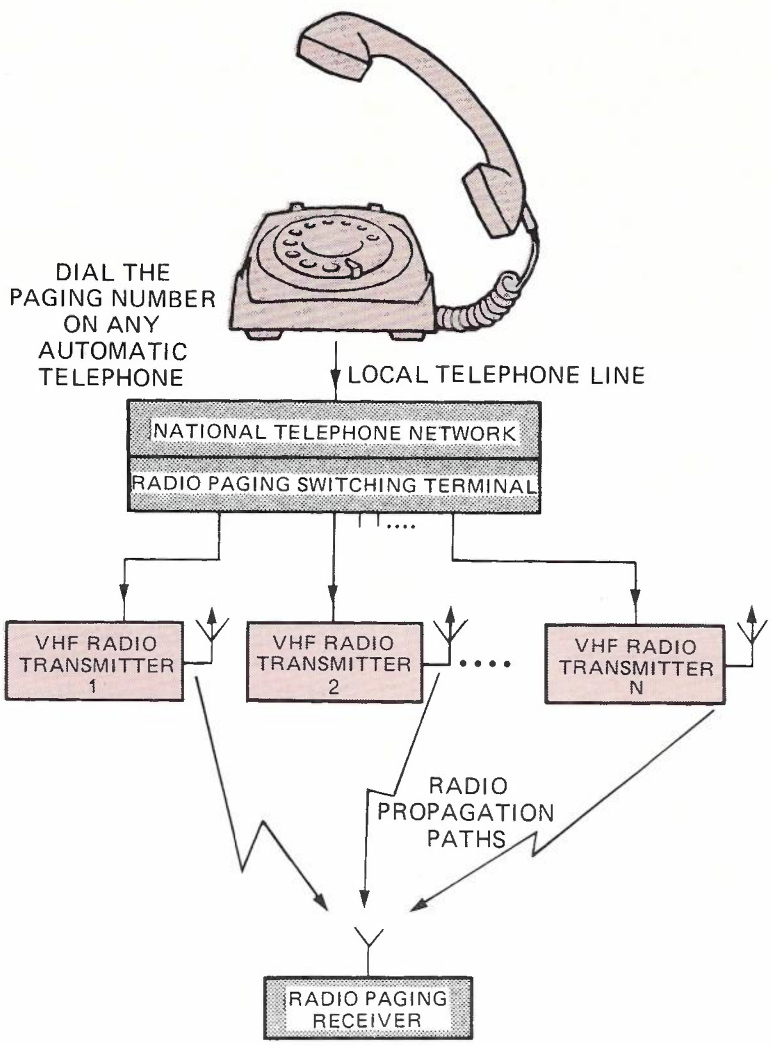


Fig. 1 — The Telefinder System.

equipment is capable of serving up to 10,000 paging customers. To provide service to several tens of thousands of paging customers, as is required in the Sydney and Melbourne networks, a number of these racks may be connected in parallel at the output. An allotter is used to allot to each terminal time slots for access to various groups of paging transmitters. Integrated circuits are used extensively throughout this equipment.

Call Input Procedure

A paging number is accepted from the exchange into the terminal which is equipped with a number invalidator unit for preventing invalid numbers from being accepted by the terminal. If the number is invalid, 7 seconds of invalid number tone is sent to the calling customer and the trunk is released. If the number is valid, 4 seconds of ring tone is sent to the calling customer, the number is stored and the calling customer is charged. A call accepted announcement stating "your call has been accepted and will be paged", is sent to the calling customer and then the circuit is released. The procedure is repeated for other calls entering on that circuit. To handle the paging traffic, a number of circuits are required between the exchange and the switching terminal. The equipment is capable of accepting simultaneous calls on these circuits

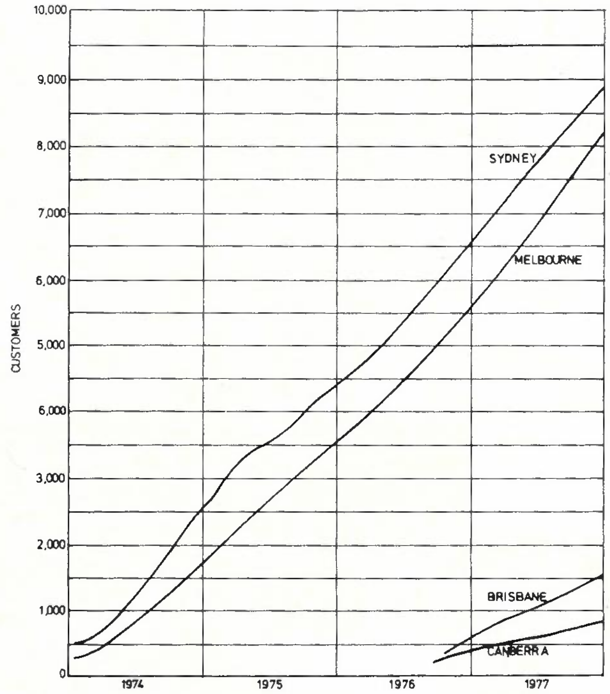


Fig. 2 — Radio Paging Customers Connected.

with a delay of not more than 25 milliseconds to any one call.

Call Output Procedure

All valid incoming calls are put into a store. In the call output procedure, which is largely independent of the call input procedure, the calls are taken out of store, encoded and sent to the radio transmitters. If the store is not empty, the next available number is removed from store and the encoding circuits are prepared. If the transmitters are not switched on, they are first switched on, and test modulation is sent. If the transmitter carrier and modulation levels are normal, the test modulation is removed and the call is encoded and sent. If transmitters are faulty, but the fault is not major then the call is processed, otherwise a major alarm stops the terminal operation. After sending a call, the next call in store is processed. When an empty store is found, the transmitters are held on for 66 milliseconds to allow calls to come in and to be processed without a transmitter check. Modulation level and power output of a transmitter is checked each time that it is turned on.

Detailed Operation

With Reference to **Fig. 3**, a number of circuits from an exchange connect to a corresponding number of input modules in the switching terminal. The input modules, together with a store are connected in parallel across an input bus. A number of transmitter control units (TCU), a tone coding timer and a tone synthesizer are connected in parallel across an output bus. A controller scans the input modules continuously at a rate of one module per millisecond, addressing each module in turn.

When an input module is addressed and is not busy sending supervisory or clear down signals back into the network and has a call ready for processing, then it puts the number which it has in its store onto the input bus and prompts the controller to process the call. The invalidator, which is also connected across the input bus, responds if the number is invalid and marks the bus accordingly. If the input bus is not marked invalid and the controller has been prompted by the input module, then the controller prompts the store which stores the number in the next available empty location. However, if the input bus is marked invalid, the controller prompts the input module to send number unavailable tone. If the store is full when the input module is addressed, then the controller does nothing. The store is addressed in the same manner as an input module and when addressed, if the output circuits are not busy processing a call, then the next call in store is placed in the controller output latch. An empty store, however, would result in no action. The latch holds the number on the output bus, freeing the controller to process other calls through the input bus. The

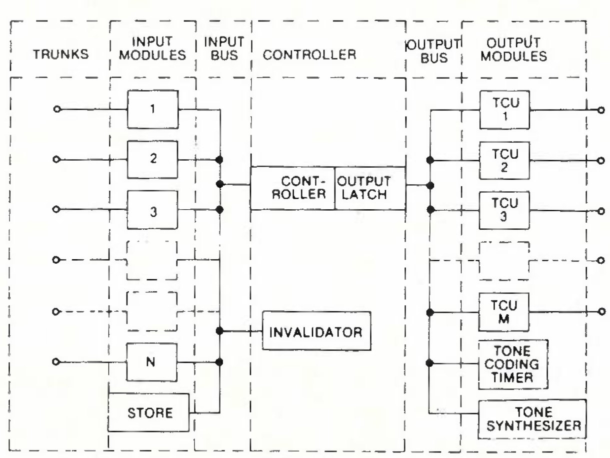


Fig. 3 — Paging Terminal Schematic.

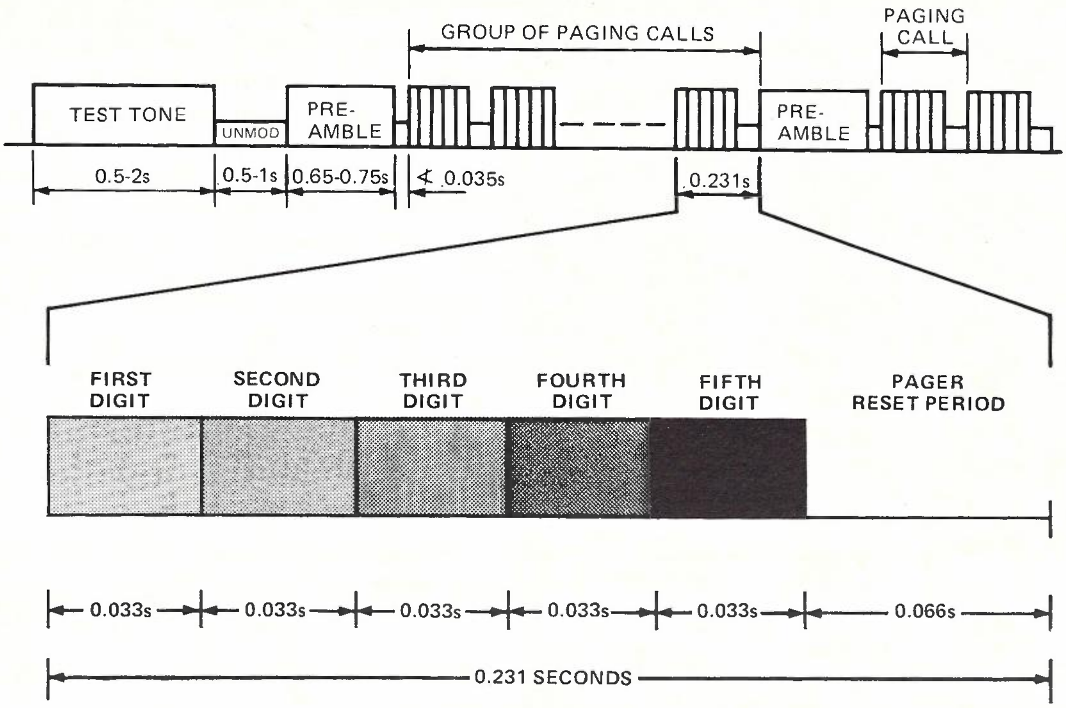


Fig. 4 — Coding of a Paging Transmission.

tone coding timer, when prompted by the controller, encodes the number in conjunction with the tone synthesizer and sends the call through the transmitter control units to the transmitters. After a call has been sent, the output modules signal the controller that call processing is complete.

Area Steering

Calls may be steered to one or more different areas. Each of these areas will be served by a transmitter or group of transmitters. Each paging number may be "tagged" in the terminal with an area code and each transmitter control unit in the terminal may be strapped to transmit calls tagged with one or more of the codes. The controller selects the areas one at a time and following each selection, it takes from store calls tagged for the area, encodes them and sends them to all transmitter control units. Prior to the first of these calls being sent, the transmitter control units strapped for the selected area switch on and test their transmitters in preparation for call transmission. The equipment currently used allows seven different areas to be served.

THE CODING SCHEME

In order that a paging number when dialled may cause the corresponding customer, and no other customer, to be alerted, a method of representing a paging number uniquely is required. This method, or code, must be suitable for transmission over interconnecting circuits, which may be physical lines or radio systems.

The coding scheme used by Telefinder is a 5 tone sequential decimal digital system shown in **Fig. 4**. For each paging call, five tones are sent in sequence, each tone representing one digit of the pager number. There are ten tone frequencies, to represent the digits 0-9 and an eleventh tone, called a repeat tone, is used to replace any tone which would otherwise be repeated, when two adjacent digits in the number are identical. This allows the paging receivers to detect the end of one tone and the start of another, when adjacent, identical digits are received, as illustrated in **Table 2**. After a period of at least 35 milliseconds of no tone, all pagers reset ready to decode the next call. A typical paging transmission starts with test tone, to test the transmitters, followed by a period of no modulation, then

TABLE 2 — CODE TONE FREQUENCIES

TONE	FREQUENCY (Hz)
R	459
0	600
1	741
2	882
3	1023
4	1164
5	1305
6	1446
7	1587
8	1728
9	1869
DUAL ADDRESS	2010

USE OF THE REPEAT TONE

NUMBER	TONE SEQUENCE
15332	153R2
11122	1R12R
11111	1R1R1

preamble tone which is used to deactivate a battery saving facility provided in some paging receivers. Next a group of paging calls, preceded, separated and followed by a reset period of no modulation are sent. All paging calls requiring transmission at this time are sent and transmission of the next group starts again with test tone.

THE SYSTEM CAPACITY

The duration of each tone of the code is 33 milliseconds and the duration of each paging call is about 200 milliseconds. Therefore the traffic capacity of the radio channel is 5 paging calls per second or 18,000 calls per hour. The measured paging call rate, based on the number of calls in the busy 3 minutes of any one week period, is equivalent to a maximum of 13 per cent of the connected paging customers being paged per hour. Therefore the maximum number of customers which may be served on one radio channel is 18,000 calls per hours traffic capacity divided by the calling rate of 13 per cent or somewhat more than 100,000. The five digit code allows 10^5 or 100,000 paging numbers to be encoded. Therefore traffic capacity and coding capacity are similar.

INTERCONNECTING CIRCUITS

Interconnecting circuits are required from the paging switching terminal to each radio paging transmitter to carry the transmitter turn-on signal and to carry the paging tone codes from the terminal to the transmitter. A circuit is also required to signal normal operation of each transmitter to a terminal. The allowable variation in the level of a signal received from a circuit is less than 6 decibels for satisfactory paging system operation. Therefore paging transmitters are equipped with an under-modulation alarm set at 2 KHz deviation and an over-modulation alarm set at 4 KHz deviation. The Telecom Planning Specification for data transmission circuits, which is applied to the circuits carrying the paging tones sets the frequency-amplitude response limits for the paging tone frequency range of 450 Hz to 2,000 Hz within +3 to −1 decibles, or 4 decibels total range. The limit set for loss variation of a circuit with time is ± 4 decibels or 8 decibels total range. Therefore the levels of tones received over these circuits may vary as much as 12 decibels with frequency and time and constant level amplifiers may be required at the transmitters to reduce these level variations to less than 6 decibels.

RADIO PAGING TRANSMITTERS

The frequency modulated radio transmitters used in the Telefinder system are similar to those used in mobile radiotelephone applications, however, power outputs may be up to 200 watts and no pre-emphasis is used as it has no advantages for the sequential tone modulation system used. A VHF radio frequency of 148.0125 MHz is currently used for all paging transmitters. Facilities are provided for remote on and off switching of the transmitters. Alarms are generated if the carrier level is low or if the modulation level is below or above the set limits. Transmitters currently being purchased for the Telefinder service use solid state devices throughout including the final power amplifiers.

RADIO PAGING RECEIVERS

Fig. 5 shows several types of radio paging receivers, commonly called pagers. The pagers are small and fit readily into the shirt pocket. All pagers of any one type are identical, except for a coding plug or coding link board which may be programmed or strapped with the paging customers number and which may be changed. This allows any pager to be assigned to any paging customer with change of plug or links only and without modification of the pager circuitry. One type of paging receiver has a switch with "off", "store call" and "on" positions and a push-down "cancel" and "interrogate" position. When switched from "off" to "on" if the battery voltage is satisfactory an alert is given which may be cancelled by pushing the switch down. In the "on" position, reception of a page gives an immediate alert. In the "store call" position a received page is held in memory and no alert is given until the switch is pushed down, which interrogates the memory and gives an alert if a call has been received previously. If the customer does not cancel the alert, it self-cancels in about 15 seconds. Other facilities available in some paging receivers include dual address, silent alert and battery saving. The dual address pagers use two telephone numbers and a different type of alert will be given depending on which number is called. Two types of alert available include continuous tone and interrupted tone. The silent alert paging receiver provides a sub-audible frequency vibration output. The battery saving facility allows the paging receiver to turn itself off for a high proportion of the time when paging calls are not being sent which extends battery life by typically three times. Some typical battery life figures are given in **Table 3**.

Paging receivers are commonly double conversion superheterodynes and the antenna may be a small loop built into the pager case, providing a gain of about 20 decibels below that of a half-wave dipole. Following demodulation of the

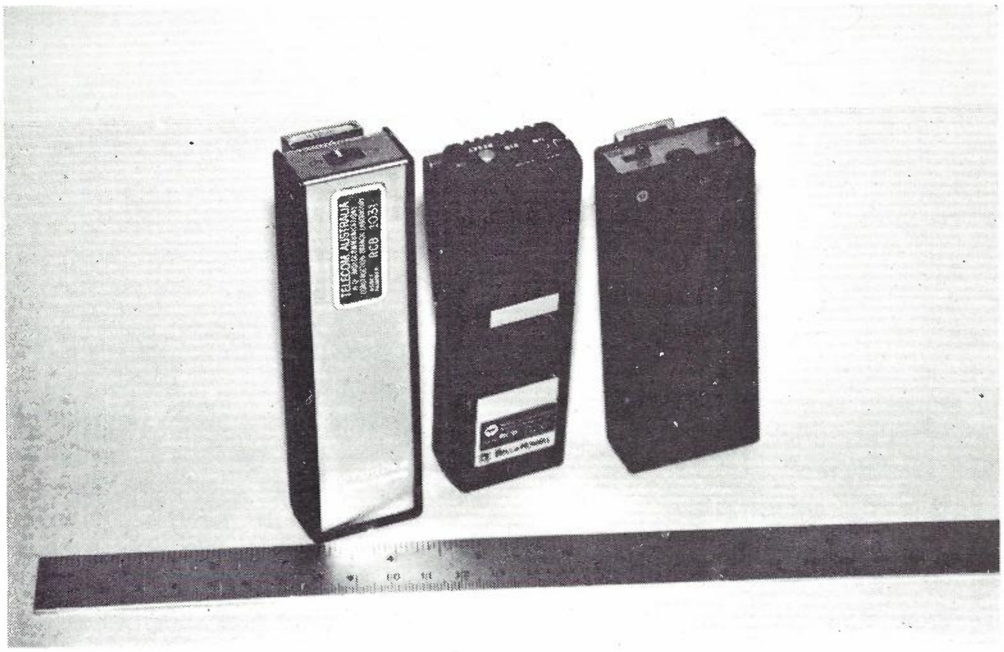


Fig. 5 — Radio Paging Receivers.

TABLE 3 — BATTERY LIFE

Battery Type	Battery Life (in weeks)	
	With Saving	Without
Alkaline	17	6
Mercury	26	10
Nicad	2	0.8

carrier signal, a 5-tone decoder and sequencer connects or programs tone selection filters under the control of a coding plug with maybe a small programmable read-only memory or a link board. In the absence of any detected tone for 33 milliseconds, the sequencer, via the coding plug, selects the filter for the tone frequency representing the first digit of the pager number. In other words, it resets. If this tone frequency is received, however, the sequencer selects the filter for the tone frequency representing the second digit of the pager number, and so for all five digits. If all five tones are received then an alert is given. For the pager to alert, all five tones of the pager code must be received and received in the correct order, between reset periods. False calls due to received noise are prevented, by limiting the maximum level of the demodulated audio frequency signals and by preventing the tone detection circuits from responding below a certain tone level.

Protection is achieved because the energy of a tone signal is concentrated within one tone filter passband whereas noise, limited to a similar level, is spread over a wider bandwidth and little noise energy falls with a filter passband. The paging receiver sensitivity is measured with a receiver worn on a person who is rotated through an azimuth angle of 360° in steps of 45°; at each step the minimum field strength needed to receive a paging call is measured. An average of these eight readings is taken and for the pager to be acceptable, this average must be a field intensity of not more than 10 microvolts per meter, for a call success rate of at least 50 per cent.

RADIO PAGER TYPE APPROVAL

Radio paging receivers are rented or purchased by the customer from one of a number of marketers. In order to ensure that a particular type of paging receiver will provide a satisfactory service to the customer, use in the Telefinder service is permitted only if it complies with certain standards laid down by Telecom Specification 1119. The specification describes the relevant characteristics of the system, the performance required and the procedure to be followed by a potential marketer who wishes to seek type approval for his paging receiver. To determine compliance with the specification, a programme of laboratory measurement is carried out on the pagers and if the pagers comply, type approval will be granted. Any alteration to a type of pager requires a new type approval.

SYSTEM DESIGN

Wide Area Coverage

Telefinder provides a service over large areas such as the extended local service area (ELSA) of the large capital cities. As the radius of these areas is typically about 40 kilometers and the service area which may be achieved with a single transmitter of acceptable power level is typically 15 to 30 kilometers, several transmitters located through ELSA are required. Calls could be sent simultaneously through all transmitters or could be sent sequentially. Sequential transmission would result in a number of problems:

- A radio paging receiver in a location capable of receiving several transmitters would produce several alerts. Under high traffic conditions, these could be spaced over such a period that they would be an annoyance to the customer.
- The traffic capacity of the radio channel would be reduced in proportion to the number of transmitters operated in sequence.

Other problems result when the alternative of using several transmitters transmitting simultaneously within one area on the same nominal frequency, is adopted:

- Destructive interference between the radio carriers, which may reduce the effective carrier level.
- A reduction in effective modulation level of the combined carriers received by a paging receiver due to a phase difference between the individual carrier modulations, as described later under "audio phase delay".

As solutions to the problems of simultaneous transmission are available, advantages over sequential transmission have been achieved by adopting this arrangement in the Telefinder network.

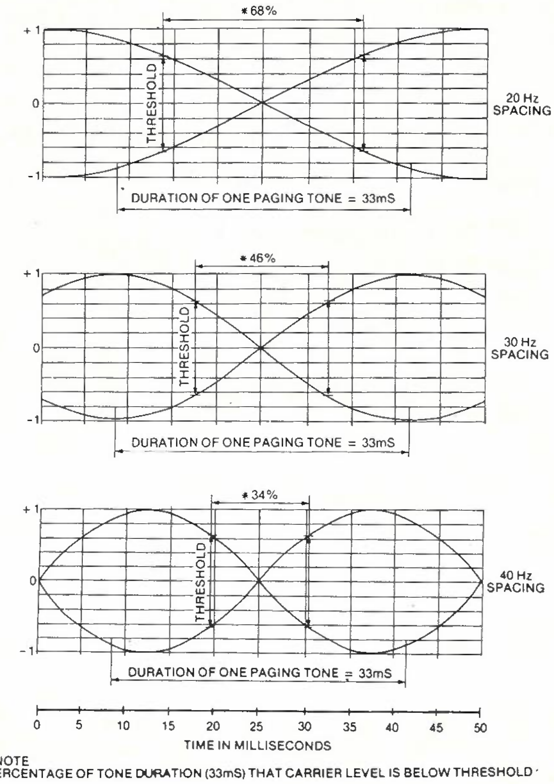


Fig. 6 — Carrier Interference.

Carrier Interference

Fig. 6 illustrates the carrier interference when a pager receives two equal level carriers from paging transmitters, at frequency spacings of 20, 30 or 40 Hz. The interference between unequal carriers is less severe. The combined carrier level varies with time from maximum to zero and for reception of a paging call some minimum carrier level is required and is shown labelled threshold. A pager will tolerate a received signal level which is below its reception threshold for up to 50 per cent of the duration of each of the five tones of its code and still receive the paging call. For 40 and 30 Hz frequency spacing between the carriers, the combined carrier is below the paging receiver threshold for less than 50 per cent of the tone duration, therefore the pager will receive calls. However, for 20 Hz spacing, or less, the received combined carrier is below threshold for more than 50 per cent of the tone duration and the pager will not receive calls. Therefore to achieve successful reception of paging calls, particularly under conditions of low received signal level, paging transmitters which may be received within one area have their frequencies maintained at controlled spacings, called frequency offsets, of not less than about 30 Hz. The effect on paging system performance of the use of various frequency offsets is shown in **Fig. 7**. Here "system performance" means the reduction in the minimum radio carrier signal level needed to receive a page when a second signal, identical except for frequency, is present. For carrier spacings of less than 30 Hz, system performance deteriorates very rapidly with reduced spacing, whereas for 30 Hz spacing, or more, it improves, when the second carrier is present, by up to 2.5 decibels. In the Melbourne and Sydney Telefinder systems, a nominal frequency offset of 80 Hz is used and is maintained at not less than 30 Hz in the presence of frequency drift in the high stability oscillators which have a temperature drift of less than ± 7.5 Hz (−30° to +60°C) and an aging drift of less than 36 Hz per annum after one year in service.

Audio Phase Delay

When two radio paging transmissions are received by a pager, the phase of the paging tone modulation on the two transmissions may differ because the transmission paths will be different. In particular the circuits from the paging switching terminal to the paging transmitters will be of different lengths as will be the radio transmission paths from each paging transmitter to a pager and therefore there will be different transmission delays. When two frequency modulated carriers having the same modulation except for a phase difference are received and the two frequencies

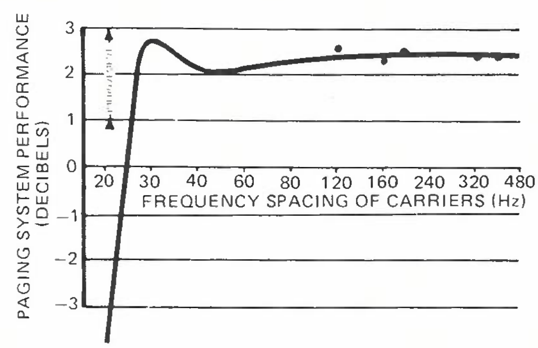


Fig. 7 — Two Carrier Performance.

are well within the receiver passband, then the signals appear to the receiver as a combined carrier. The modulation level of this combined carrier is, however, reduced relative to the modulation of the individual carriers, due to this phase difference between the modulations. **Fig. 8** shows this effect, for the case of reception of two equal level carriers. Large decreases in deviation of the received signal, relative to the individual carrier modulations, will occur as the phase difference between the carrier modulations approaches 180°. Consequently, a limit of 90° has been adopted as the maximum allowable phase difference between any two carrier modulations at a pager location anywhere within the service area and absolute delay equalisers are provided and adjusted to achieve this requirement. **Fig. 9** shows the influence of modulation deviation on pager reception threshold. For deviations between 2 and 4 KHz, which is the maximum deviation range permitted in a paging transmitter, the minimum carrier signal level needed to receive a page of "threshold" deteriorates by up to 1.5 decibels relative to the threshold at the optimum deviation. However, the effective deviation of a combined carrier received by a pager, when the individual transmitter deviations are as low as 2 KHz and the phase difference between the individual carrier modulations at the paper location is 90 degrees, may be as low as 1.4 KHz and the pager threshold would then be up to 3 decibels poorer than optimum. Under this condition an improvement of up to 2 decibels can be obtained by using a constant level amplifier in each transmitter input to hold the modulation level at 3.5 KHz deviation. Results of absolute phase delay measurements of the Melbourne Telefinder service after absolute delay equalisation are shown in **Fig. 10.** These measurements include the paging transmitter to off-air monitor paths, which are of different lengths and delays, and therefore the curves do not coincide. After allowing for these paths, the delay errors remaining are shown in **Fig. 11.** The maximum error remaining is about 20°. However, errors up to about 45° need to be accepted when the minimum available phase equaliser adjustment is 50 microseconds. Therefore of the 90° maximum allowable phase error at a pager between the modulation of any two carriers of near equal level, 45° may be allocated to all sources up to the paging transmitter outputs and 45° is then available for the difference in path lengths of the radio propagation paths from paging transmitters to any pager, which is equivalent to 19 km difference. Single channel radio bearers have been used to connect paging terminals to a group of paging transmitters so as to achieve similar group delay characteristics on the various lines and allow equalisation to be achieved with simple absolute delay equalisers.

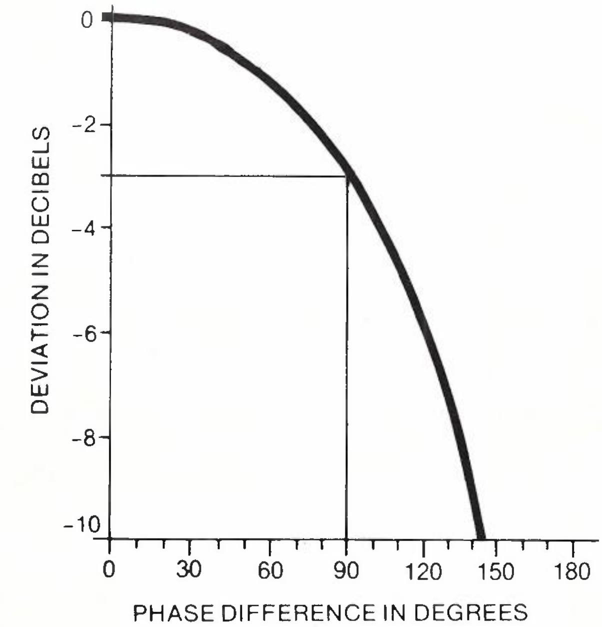


Fig. 8 — Phase Delay and Deviation.

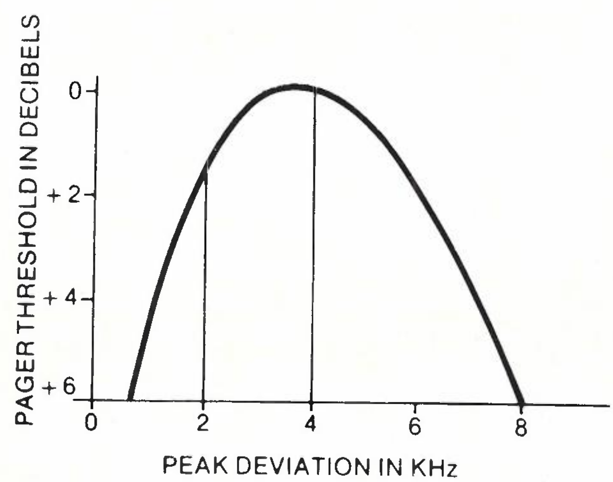


Fig. 9 — Deviation and Threshold.

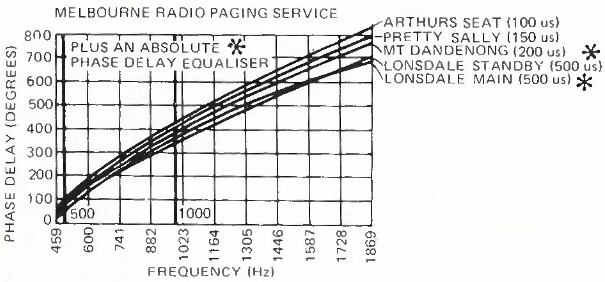
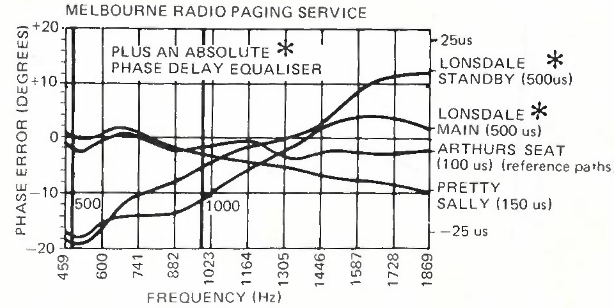


Fig. 10 — Melbourne Delays.



NOTE: THE DELAY TIMES (IN BRACKETS) ARE THE DELAYING EQUALISER VALUES CONNECTED.

Fig. 11 — Melbourne Delay Errors.

Service Area Design

Objectives

In radio paging service area design, an objective is to achieve, throughout the service area, a signal strength sufficient to provide a high probability of successful paging. In central city areas the locations served include the interior of all buildings and most basements and sub-basements. In the suburbs, service in buildings and vehicles is provided. The most convenient location to measure radio field intensities is in streets and open areas as the problems of gaining access to enclosed areas is avoided. The field intensities required, in open areas, to achieve not less than a 90 per cent call success rate in adjacent buildings are 70 decibels above 1 microvolt per meter (dBu) in the central business district of the larger capital cities, 50 dBu in cities with an insignificent number of basements and 30 dBu in suburban areas. These field intensities must be exceeded at not less than 90 per cent of locations. A margin of about 6 dB is added to these figures to allow for drops in transmitter power and modulation levels, above the alarm settings.

Predictions

To predict field intensities throughout an area, a computer programme called FIAP is available on the Telecom Australia computer system. Data includes ground heights along radial lines from the transmitter location, transmit and receive aerial heights above ground, transmitter radiated power and operating frequency. The predicted field intensity at each given ground height point is both printed and plotted. The propagation model has been derived using classical theory for free space propagation and for diffraction loss over obstacles, plus a specially derived method of dealing with foreground reflections and slope near the receiver. It applies to the special case of the receiving antenna being at a low height above ground, which is the case in radio paging.

Reliability of Coverage

To achieve reliable coverage of the required service area, standby transmitters are used at some sites. In cases where several transmitter sites are required to provide service throughout an area, advantage is taken of the overlap of the service areas of individual transmitters, to minimise decrease in coverage under conditions of failure of any one transmitter.

Proof Measurements

After completion of a paging system installation, the limits of the service area of the individual transmitters are measured to determine the amount of overlap in service areas. Also the limits of the service area of the system with all transmitters operating is measured and compared with the design objectives. To measure a radio paging service area directly, paging calls to a pager number are originated automatically at intervals. Then the paging receivers on that number are used throughout the required areas to test reception. At each location, the success or failure of reception is recorded and from these results, the limit of the service area is assessed. A practical design objective is an average call success rate of 90 per cent at the outer fringe of the service area, which provides more than 90 per cent call success overall.

COST OF THE SERVICE

Radio paging receivers may be rented, or purchased outright from a marketing distributor.

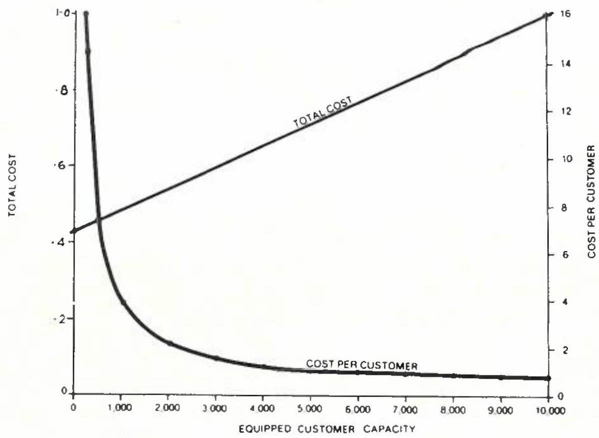


Fig. 12. — Switching Terminal Costs.

Prices depend on make and facilities and range from $17 to $18 per month for rental, including maintenance and from $350 to $400 for purchase. The paging telephone number is rented from Telecom at $45 per annum for each number. Local and trunk calls to paging numbers are charged at standard rate. A licence for each pager must be obtained from the Posts and Telecommunications Department.

EXPANSION LIMITATIONS

The Telefinder service makes use of the telephone switching network and requires a switching terminal, radio transmitters, relay sets to interface the switching terminal with the telephone network and circuits from the switching terminal to the transmitters. The cost of this equipment and of maintaining it, sets a lower limit to the population size of a paging customer district which may be served profitably. In **Fig. 12** is shown the cost of a paging switching terminal for various equipped subscriber capacities. The total cost when equipped for 10,000 customers is taken as 1 unit and when the terminal is equipped for zero customers it is about 0.44 units. The cost per customer is fairly steady at about 1 unit for the high equipped capacities but for equipped capacities of less than about 1,000 customers increases steeply.

This influence of switching terminal costs on total paging system cost, restricts terminals to cities capable of supporting a high paging customer connection rate. All of the capital cities except Canberra and Hobart meet this requirement. However, a paging service in the smaller cities may be operated from a paging switching terminal located elsewhere and if the number of paging customers connected to that terminal is sufficiently high, then the cost of serving these smaller cities is dependent mainly on the cost of providing and maintaining the radio transmitters and interconnecting circuits. One main and one standby transmitter only would usually be required in these smaller cities. Any reduction of the number of paging transmitters or of transmitter powers used in an area of low population to make a paging service to the area economically viable must reduce the size of the service area.

THE AVAILABLE MARKET

From the experience of overseas marketers, a radio paging market reaches saturation when 1 per cent of the population of the service area are paging customers. **Table 4** has been derived accordingly for cities which are expected to provide at least 500 customers at market saturation and a connection rate of at least 50 per annum.

The total market for these cities is about 97,000 subscribers, which encompasses 72 per cent of the Australian population. As the number of paging customers estimated in the table is approaching the 100,000 number capacity of the Telefinder system, provision of a second paging system will eventually be required. To meet this requirement, Telecom Australia is planning a National radio paging service for introduction probably in the mid 1980's.

TABLE 4 — PAGING MARKET

CITY	POPULATION	PAGING CUSTOMERS
SYDNEY	2,990,000	29,900
MELBOURNE	2,690,000	26,900
BRISBANE	948,000	9,480
ADELAIDE	904,000	9,040
PERTH	770,000	7,700
NEWCASTLE	372,000	3,720
WOLLONGONG	214,000	2,140
CANBERRA	193,000	1,930
HOBART	164,000	1,640
GEELONG	132,000	1,320
GOSFORD-WYONG	103,000	1,030
GOLD COAST	89,000	890
TOWNSVILLE	80,000	800
TOOWOOMBA	64,000	640
ROCKHAMPTON	50,000	500
TOTALS:	9,763,000	97,630

A NATIONAL SYSTEM

Plans

Telecom Australia is planning for the long-term growth of radio paging services. These include provision for the greater utilisation of existing equipment followed by the implementation of a system with expanded facilities. The plans include provision for:

- Home Area Service which will be a service within an area which will generally conform to the telephone local call area. Calls to these customers will be broadcast throughout the Home Area.
- Regional Services which will be a service within an area which will be an aggregation of all Home Service Areas within the region. This will generally be a State or part of a State.
- Telephone Network Interworking which will provide for each paging customer to be associated with the local charging district and its numbering scheme, although the interfacing with the paging equipment may be remote, as a few centralized radio paging terminals are expected to be used.
- Reception Reliability which will be a paging call reception average success rate of not less than 90 per cent throughout at least 90 per cent of a paging service area. In achieving this minimum, the average call success rate at most locations within a paging district will approach 100 per cent.
- Facility Options will include the single and dual address, memory, silent alert, battery saving and battery indicator currently available. In addition, facilities which include the single and multiple service area option mentioned above, a group paging facility in which a group of paging receivers may be paged by ringing one group number or paged individually by ringing individual numbers and a stored message facility which allows a paged customer to ring a number at which a message has been recorded by the person who originated the paging call are being considered. A facility for transmitting a numerical message to a pager, where it would be displayed, is possible now that Touchfone telephones are supported by some exchanges. In addition to tone coded systems, such as the one currently in service, digital systems using various bit rates and error control methods, which are now in service, will be considered. In overseas markets there is a trend towards digital systems of about 300 bits/second signalling speed, which can offer a maximum call rate and signalling error comparable with the Telefinder tone coded system. The availability of radio paging terminal equipment to service one or more types of paging receivers, is not expected to influence the choice of paging receiver as considerable flexibility in providing terminal facilities to meet any requirement is expected to be available. The most economical way of serving both city and country areas is expected to be by the use of one or two large radio paging terminals to serve all areas. The cost of small paging switching terminals for use in an area of small pager population is not expected to compare favourably with the cost of part of a larger centralized terminal and of interconnecting lines to serve such an area.

CONCLUSION

In the Telefinder network, Telecom Australia has offered a new system which is now used by more than 20,000 customers. The popular acceptance of radio paging will permit Telecom to offer the service in new areas and to offer additional optional facilities to paging customers.

Digital Transmission in National Telecommunications Networks

W. H. THURMAN, B.Sc., MIE Aust.

An overview is presented of the application in national telecommunications networks of transmission systems making use of digital techniques and of equipment to transmit signals originating in digital form over analogue transmission systems. The paper includes an outline of factors influencing present and future application together with analyses of current application including that in the Telecom Australia network.

Editorial Note.

The paper on which this article is based was presented to a Radio Research Board Symposium on Digital Communications in December, 1977. Appreciation is extended to the Radio Research Board for agreeing to publication in this journal. For the benefit of readers of this journal some of the material has been expanded.

INTRODUCTION

There is an increasing use of digital communications in national telecommunications networks both in the sense of communicating information originating in digital form and in the sense of transmission systems which employ digital techniques for the transmission of a range of telecommunication signals.

This overview concerns the use of two forms of digital transmission equipment employed in national telecommunications networks. In the first to be examined, signals originating in either analogue or digital form are conveyed but the signals in the bearer system are in digital form and the signal restoration process is one of reshaping these digital signals.

Almost universally in such systems the multiplexing process is by time division. These systems will be referred to as digital transmission systems.

The second form of digital transmission equipment examined is that which enables digitally originating signals to be conveyed either separately or in multiplexed form over analogue transmission systems by modem technology. This equipment will be referred to as digital-on-analogue transmission equipment. The distinction is indicated in **Fig. 1**.

FACTORS GOVERNING APPLICATION OF DIGITAL TRANSMISSION EQUIPMENT

Many technical advantages can be claimed for digital transmission systems. These include:

- no accumulation of noise and distortion
  - — provided regeneration is frequent enough to minimise errors.
  - — of particular benefit in a "difficult" transmission medium.
- circuits can operate at lower loss
- more suitable for data transmission
- many different types of signal can be readily conveyed on the one system
  - — no loading problems with many data or video circuits
- techniques are particularly suited to optical fibres and waveguides
- easier to remove signal redundancy with a digital encoding process
- suited to low cost micro-electronics.

Even leaving aside some technical disadvantages associated with digital transmission systems, it has to be recognised that analogue transmission systems performing to international standards have continued to benefit from technological refinements and production efficiencies to economically provide increasing circuit capacities. Thus, despite the advantages claimed for digital transmission systems, the extent to which these systems can initially make inroads into national telecommunications networks depends on their ability to provide transmission capacity at lower cost than analogue systems. Later phases of their introduction may be influenced by other factors but relative current costs will always remain an important factor.

On the other hand, digital-on-analogue transmission equipment has a field of application wherever digitally originating signals must be transmitted over analogue systems. As mentioned previously, traffic of this nature is increasing, and in a number of networks developments are in hand to multiplex such traffic by time division multiplexing (TDM) processes into high bit rate streams for transmission (Ref 1). The need for digital-on-analogue transmission equipment will continue as long as telecommunications links consisting of only analogue transmission systems exist.

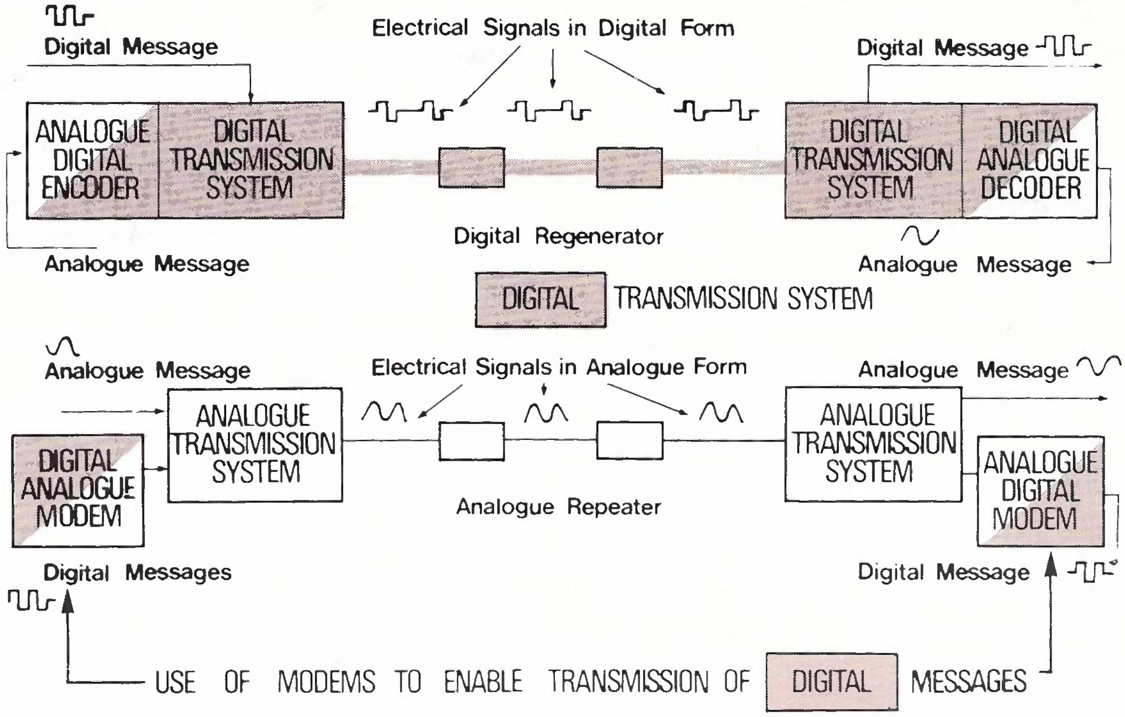


Fig. 1 — Two Forms of Digital Transmission Equipment.

ECONOMICS OF ANALOGUE AND DIGITAL TRANSMISSION SYSTEMS.

Fig. 2 illustrates the broad component costs which make up both the terminal costs and the line transmission costs for switched telephone circuits provided by carrier systems.

Influence of Signalling Costs on Terminal Costs.

A very important component of the terminal costs is the cost of relay equipment required to transmit information and line signals in association with a derived channel. In an analogue system generally only one signalling channel is associated with each voice channel, whereas in a digital transmission system at least two signalling channels are readily associated with a voice channel, thereby reducing the complexity of relay set design.

Signalling relay set costs thus progress upwards for physical circuits, circuits associated with digital transmission systems and circuits associated with analogue systems. The relativity varies from administration to ad-

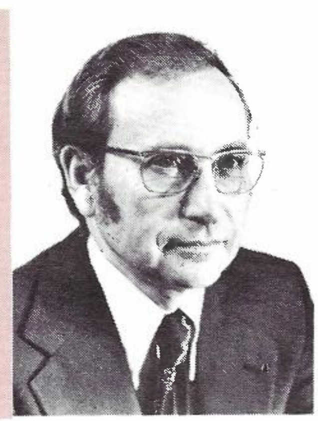
W. H. THURMAN became a Cadet Engineer with the APO in 1948 after experience as a public service clerk and war service with the RAAF.

He later occupied Engineering positions in Primary Works, District Works, Engineering Studies and Postal Workshops in the Victorian Administration. In 1956 he was involved in technical liaison and planning for the Melbourne Olympics.

Seconded as an advocate for the CPS Professional Officers Association in 1958, he took part in the industrial arbitration case leading to the 1961 and 1962 Professional Engineer judgements.

He was subsequently involved in metropolitan subscriber and junction network planning in the Victorian Administration, and since 1969 has been engaged in system planning as a Supervising Engineer in the Headquarters Transmission Planning area.

During overseas investigatory visits he has represented Australia at meetings of the CCITT G.A.S.3 Working Party.



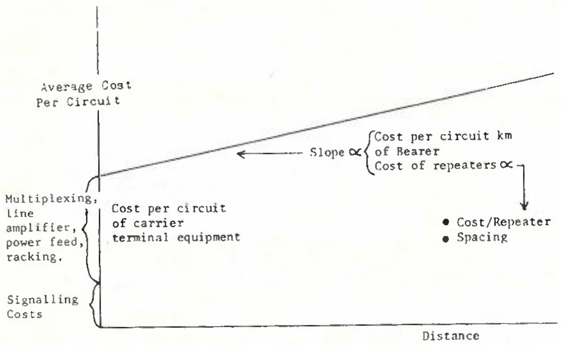


Fig. 2 — Carrier Circuit Cost Components

ministration depending on the nature of the signalling systems and equipment employed. The higher cost of signalling relay sets for circuits associated with analogue transmission systems has had a significant effect on the justification for introduction of digital transmission systems in overseas networks.

Distinction between Long-haul and Short-haul Systems.

Fig. 2 also indicates the factors which contribute to transmission cost per unit length of a circuit provided by a carrier system, represented by the slope of the graph — cost of bearer, repeaters, and the required spacing of repeaters.

This graph illustrates the obvious point that for long systems it is desirable to keep line transmission costs low, even at the expense of higher multiplexing and signalling costs. Conversely, for short distances, lower terminal costs are necessary even at the expense of higher line transmission systems costs. This is particularly necessary if the systems are to compete with passive physical circuits where the terminal costs may consist only of the signalling relay set costs. The configuration for long-haul and short-haul systems is indicated in **Fig. 3**.

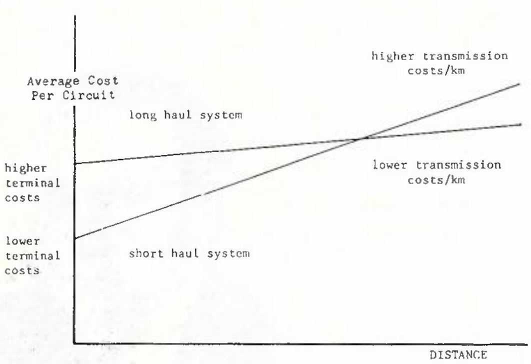


Fig. 3 — Distinction between Short Haul/Long Haul Carrier

Analogue and Digital Transmission Systems for Telephony.

Generally the costs of multiplexing and signalling equipment associated with digital systems are lower than those for analogue systems. However line transmission costs for digital transmission systems conveying PCM encoded voice, are higher than for analogue systems. This is why the greatest current application of digital transmission systems in national telecommunications networks is of short-haul systems of the PCM Primary multiplex type.

Cost of Long Transmission Paths for Telephony and other Signals.

Although the line transmission costs for voice circuits provided by digital transmission systems are greater than for analogue systems it is not possible to generalise that the position is similar for other forms of information transfer. **Fig. 4** illustrates the bearer capacity requirements of some important services under both digital and analogue transmission conditions. This table also compares the consequent capacities of a 60 MHz analogue system, the largest commercial system exploiting 2.6/9.5mm coaxial cable tubes, and a 400 Mbit/s digital transmission system exploiting the same cable with the same repeater spacing. Such a system is operational in Japan. Reference to the table will confirm that if the 60 MHz repeater costs were the same as the 400 Mbit/s regenerator costs, thus making the line transmission costs of both systems equal, the analogue system would provide both speech and programme quality television circuits more economically, and the digital transmission system would provide data and visual telephone circuits more economically. Currently for systems of these capacities, costs of digital regenerators tend to be greater than those of analogue repeaters, but not to the extent that the apparent cost advantages of digital systems for data and visual phone are lost.

The required bit rate capacities for visual information transfer listed in Figure 4 are those which might be obtained with encoding equipment if it were possible to buy

SERVICE	CIRCUIT BANDWIDTH IN ANALOGUE SYSTEM	NUMBERS OF CIRCUITS IN 60MHz ANALOGUE COAXIAL CABLE SYSTEM*	CIRCUIT BIT RATE FOR DIGITAL TRANSMISSION	NUMBERS OF CIRCUITS IN 400 MBIT/S COAXIAL CABLE SYSTEM*
Speech	4 KHz	10 800	64 Kbit/s	5 800
Data (4.8 kbit/s)	4 KHz	10 800	6.4 Kbit/s	58 000
Visual Telephone	1MHz[1] 4MHz[2]	36[x] 9[x]	6.3 Mbit/s[1] 6.3 Mbit/s[2]	60 60
TV Programme (Colour)	6MHz	6[x]	120 Mbit/s	3

* Repeater spacing of 1.5km on 2.6/9.5mm cable
x Limited by loading criteria

1. USA at time of Picturephone introduction.
2. JAPAN recently announced by NTT.

Fig. 4 — Comparison of Transmission Capacities of Analogue and Digital Systems — Digital Tranmission of Video Information with Current Levels of Redundancy Removal.

it off the shelf at the moment. However attention is being given to reducing the amount of redundant video information transmitted, by techniques practicable in conjunction with a digital encoding process. In **Fig. 5** the second column indicates rates recently postulated for conditions of redundancy removal. Columns 3 and 5 of this figure allow comparison of the resultant bearer capacities of the 400 Mbit/s and 60 MHz systems. The commercial achievement of the stated levels of redundancy removal is probably not far away. Although the resulting additional terminal costs will be significant, if these decrease in time, and if the ratio of regenerator/repeater costs reduces, the current economic advantage of analogue transmission systems to provide broadcast television relay may be lost.

SERVICE	CIRCUIT BIT RATE WITH INCREASED REDUNDANCY REMOVAL	NUMBERS OF CIRCUITS IN 400 MBIT/S SYSTEM	NUMBERS OF CIRCUITS IN 800 MBIT/S SYSTEM	NUMBERS OF CIRCUITS IN 60MHz ANALOGUE SYSTEM
Speech	64 kbit/s	5 800	11 600	10 800
Data (4.8 kbit/s)	6.4 kbit/s	58 000	116 000	10 800
Videophone				
1MHz	1.5 Mbit/s[1]	240	480	36
4MHz	6.3 Mbit/s[1]	60	120	9
Colour TV	60 Mbit/s[2]	6	12)	6
	34 Mbit/s[3]	12	24)	

1. Japanese development
2. Proven UK development for 5.5MHz PAL
3.) Japanese development for 4.2MHz NTSC
) UK development aim for 5.5MHz PAL

Fig. 5 — Comparison of Transmission Capacities of Analogue and Digital Systems — Effect of Increased Redundancy Removal, Higher Capacity Digital Systems.

For some years it had been an objective of some administrations to produce an 800 Mbit/s system. It will be seen from column 4 of **Fig. 5** that if this occurred, and if regenerator/repeater costs were comparable, it would be possible to provide voice circuits over long distances more economically by a digital system. Present European objectives however are to develop a system operating at 560 Mbit/s with regenerators spaced at the equivalent (1500 metre) separation for 60 MHz systems.

The above discussion has been restricted to cable transmission systems, whereas a large proportion of trunk telephone and television circuits are currently provided by means of microwave relay systems. The circuit capacities of digital radio systems operating in the current bands allotted to radio relay systems are much lower than those of analogue systems. This situation also poses a radio spectrum utilisation penalty which is regarded seriously. In this respect the US FCC has stringent rules which ensure that in the areas of high telecommunications density, digital radio systems are not utilised unless they provide a minimum number of circuits which is related in some way to the capacity of existing frequency division multiplexing (FDM) FM systems. There may be difficulty in accommodating even redundancy reduced TV signals on radio bearers within the currently allotted bands. There are, of course, certain isolation advantages which are claimed for digital systems when many systems converge at a physical network node. Also, because of propagation conditions digital radio systems may well be the only systems which can be exploited above 11 GHz, although at these frequencies the close spacing of repeaters will no doubt attract environmental interest.

Effect of Relative Traffic Mix.

Having noted the markedly different economic application patterns in digital and analogue systems for transmission of telephony, data, and the various forms of television transmission, it will be obvious that the relative amounts of these traffics to be carried in a network or on particular routes of the network will influence the extent that analogue or digital transmission systems have economic application.

Effect of Time Division Switching.

The introduction of time division switching (TDS) will affect the economic field of use for digital transmission systems. Indeed this development will have a critical impact on the rate of progression to completely digital networks. Although the effect of TDS can be considered from a number of viewpoints, the simplest is to consider a situation where the cost of time division switching of analogue circuits is approximately equal to the cost of space division switching. In these circumstances there would be an effective reduction in the terminal costs of two digital circuits to be switched together at a TDS exchange, there being no need for a codec in each circuit because digital/voice and voice/digital conversion at the switching location is obviated. One could also expect some savings in signalling costs for the circuits being switched in this way. It will be seen that even if the time division switching is a little more expensive than the space division switching, overall economies may still flow from such integrated switching and transmission (IST). The literature contains reports of quite complex studies on the subject which set out to quantify the situation in various networks.

Because TDS allows effective reduction in transmission system terminal costs only, the effect of integration will be much less marked on the economics of long-haul transmission. On the other hand if the favourable economic situation postulated above for TDS occurs at both ends of a metropolitan junction circuit there could be an "explosive" economic justification for digital transmission in metropolitan networks.

It had previously been put forward that TDS would prove-in economically only after significant penetration of digital transmission. The impression gained by the author in discussions in 1975 with manufacturers and overseas administrations was that the cost of TDS would reduce more quickly than the cost of digital transmission. This now seems to be supported by the belief of many switching planners that TDS will be viable more quickly than previously suspected. On the other hand, AT&T, an

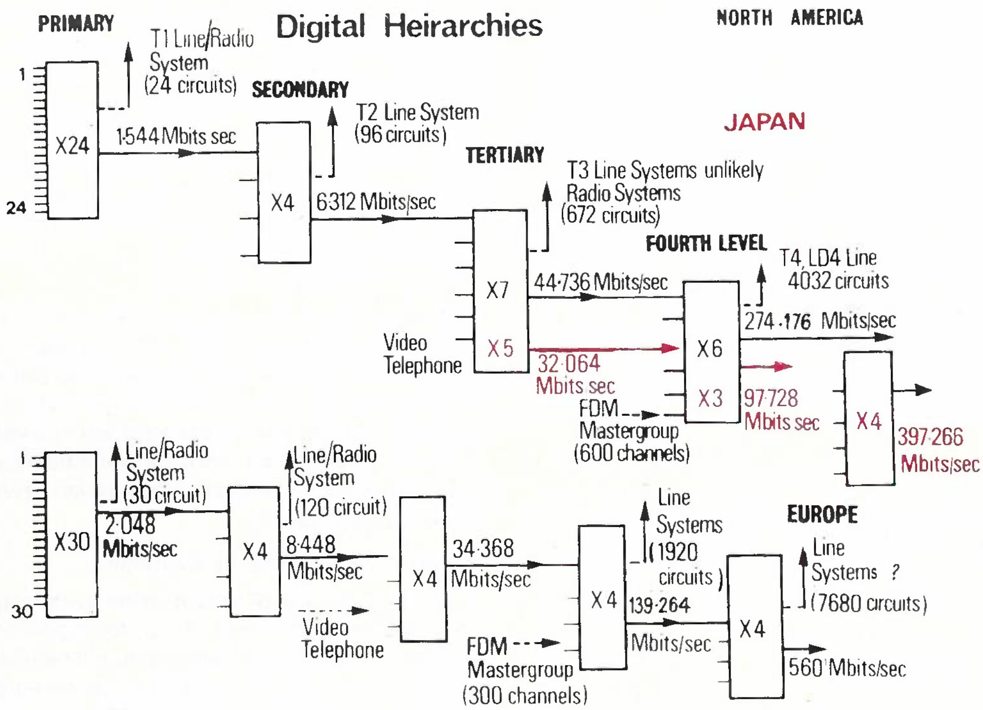


Fig. 6 — Digital Hierarchies

organisation actually making use of IST (in very large metropolitan networks and employing large TDS machines already in situ to switch analogue trunk circuits, and economic for this purpose because of their size) seems cautious about the viability of TDS for smaller switching machine sizes (Refs 2,3). This topic has been the subject of much discussion at the 1977 IEEE International Conference on communications. (Ref 4).

There are some marked differences between the use of IST in a desert situation and the exploitation of the concept in an existing network. The need to interface between an overlaid IST network and the existing space division network may mute the economic advantages in the early years of introduction.

Practical Economic Studies.

Although it is reasonable to talk in broad discussions such as those above in terms of average costs per circuit, the study of practical network incrementing by alternative transmission systems must be on the basis of present value of annual charges comparisons. Only such comparisons can take account of the effects of circuit growth rates, run-out time of existing equipment, and the different plant lives and circuit-block incrementing capabilities of alternative systems. (Refs 5,6).

DIGITAL TRANSMISSION SYSTEMS

Use of Pulse Code Modulation Technique.

With few exceptions the digital transmission systems being exploited in national telecommunications networks employ pulse code modulation (PCM). PCM is a coding technique which enables both voice signals and voice-band data modem signals to be encoded with reasonable efficiency in terms of bandwidth, and to be transmitted with comparable performance. This does not necessarily occur with other forms of digital encoding. It is important in networks where a data connection can be made over the switched network that a circuit provided by a digital transmission system be as transparent as a physical cable pair or an FDM voice circuit.

PCM System Hierarchies.

Transmission systems hierarchies are developed and standardised to facilitate interconnections between systems of different capacities within a national network or between systems in one country and another. The particular hierarchy developed must recognise the need to accommodate a variety of different services. Thus the multiplexing equipment at each level of the hierarchy can accept input signals from different services and can output them as one signal. **Fig. 6** indicates the PCM hierarchies which have evolved in North America and Europe. Initially only the primary and secondary levels of each were the subject of CCITT recommendations. Third and fourth levels of the European hierarchy are now also endorsed.

The primary building block of the former hierarchy is the T1 system, the line bit rate for which is 1.544 Mbit/s, which provides for 24 speech channels. This was dictated by the performance of North American type VF junction cables and the desirability of placing the regenerators at the locations of the loading coils in those cables.

The base of the European hierarchy is a Primary Multiplex having a line bit rate of 2.048 Mbit/s for a 30 circuit system, the configuration of which was developed by the European Conference of Posts and Telecommunications (CEPT). In addition to providing more speech channels, these systems devote greater capacity to synchronising and signalling functions.

Both hierarchies provide for encoding of voice channels into basically 64 kbit/s digital signals (eight bit encoding, sampling rate of 8000 per second), although a very limited amount of bit stealing is allowed in the North American hierarchy. (The multiplex configurations of earlier T1 systems and the United Kingdom 24 channel systems do not conform to CCITT recommendations.)

The Japanese administration has adopted the first and second levels of the hierarchy favoured in North America but prefers different third and fourth levels. A factor of 5 is favoured for the tertiary level because the FDM mastergroup employed by that administration, which would be an input to the fourth level, is smaller than that employed in North America. Although multiplexing equipments do exist and are planned above the tertiary levels in these countries they tend to be seen as being for national systems only. It is probable that intercontinental links established via satellite or cable will operate at or below the tertiary rates.

Use of Digital Transmission Systems in Overseas Inter-exchange Networks.

Digital transmission systems are being exploited in overseas networks to differing extents. Some indication of the extent and nature of application may be gained from the analyses of **Figs. 7, 8, 9 and 10,** concerning the situation in USA, Canada, UK and The Federal Republic of Germany (FRG) respectively, and in related paragraphs. Extensive use of digital transmission is being made in the three first-mentioned countries and Japan. The different applications and the backgrounds to introduction in each country are illuminating.

Discussions with network and system planners in each of these countries enable the relative present and expected levels of application in these and other countries and Australia to be reasonably understood in terms of network and other factors, which include:

- demographic dispersion, network shape and route densities,
- network switching systems and signalling relay set characteristics and costs,
- outside plant practices, cost structures and planning organisations,
- radio spectrum aspects.

What inconsistencies remain, and some will be obvious from the information presented, may be explained by different needs and/or enthusiasm to make early investment in the future technology.

System	Bit Rate Mbit/s / v.f. ccts.	Bearer System	Extent of Application/ Remarks
Primary PCM (T1)	1.544/24	v.f. cables, mid-screen cables.	Very extensive metro use - also other short haul.
		FCC rules limit bandwidths and regions of use and ensure radio systems must carry minimum number of streams eg. 2GHz, 4xT1 11GHz, 12xT1	Some use of 96 circuit systems. Also recently developed for 288 and 576 circuits.
(TIC)	3.152/48	As for T1	Introduced 1976 to over-build on T1 routes (Effectively multiplexes 2-T1's).
Secondary PCM (T2)	6.312/96	Low capacity cable	Slow growth routes. Appeared slow to gain acceptance. (Multipair cable carrier strategies less popular than coaxial)
		Limited radio application possible - see above.	Some 96-circuit systems installed.
Third Order PCM	44.736/672	Radio Systems 11GHz 1/2 streams per bearer	Developed for inter-connection of many T1 systems in short haul applications.
		Experimental optical fibre systems	Several trials in progress.
Fourth Order PCM (T4M)	274/4032	2.6/9.5mm coaxial cable	One installation New Jersey - New York. In 1975 examining possible applications, Chicago, San Francisco in c/w ESS4 t.d.s. switcher.
(DR18)		18 GHz radio systems	Special applications large cities.
(WT4)		Multi-channel wave guide application (50 channels)	Expected long haul system - 1980's.

Fig. 7 — Digital Transmission Systems — USA

System	Bit Rate Mbit/s / v.f. ccts.	Bearer System	Extent of Application/ Remarks
Primary PCM (LD1)	1.544/24	v.f. junction cables	Extensive in metropolitan and urban networks.
		Short haul radio	Some application in rural areas.
-	-	-	No intention to develop system.
Third Order PCM (DRS-8)	2x44.736/1344	8GHz microwave radio system. Suitable for overbuilding on 4GHz analogue radio system structures	Expected in service 1978 - Alternative long haul system to new cable installations for LD4 systems. Will also provide diversity on LD4 routes.
Fourth Order PCM (LD4)	274/4032	Special design of 2.6/9.5mm cable	First parts of Montreal-Ottawa-Toronto System 1975. Second system on cable 1978. Heavy first-in costs. Less economic than digital radio for medium size routes.

Fig. 8 — Digital Transmission Systems — Canada

USA

AT&T, although having greatest application of Primary PCM systems which went into service in the early 1960's and having developed high capacity digital systems, cannot yet economically justify use of digital transmission systems in the long-haul network. Great optimism has been expressed within AT&T that SSB AM microwave technology can be successfully exploited to effectively double the already high capacity of the existing analogue long-haul radio relay network (Ref 7,8). In addition AT&T are about to exploit a super 60 MHz analogue system having 20% additional capacity. These developments could postpone any transition to a digital long-haul network for many years.

Canada

In marked contrast, Bell Canada and associated companies have independently developed and installed a long-haul digital coaxial cable system between Montreal, Ottawa and Toronto, the first parts of which went into service in 1975. The decision to develop this system which uses a special coaxial cable was taken following studies in Bell Canada and the associated research arm, Bell Northern Research. These studies considered the long term network requirement of various services, and the potential changes in cost relativities of analogue and digital systems. The studies, which assumed a very high projected requirement for digital data transmission, showed that attainment was possible without apparent cost penalty. The second working system will be added to this cable between Ottawa - Toronto in 1978 and extended to Montreal in 1980.

Future development of the long-haul trunk network will be by digital radio systems employing two third-order digital streams in the 8 GHz band, a band not available to operators in USA. The only new analogue systems installed will exploit remaining capacities of existing systems. Digital switching systems are to be installed in 1979.

United Kingdom

The United Kingdom has also embarked steadfastly on the path to a completely digital network, following a Task Force Study which culminated in a recommendation in 1971 to proceed in stages in such a direction.

The fourth-order system indicated in **Fig. 9** is a system developed for application on the extensive network of small diameter coaxial cables installed in conduits in the UK trunk system. Network application is expected in 1978. The 12 MHz systems which are currently exploited on these cables provide for 2700 circuits whereas the 120 Mbit/s systems provide only 1620 circuits at the same repeater spacing. However much shorter average system lengths are involved than in Australia; thus the transmission cost penalty of the loss of 40% of circuits on a bearer is much lower. Also significant savings are to be achieved in the UK environment by the use of signalling systems having much lower costs than those used with the BPO's FDM analogue systems.

The developments in respect of second order PCM in both cable and radio systems will extend and add to the reliability of the cable network based on 120 Mbit/s systems. Developments are also proceeding to stretch the 120 Mbit/s system to 140 Mbit/s and to produce a 560 Mbit/s fifth-order system.

Federal Republic of Germany

In FRG, which is a country with a very well developed FDM coaxial cable and radio network in which 60 MHz analogue systems are currently being introduced, there appears to be no immediate intention to introduce digital transmission systems other than primary multiplex systems. Field trials of second-order PCM systems for cable and radio application, and development of special cables to deal with digital signals above primary level are nevertheless in hand.

Other Countries.

Although not detailed in separate tables it may be helpful to indicate the position concerning digital systems in Japan. This country has made considerable use of primary PCM systems, some use of secondary PCM systems and, although making use of 60 MHz analogue systems, is also employing 100 Mbit/s and 400 Mbit/s systems.

In other countries the exploitation of digital transmission seems mainly to be confined to the short primary multiplex cable systems, although development of secondary and tertiary systems and special bearer plant is taking place.

System	Bit Rate (Mbit/s) / v.f. ccts.	Bearer System	Extent of Application/ Remarks
Primary PCM	1.536/24 (non CCITT)	v.f. junction cables	Very extensive in local networks.
	2.048/30 (CCITT Rec.732)	v.f. junction cables	CCITT system. First installations 1977.
Secondary PCM	8.448/120	Existing trunk carrier cables. Microwave radio systems (11GHz).	Triangulation & duplication of digital network in conjunction with high capacity cables. 1980.
Third Order PCM	34.368/480	-	-
Fourth Order PCM	120/1620	Small diameter (1.2/4.4mm) coaxial cable. (Same repeater spacing as 12MHz)	120 Mbit/s tested 1975. Limited network application expected from 1978.
	140/1920	As above	"Stretched" version under examination.
	140/1920	Radio system	Under development.
Fifth Order PCM	560/7680	Small diameter (1.2/4.4mm) coaxial cable (half 12MHz repeater spacing) and/or 2.6/9.5mm coaxial cable.	Development contracts in hand.

Fig. 9 — Digital Transmission Systems — United Kingdom

System	Bit Rate (Mbit/s) / v.f. ccts.	Bearer System	Extent of Application/ Remarks
Primary PCM	2.048/30	v.f. junction cables	150 in service.1975 Expected 200 per year from 1976.
Secondary PCM	8.448/120	New symmetrical cables with screened units. (Repeaters at 4km).	Field trials 1975
	2 x 8.448/240	15GHz radio relay (maximum hop length approx. 25km).	Field trials 1975
Third Order PCM	34.368/480	New symmetrical cables with screened units.	Under consideration 1975.

Fig. 10 — Digital Transmission Systems — Federal Republic of Germany

Optical Fibre Transmission Systems in Overseas Inter-exchange Networks.

Optical fibre transmission systems being developed for inter-exchange application will exploit digital transmission. Some systems have been developed to provide a transmission medium for the lower levels of the hierarchies, however most effort seems to be directed to the third and higher levels. In this way the average bearer cost per circuit is reduced. Trials are in progress.

Digital Transmission Systems in Overseas Local Networks.

Some network application is being made of Primary PCM systems in subscriber networks in USA and Japan, generally in conjunction with an integral concentrator facility, to serve groups of subscribers a considerable distance away from an exchange.

Baseband digital transmission systems exist and others are under development (Ref 9) to transmit digital data on a point to point basis or from subscribers premises to collection points for either multiplexing and application to higher capacity digital transmission systems, or for separate or multiplexed transmission by modem technology over analogue systems.

DIGITAL-ON-ANALOGUE TRANSMISSION EQUIPMENT.

As digitally originating traffic grows, and until digital transmission systems are available on all routes there will be an increasing amount of digital traffic carried over analogue systems by means of modem technology. As economies arise from the time division multiplexing of this traffic, the trend will be to reduce the extent of voice band modem traffic circuits and to encourage the use of a smaller number of higher capacity digital-on-analogue paths.

Clearly the most straightforward approach is to exploit the existing analogue systems without change to the existing FDM hierarchy by making use of modems which accept as an input a digital stream, and have as an output an analogue signal appropriate to a single band of the FDM hierarchy. **Fig. 11** indicates how commercially available modems accepting different bit rates may be fed directly into the combining equipment of the FDM hierarchy. This process is referred to as data in-voice (DIV). **Fig. 12** indicates DIV modems available with outputs in single bands of the FDM hierarchy. Development is proceeding of modems which have outputs in these bands and which accept higher bit rates.

For transition interconnection of digital and analogue networks it would be desirable to have modems which accept bit rates of the various levels of the PCM hierarchy and have outputs appropriate to single bands of the FDM hierarchy. CCITT has endorsed this approach and has suggested two suitable forms for examination (6.312 Kbit/s over one FDM master group, 8,448 Kbit/s over one FDM supermaster group). These tend to be

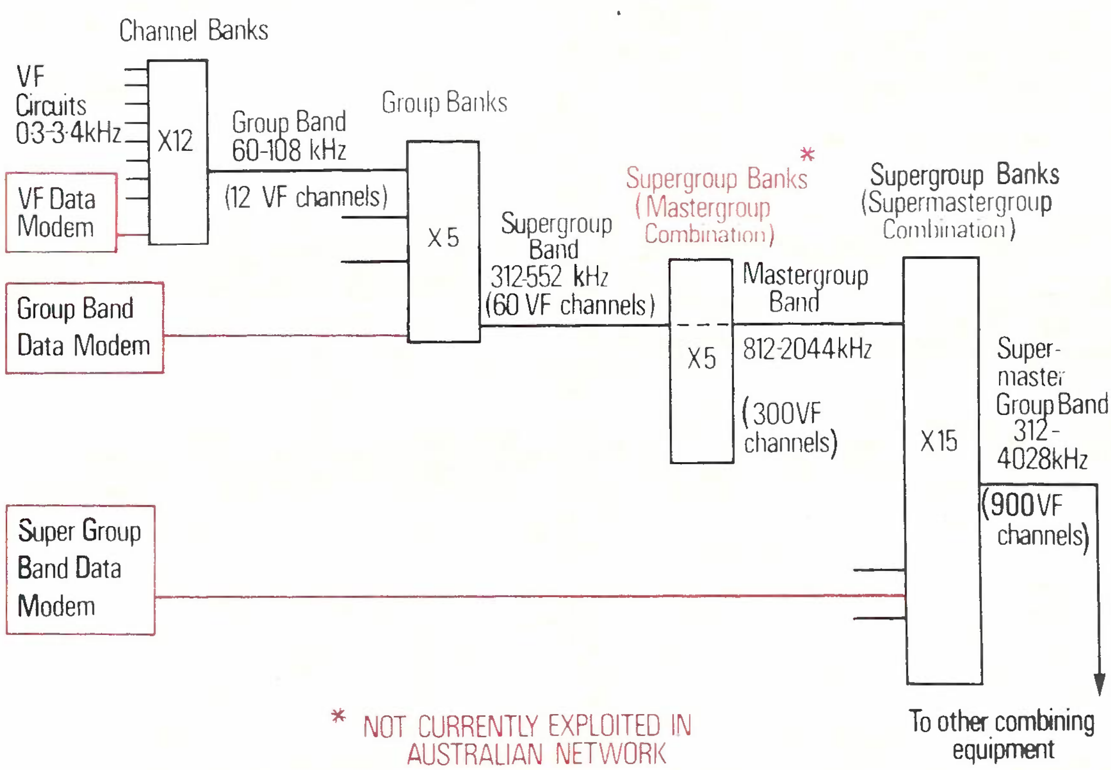


Fig. 11 — Some DIV Modems and the FDM Hierarchy.

Band	Input Bit Rate (kbit/s)	FDM Band Displaced	Bit/s Per Hz	Remarks
Voice	4.8	300-3400Hz (3.1KHz)	1.5	In Service, Telecom
	9.6		3.0	Recently in Service, Telecom
Group	24	60-108KHz (48KHz)	0.5	
	36		0.75	
	48		1.0	In Service, Telecom
	64		1.3	
	72		1.5	
Supergroup	240	312-552KHz (240KHz)	1.0	In Service, Facsimile Telecom

Fig. 12 — Available Modems for Digital Transmission with Outputs in Single FDM Bands — High Speed Modem for Voice - Band, and Modems for other Bands

Band Designation	Input Bit Rate (Kbit/s)	FDM Band Displaced	Bit/s Per Hz	Remarks
Single Supergroup	704	312-552 KHz (240 KHz)	2.9	Field Test, France
Two Contiguous Supergroups	1 544	1060-1548KHz (488 KHz)	3.2	In Service, Japan
Three Contiguous Supergroups	2 048	- (736 kHz)	2.8	Earlier BPO Study
Mastergroup	6 312	812-2044 KHz (1232 KHz)	5.1	Developed, Japan

Fig. 13 — Modems suitable for Transmission of Higher Capacity Bit Streams

DIV	Data (or digital) in voice	Digital streams within FDM hierarchy.
DUV	Data (or digital) under voice	Digital streams injected onto an analogue bearer system at a lower frequency than the FDM multiplex signal.
DOV DAV	Data (or digital) over voice Data (or digital) above voice	Digital streams injected onto an analogue bearer system at a higher frequency than the FDM multiplex signal.
DAVID	Data (or digital) above video	Digital streams injected onto an analogue bearer system at a higher frequency than a television signal.

Fig. 14 — Forms of Digital on Analogue Transmission

Description	Capacity	Major Utilization	Status/Remarks
DUV for Microwave Radio	1.544Mbit/s	Digital Data Network	Operational
DAVID for Microwave Radio	1.544Mbit/s	?	Developed
Modem for U.S. Mastergroup (2450KHz)	13Mbit/s	Developed to carry two visual telephone circuits (coaxial cable systems)	Developed
Alternative modulation system for microwave radio bearer (20MHz)	20Mbit/s	Developed to carry three visual telephone circuits (radio systems)	Developed. Regeneration carried out at some repeaters
Alternative modulation system for microwave radio bearer (30MHz)	19.2Mbit/s	Developed for DATRAN digital data network	Developed. Regeneration carried out at all repeaters

Fig. 15 — High Capacity Digital on Analogue Equipment — USA

large for some likely applications, but there are difficulties with respect to modems dealing with lower bit rates. Such modems interconnecting single levels of both PCM and FDM hierarchies are either not currently achievable or exploit the FDM bandwidth inefficiently. CCITT has deferred consideration of modems accepting PCM hierarchy bit rates with outputs spanning two or more FDM bands, or modems with outputs in single bands of the FDM hierarchy but accepting bit rates which are fractions of the PCM hierarchy bit rates. Modems under development in each of these categories are included in **Fig. 13.**

With some types of analogue transmission systems it is possible to inject digital signals which modulate a carrier and occupy a band of frequencies either below or above the spectrum occupied by the FDM multiplexed signals being carried on that system. For example, in the case of FDM/FM radio relay systems carrying certain types of FDM multiplex signals, digital information can be injected into the modulating signal at frequencies below the FDM multiplex signal. This is known as "data (or digital) under voice" and abbreviated "DUV".

It is also possible to inject digital streams on to the analogue bearer at frequencies above either an FDM voice multiplex signal, or a video signal. The appropriate abbreviations are indicated in **Fig. 14.**

The ability to exploit any or all of the techniques other than DIV is very much dependent on the type of analogue transmission systems employed in the particular national network and possibly on particular routes within that network. CCITT has given priority to consideration of DIV modems.

Developments in Overseas Networks.

The situation in the USA and Canada concerning digital-on-analogue transmission equipment is depicted in **Figs. 15 and 16.**

USA

As could be expected, with a completely analogue long-haul network and large amounts of concentrated digital data traffic to move around it, AT&T have developed for their digital data network, a DUV system which can be associated with each of their high capacity

Description	Capacity	Major Utilisation	Status
DUV for microwave radio	1.544Mbit/s	Trans Canada Data Route Network	Operational
DAV for microwave radio	1.544Mbit/s	Studied for use in conjunction with Canadian Pacific FM/FDM microwave relay system	Computer study showed feasible
DAVID for microwave radio	1.544Mbit/s	As above	Computer study showed feasible

Fig. 16 — High Capacity Digital on Analogue Equipment — Canada

FDM/FM radio bearers. This system carries the equivalent of a T1 system bit stream (1.544 Mbit/s). The influence of AT&T's previously projected Picturephone network can be seen in the availability of 13 Mbit/s and 20 Mbit/s modems for operation over analogue coaxial cable and FDM/FM radio systems respectively.

Canada

Bell Northern Research and Bell Canada have developed a different form of DUV system to be used in conjunction with their microwave radio relay systems. RCA engineers have executed studies confirming the practicability of DAV and DAVID systems for use in conjunction with the microwave radio relay systems operated by Canadian Pacific.

United Kingdom.

This country was developing a 2048 Mbit/s DIV Modem for operation in a 720 KHz band spanning 3 supergroups. This was to be used during the analogue/digital transition phase and to provide streams for a projected digital data network. It is understood that the latter has been deferred and the modem development may have been deferred.

FRG.

This country has a unique solution for providing the links of a digital data network. Linking the main centres of the German network is a dual cable network consisting of single standard coaxial cable tubes and plastic insulated symmetric pairs which currently carry 120-circuit FDM systems. It is planned to use the phantoms of these circuits to convey 2.048 Mbit/s streams around the network. The signals will be translated to within the 1 to 3 MHz band to avoid interference with the 120-circuit FDM signals.

DIGITAL TRANSMISSION IN THE AUSTRALIAN NATIONAL TELECOMMUNICATION NETWORK

Introduction to Digital Transmission Systems.

Telecom Australia, although fully aware of potential advantages of digital transmission systems is not at the moment committed to their introduction into any sectors of the network until the systems are proved economical in that sector. However the matter is kept under continuing review, and a decision to introiduce Primary PCM systems has been made. At the moment a task force is examining the desirable tandem switching structure of future metropolitan networks. The potential application of time division switching and consequently a form of IST in these networks will be examined.

Primary Multiplex PCM Systems.

Installation of Primary PCM cable systems as standard network systems is expected to commence in 1978. This follows an early 1976 engineering policy decision which among other factors took into account that sufficient savings would accrue to justify network application at about that time. Trial systems have been installed since 1969.

In the metropolitan networks of Australia, 95% of the interexchange circuits are provided by two wire physical circuits. The remaining 5% are provided in part by some small capacity FDM systems, and a much larger proportion of the 5% are provided on FDM broadband systems linking the network hub to the larger ELSA areas. These networks will provide the first economic application for PCM systems — mainly at the expense of circuits which would otherwise be provided by separate physical pairs (Ref. 6).

Application is expected to be in all capital cities. Some inroads will be made into the utilisation of FDM systems in these networks, but for the time being at least such systems will continue to be exploited in circumstances where they remain the most economic alternative.

System Choice, Hierarchy Adopted.

Following the decision to adopt Primary PCM systems as standard network systems a decision was taken late in 1976 concerning which of the two CCITT endorsed primary multiplex systems should be selected.

The more important factors considered were:

- Total systems costs
- Line system costs
- Ease of engineering and "penetration" in 0.64mm v.f. junction cables
- Sources of supply
- Attractiveness in respect to time division switching
- Ease of interfacing with digital data streams
- Distortiton, synchronisation and transmission characteristics
- Ease with which related digital-on-analogue equipment can be engineered
- Service characteristics
- Application to radio systems
- Hierarchical implications

The system with multiplex arrangements meeting Recommendation 732 was adopted. Some of the important parameters of the systems are listed in **Fig. 17.**

Main Characteristics	CCITT Rec. 733	CCITT Rec. 732
No. of v.f. Circuits	24	30
No. of Time Slots	24	32
Line System Bit Rate	1.544Mbit/s	2.048Mbit/s
Nature of Line Code	A.M.I.	HDB3
Compression Law	μ = 255 (15 segment)	A = 87.6 (13 segment)
Channel Associated Signalling Capability per v.f. channel	1,333Kbit/s	2,000Kbit/s
Common Channel Signal Capability	4Kbit/s	64Kbit/s

Fig. 17 — PCM Primary Multiplex Systems

Digital Systems other than Primary PCM. Factors Affecting Rate of Progression to a Digital Network.

Although the introduction of Primary PCM systems into the Telecom Australia network has been justified only comparatively recently, the developments taking place with respect to TDS and optical fibre transmission emphasise the need to maintain the process of continuing review concerning the potential for exploiting other digital transmission systems. Such a review cannot solely be a "bottom up" one in terms of potential economic application of particular systems in the separate trunk, junction, and subscriber networks but must also embrace a "top down" approach. The position with both of the aforementioned catalysts is not yet sufficiently advanced to enable any current review to yield a firm plan for the future. However aspects flowing from a sector-by-sector examination which would be taken into account in developing firm plans include the following:

- In metropolitan networks scope exists for economic application of higher level digital transmission systems. Whilst both 400 Mbit/s and 140 Mbit/s systems could be construed as commercially available and could be exploited as alternatives to the existing 12 MHz broadband FDM systems, only the latter digital system is within the adopted hierarchy.
- In the trunk network because of the smaller route dimensions, the nature of traffic mixes are important considerations. A traffic mix on the dense Melbourne-Sydney route postulated for 1995 with resultant system quantities is depicted in **Fig. 18.** Although this is a simplistic approach based on coaxial cable technology only, the result is of interest. It is seen that a stronger incentive to introduce digital transmission to the trunk network would arise after commercial availability of equipment providing redundancy removal from programme television signals, and/or an upsurge in demand for visual telephone facilities. The expected upsurge in data traffic is insufficient of itself to justify the provision of digital transmission systems.
- In the subscriber networks, partly because of low spatial subscriber densities and existing exchange layouts it could be many years before digital transmission systems operating at bit rates above those required for data transmission are employed in any quantity. However digital carrier/concentrator systems might find application as alternatives to small exchanges in some non urban areas.

Aspects to be taken into account in the "top down" overall network approach, will include —

- the relative investments in transmission plant in each of the three network sectors.
- the relative circuit quantities in each of these networks
- the interrelationship of these networks with each other, and
- the influence of TDS.

Type of Circuit	Telephone Circuits or Equivalent Telephone Circuits in Analogue	No. of 60MHz Analogue Systems	No. of 400 Mbit/s Digital Systems: Without Addit. Redundancy Removal	With Addit. Redundancy Removal
Switched Voice	18 000	1.7	3.0	3.0
Other Voice	3 500	0.3	0.6	0.6
Data	4 000	0.4	0.05	0.05
TV) PROG 12)) EDUC 6)) CONF 6)	43 200	4.0	7.2[1]	2.4[2]
(1800 Voice Circuits)		6.4	10.85	6.05
1MHz Visual Phone (180 or 1800 i.e. 1% or 10% of switched voice circuits)	54000/540 000	5.0/50	3.0[3]/30[3]	0.75[4]/7.5[4]
		11.4/56.4	11.85/40.85	6.8/13.55

1. @ 120 Mbit/s per circuit
2. @ 40 Mbit/s per circuit
3. @ 6 Mbit/s per circuit
4. @ 1.5 Mbit/s per circuit

Fig. 18 — Possible Traffic Mix Melbourne-Sydney Route 1995 — Numbers of Analogue or Digital Systems

Digital-on-Analogue Transmission Equipment

Digital information has been transmitted over single vf and group bands of the FDM hierarchy for many years. It has been resolved that to transmit higher capacity digital streams, earliest attention will be given to the use of DIV modems. The situation concerning exploitation of DUV and DOV facilities in Australia is not as attractive as it might appear from the existence of such systems in other networks — particularly the North American situation relating to DUV systems for FDM-FM radio relay systems. The frequency bands of the FDM multiplexes employed in North American and Australian networks are different. Systems in the Australian networks have much less spectrum in which to insert digital information than is available in the Northern American systems. Comparison of **Figs. 19a, 19b, 19c** will illustrate this situation.

Japanese manufacturers have developed a system to transmit a 1.544 Mbit/s stream under the speech multiplex band of 1800 and 2700 voice circuit FDM/FM radio relay sytems, similar to those employed in Australia. Telecom Australia's opting for the 2.048 Mbit/s primary level makes this of limited interest, transmission of the latter stream in the same band being a much more demanding process.

Exploitation in Australia of a DAVID 2.048 Mbit/s system which is compatible with Australian microwave TV radio relay links may be possible. Although some DOV systems have been developed in Europe for operation with 12 MHz coaxial cable systems it is not believed that these would operate successfully on equipment installed in the Telecom Australia network. However the recent development of 18 MHz coaxial cable repeaters to give satisfactory operation at the nominal 12 MHz (4.5km) spacing, should allow streams of at least 8 Mbit/s to be added to existing coaxial cable systems.

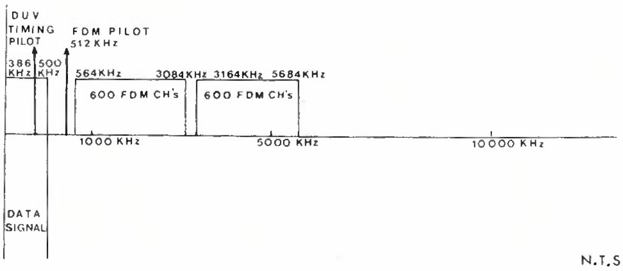


Fig. 19(a) — ATT DUV (Data Under Voice)

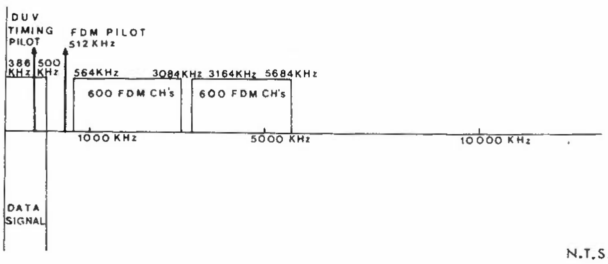


Fig. 19(b) — Telecom Australia 960 & 1200 Channel Radio Systems

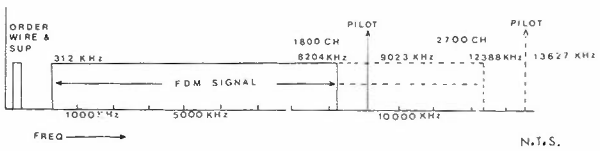


Fig. 19(c) — Telecom Australia 1800 & 2700 Channel Radio Systems

Summary Concerning Digital Transmission in Telecom Australia Networks

Digital transmission by means of ditigal-on-analogue transmission facilities has been in operation in the Telecom Australia network for many years. The potential application of digital transmission systems has been under review for at least 10 years, and trial systems have been in operation for about 7 years. Primary PCM systems will be installed as standard network components for short-haul application from 1978.

Although it has not yet been determined when other digital transmission systems will be economic in the Australian network, a process of continuing review operates. Current studies concerning the use of optical fibre bearer systems and alternative schemes for tandem switching in metropolitan networks will be components of this review and important inputs in the subsequent development of formal plans.

In the meantime signals originating in digital form will continue to be transmitted over analogue transmission systems. It is likely that the numbers and capacities of modems for this purpose will increase to enable trans mission of streams of time division multiplexed data traffic.

REFERENCES

1. Gannon, D. J. and McKenzie, A. J.; "Digital Data Network Overview," presented to Radio Research Board Symposium Dec. 77.
2. FORUM correspondence from Irwin Dorros, Bell Laboratories, Holmdel, IEE Spectrum, May, 1977, p.10.
3. Private discussion with A.T. & T.
4. Meier, A. R.; "ICC '77 Reveals Advances in Communications Technology," Telephony, July 4, 1977, p.25.
5. Collier, M.E.; "Economic Planning of Transmission Systems," Electrical Communication Vol. 48, Nos. 1 & 2, pp. 189-192, 1973.
6. Carroll, D. P. and Thurman, W. H.; "Factors affecting the application of Primary Pulse Code Modulation (PCM) Systems in Telecom Australia Metropolitan Junction Networks," presented to Radio Research Board Symposium, Dec. 77.
7. Private discussion with A.T. & T.
8. Meier, A. R.; "ICC '77 Reveals Advances in Communications Technology," Telephony, July 4, 1977 p.25.
9. Smith, B. M.; "A Short Overview of Baseband Digital Data Transmission in the Telephone Network," presented to Radio Research Board Symposium Dec. 77.

In Brief

NEW FIRST IN TELECOMMUNICATIONS LINKS MANGANESE ISLAND WITH MAINLAND

Australia's first low-power tropospheric radio link will soon be installed to link Groote Eylandt, in the Gulf of Carpentaria, with the mainland.

Systems of this type will open up new possibilities for reliable trunk line telephone communications in remote parts of Australia and other countries.

Designed and built by Amalgamated Wireless (Australasia) Limited, Australia's largest electronics company, which pioneered many of this country's most important communications developments, the system is expected to be in operation within a few months.

Groote Eylandt, a 2000 sq. km island 48 km from the east coast of Arnhem Land, has the largest single manganese mine in Australia, operated by the Groote Eylandt Mining Company, a subsidiary of the Broken Hill Proprietary Company Limited. The island's total population is about 2200.

Opened in 1966, Groote Eylandt has had to rely on HF (high frequency) radio for communications with the mainland. This service has often been restricted by adverse atmospheric conditions.

The Groote Eylandt tropospheric scatter radio system will connect into Telecom's national telephone network at Gove. Gove is linked to Darwin by an existing Telecom high powered 120 channel tropospheric scatter radio system.

Tropospheric radio systems are used to a limited extent throughout the world for providing a small number of telephone circuits over distances of one hundred to a few hundred kilometres. Their operation depends on the troposphere reflecting or scattering the radio beam from a transmitter to a distant receiver. The troposphere is the layer of the atmosphere closest to the earth which extends upward for distances of 10 to 15 km.

Tropospheric communications can thus be used to eliminate the need for line-of-sight transmissions. Normally, they require extremely powerful transmitters and very sensitive receiving equipment, such as are used in Telecom's mainland systems.

AWA designed a system to meet the special needs of Groote Eylandt. High power was not necessary because of the smaller number of telephone and telex services called for by the island's population. Their system will link with the Telecom system in the Northern Territory and thus with the rest of Australia.

The AWA tropospheric radio system will provide a 24-hour seven day a week service, and will provide 12 channels for speech or data.

The system incorporated quadruple diversity. On the island will be two seven metre dish antennae, 30m apart, each with matching transmitters and receivers.

Each unit will operate on a slightly different frequency, to guard against fading. This equipment will be duplicated on the mainland where it will connect with the Telecom trunk system.

The concept of a low-powered tropospheric system which needs no line-of-sight radio paths, promises communications possibilities for remote townships, mining sites, oil rigs, and other isolated locations where telephones are vital.

Grade of Service and Performance Monitoring of Traffic in the Australian Telecommunications System

J.P. FARR, B.E., B.Ec., M.A.Sc., C.Eng., M.I.E.E.

This article outlines the measurement techniques used by Telecom to assess grade of service and switching loss performance in the telecommunications system. It includes methods of undertaking traffic recording on final choice circuit groups, service assessment of live traffic, artificial traffic call generation, automatic monitoring of live traffic and the analysis of subscriber trouble reports.

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INTRODUCTION

Within Australia, public telecommunications services are provided and operated by Telecom Australia, whilst services to other countries are the responsibility of the Overseas Telecommunications Commission. This paper is limited to a description of the measurement practices followed by Telecom Australia.

In common with other administrations, Telecom Australia makes regular measurements on its telephone and telex systems in order to compare the observed performance with standards. Many different aspects of service are assessed, including for example, effective call rate, plant congestion, switching loss (i.e. calls unsuccessful due to equipment defects), delays in establishing a connection, incidence of faults reported by subscribers, crosstalk, transmission loss, etc. However, so as to keep within the confines indicated by the title of this Session of the Symposium, this paper will only cover the measurement techniques used to assess:

a. the Grade of Service, and

b. Switching Loss Performance

of traffic in the Australian national telecommunications system.

The opening section of the paper outlines an adaptive approach aimed at obtaining a balance between the costs of measurements and the value of the potential benefits. The measurement techniques covered in the main body of the paper relate to:

- Traffic recordings on final choice circuit groups,
- Manual service assessment of live traffic,
- Artificial test call generators,
- Automatic monitoring of live traffic, and
- Automatic marker disturbance recording.

Other aspects dealt with include:

- The role of analysis of technical assistance (trouble) reports from users in assessing the performance of telecommunications networks,
- The effect of traffic overload on grade of service, and
- International implications of unsatisfactory grade of service.

SPECIAL TERMINOLOGY

ARE-11, ARF, ARM, METACONTA 10C

Types of common control (crossbar or SPC) exchanges mentioned in this paper.

CALL CONGESTION LOSS (or CALL BLOCKING)

The ratio of the number of first call attempts which were unsuccessful (owing to the unavailability of suitable connecting paths) to the total number of first call attempts during the same period of time.

DISPERSION

Traffic dispersion is the spread of an exchange's originating or incoming traffic offered to the different destinations.

GRADE OF SERVICE (GOS)

Busy signal systems:

- The GOS is the probability of not being able to set up a connection to a chosen route or destination because of insufficient circuits.
- The network GOS is the average of the nominal terminal exchange-to-terminal exchange

grades of service over the whole network, weighted in proportion to the traffic flowing between the various pairs of terminals.

- The overall GOS is the total probability of call loss (from origin to destination) due to congestion at any switching stage involved in the connection.

Delay systems:

- GOS is expressed as the probability of a call being delayed by more than some specified time; sometimes average delay on all calls is used as a measure of delay GOS.

NOTE 1—Strictly speaking, Call Congestion Loss is a measurable quantity, whilst GOS is a design concept dependent upon specified assumptions about the traffic and switching system. The two terms are often used interchangeably.

NOTE 2—The French term 'qualité de service' includes calls which fail due to insufficient circuits and other factors, and is therefore not equivalent to the term 'grade of service'. The French equivalent of GOS is probably 'qualité d'écoulement du trafic'.

MULTIFREQUENCY CODE SIGNALLING (MFC)

A method of forward and revertive, compelled sequence signalling used for calls handled by crossbar and SPC exchanges.

NETWORK PERFORMANCE AND ANALYSIS CENTRE (NPAC)

An operational centre which gathers, records, analyses and distributes information about the performance of a telecommunications network.

OCCUPANCY

The mean traffic intensity, over a period of time, on a circuit or group of circuits.

SPC

Stored Program Control.

STD

Subscriber Trunk Dialling (equivalent to Direct Distance Dialling — DDD).

SWITCHING LOSS

The proportion of calls, in a network, or a part of it, which are unsuccessful due to faulty performance of the switching equipment.

TA

Request for Technical Assistance from a user whose call attempt has been unsuccessful.

TRUNK CALL

A call which is charged at more than the unit-fee rate.

ADAPTIVE ADJUSTMENT OF THE MEASUREMENT PROGRAMME

The objective of GOS and Switching Loss Performance measurements are to ensure that adequate quantities of switching equipment and speech (or data) circuits are provided to carry the offered traffic at the desired GOS and to ensure that this equipment is being maintained in a manner which gives satisfactory results to the users. Only a very small sample of all traffic is assessed, but even so, the volumes of data involved are very large and the costs of taking the measurements, and then processing and analysing the results represent a significant overhead.

Consider then these objectives and the possible benefits which may be obtained as a consequence of the measurements. I would suggest that the amount of resources devoted to a measurement programme should be adjusted from time-to-time in an ADAPTIVE manner so that the effort expended is correlated to the difference between the actual and the desired performance of the equipment or network. This approach reflects the economic balance which should be maintained between the costs of measurements and the potential benefits to be gained from applying the measurement results. In exchanges or networks which have a performance which causes dissatisfaction to many users, the users will lodge an inflated level of complaints and the administration will incur high costs in investigating the complaints and initiating ad hoc corrective action. In addition, revenue may be lost since the poor performance of the communication facilities will act as a deterrent to users. Some users will either forego potential calls or utilise alternative means of communication. Thus, an improvement in the performance to a generally acceptable level will reduce the administration's operating costs per service, prevent loss of revenue, and may (in some instances) generate extra revenue.

As an example, consider an exchange or network in which congestion in the switching equipment or junction routes greatly exceeds the administration's standard (i.e. target). It would be appropriate to expend a relatively high level of measurement resources aimed at determining the equipments which are deficient or faulty. Explicit corrective action could then be initiated. We would utilise appropriate GOS measurement techniques to monitor the reduction in congestion which should result from the corrective action. However, once the congestion in that exchange or network reaches the desired target, the resources devoted to measurements should be reduced to the minimum level necessary to determine (with adequate confidence) that the overall GOS meets the standard.

We can also use the adaptive approach in programming those traffic measurements which are specifically performed to provide base information for future planning. Thus, for example, exchanges and traffic routes which are experiencing slow rates of traffic growth only warrant infrequent measurements. On the other hand, those trunk routes with high rates of growth warrant more frequent traffic measurements to assist forward planning, especially if under-provision of circuits is likely to cause customer dissatisfaction or significant loss of revenue.

TRAFFIC RECORDINGS ON FINAL CHOICE CIRCUIT GROUPS

Introduction

CCITT Recommendation E500 deals with the Measurement and Recording of Traffic on international circuit groups. The Recommendation suggests that "the recording equipment should make a record of the traffic flow carried during the mean busy hour for at least the 30 days of the year in which the mean busy hour traffic flow is the highest". Processing methods may then be employed to calculate values for the average traffic flow for the 30 and for the 5 busiest days during the year. This is the preferred method. The second preference in the Recommendation suggests "a measuring period of 10 consecutive normal working days during the busiest season of the year." Such comprehensive measurements, warranted in the case of international circuit groups because of the exceptionally high cost of each circuit and fast rate of growth in offered traffic, are not generally justified in national networks, except perhaps in the case of high cost trunk routes.

However, recent progress in electronic instrumentation has been so great that it is now becoming economically feasible to justify more extensive traffic measurements than formerly. Furthermore, Individual Circuit Monitoring equipment, in the course of gathering circuit occupancy data to assist in the maintenance of the network, provides as a bonus useful traffic data for monitoring and planning purposes. Finally, SPC exchanges, with their inbuilt capacity to measure traffic are lowering the cost of obtaining traffic data compared to conventional exchanges.

The approach adopted by Telecom Australia to traffic measurements aimed at monitoring congestion due to traffic flow will only be outlined here as full details of traffic measurement techniques are given in my companion paper to be presented in another Session of the Symposium (Ref. 1).

In networks which utilise alternative routing, only the final choice circuit groups can experience traffic congestion. It is therefore our practice to monitor the final choice routes more carefully than high usage routes. Fortunately, the final choice routes comprise only a small proportion (e.g. 20%) of the total number of routes in a network, thus minimising to some extent the resources required for this aspect of network management.

Measurement Standards and Procedures

In the Australian urban networks, full-scale occupancy and dispersion traffic measurements are taken at terminal exchanges at approximately two-yearly intervals. At tandem and transit exchanges these full-scale readings may be done more frequently if warranted, but usually not more often than once per year. By a full-scale reading I mean a route-occupancy reading over a period of five or possibly ten days, with sampling scans generally at three-minute intervals, covering the busier periods of each day. Traffic dispersion measurements are generally taken at the same time as the route occupancy reading. Call holding time information is obtained as a by-product of the dispersion measurements. Individual circuit measurements (i.e. circuit occupancy) are done on an as-required basis.

At rural exchanges, traffic measurements are made at intervals varying from two to five years depending on the size and importance of the exchange. The rural networks in Australia utilise transit centres called Minor Switching Centres. This is fortunate from the point of view of network monitoring since, as the rural terminal exchanges tend only to have routes to the parent minor switching centre, it is possible, at a minor switching centre to measure the traffics on most of the junction routes in and out of the subsidiary terminal exchanges.

The standard measuring equipment used in most of our crossbar and step telephone exchanges and in the telex exchanges is called Traffic Data Equipment (TDE). The equipment has been designed to permit the most commonly required measurements to be performed for a complete exchange at the one time.

An important feature of TDE is that the measurement process is fairly automatic, and the output data is recorded onto reels of computer compatible magnetic tape. These aspects assist considerably in controlling the costs of gathering (and processing) the large amounts of data involved.

The processing of TDE measurement data is done off-line on a large computer. For a route-occupancy measurement, the computer printouts show, for each circuit group:

- busy hour time, and mean and variance of the daily busy hour traffic.
- maximum and minimum number of devices

in use each day.

- over the period of the measurement, the (post-selected) time consistent busy hour (TCBH), and the mean and variance of the TCBH traffic.

Accuracy

The accuracy of the sampling method of performing traffic intensity measurements is a function of the scanning interval (t), the number of busy hours over which the observations are averaged (T), the average holding time of calls (d), and the actual traffic (A) being carried on the route (Ref. 2). We can predict with 90% confidence that the mean of the measured observations will lie in the range—

$$A \pm 1.645(A.t/d)\,[1 + e^{-t/d})/(1 - e^{-t/d})]^{1/2} \quad (1)$$

Knowing the TCBH traffic on a final choice circuit group and the number of circuits in the group, one may consult the appropriate traffic capacity table to obtain an estimate of the GOS (strictly speaking, the Call Congestion Loss) being experienced by traffic offered to the route. The figure obtained can only be regarded as an estimate of the Congestion Loss due to:

- Measurement errors caused by sampling; see Equation (1).
- Traffic tables are based on ideal assumptions about switching systems and the statistical properties of the offered traffic.
- The carried traffic is generally less than the offered traffic.

Kuczura and Neal (Ref. 3) have made an analytical study, backed up by computer simulation, of the accuracy of estimating congestion loss on intermediate high usage, and final choice routes with overflow from high usage routes. They have concluded that the relative accuracy of call congestion measurements decreases as the blocking probability decreases. An earlier paper by Descloux (Ref. 4) on the same subject, deals with a traffic system in which call arrivals follow a Poisson process; the results are useful for first choice routes but can only serve as a guide for routes carrying overflow traffic. He has compared the accuracy of estimating loss probabilities by several measurement methods, i.e. time congestion, call congestion, route occupancy by scanning, and route occupancy by continuous recording. For offered loads (in erlang) less than the number of trunks, his simulation results show that loss probabilities estimated from carried loads have smaller variances than other measurement methods.

Measurements at SPC Exchanges

It is not necessary to use the TDE to obtain traffic measurements from our Metaconta IOC SPC trunk exchanges. Instead, when occupancy or dispersion measurements are required, the appropriate computer programs are loaded into the central processor and the measurement process proceeds concurrent with the normal switching functions of the exchange. The data obtained is transferred from a buffer area to magnetic tapes. These tapes are processed by the same computerised system as is used for TDE data. The recording system has had some problems — e.g. in the busy season (i.e. pre-Christmas), the extra processing load from the traffic measurements has, on occasions, degraded the traffic handling capacity of the IOC central processors.

For the SPC local exchanges we expect to be installing by the early 1980s we have specified a requirement for traffic data, including the following, to be gathered on-line, and transmitted at 30 minute intervals to a central location:

- Total originating, total terminating and total incoming traffic;
- Traffic load statistics on selected groups;
- Total call count on traffic offered to outgoing routes and selected circuit groups — i.e. calls offered and calls failed due to congestion.

More extensive data (e.g. traffic dispersion) will be gathered for planning and design purposes.

Supplementary Route Occupancy Measurements

A full-scale traffic measurement at an exchange using TDE is an efficient way of measuring the mean and the variance of the traffics carried on a large number of circuit groups. As stated earlier, it is used to give a comprehensive traffic reading at intervals of approximately two years. We use supplementary measurements to provide monitoring information about the traffic carried on some of the final choice trunk and junction routes. One of these methods is to do a manual reading at the exchange using the Erlangmeter which is part of the permanently installed TDE equipment. Traffic intensity is sampled on the desired routes at intervals of (say) three or five minutes during the busy hour for five successive days. Sample values are recorded manually and the average is computed, thus yielding an estimate of the mean busy hour traffic. A further refinement in use is to transmit route occupancy data for the busy hour each day to a central location where it is automatically stored on magnetic tape ready for off-line computer processing. (Ref. 5). It is possible that on-line processing of this data by minicomputer will be used in due course.

Another method giving regular surveillance of final routes involves the use of Erlanghour meters (Ref. 6). The Erlanghour meter is an integrating current meter which is calibrated to give a numerical indication of the traffic in erlang-hours which a circuit group has carried over the period of the measurement. The Erlanghour meters are switched on by a clock for the period of the busy hour only, and thus the reading on the meter corresponds to the busy hour traffic in erlangs. One may compute from the appropriate traffic capacity tables the traffic that the route is designed to carry, knowing the number of circuits on the route, the design GOS and an estimate of the variance-to-mean ratio. At regular intervals the measured traffic is plotted on a graph and compared with the designed traffic capacity of the route. In addition, the theoretical GOS on the final route may be computed from standard traffic tables. When the carried traffic is nearing the design figure, corrective action may be initiated in time to prevent the route going into congestion. One reason for Telecom Australia using Erlanghour meters for final route supervision is that the measurement data may be telemetered to a central location over junction cables and thus a considerable number of final choice circuit groups may be monitored from one location (Ref.5). On the other hand, Erlanghour meters are not very accurate, especially the types which depend on a variable speed direct-current motor for current integration.

When ad hoc rather than regular surveillance of traffic intensity on a final route is required we often use a chart recorder. The recorder can be set up fairly easily and may be left unattended. A drawback is that the time taken to process the data is rather extensive.

At ARM trunk exchanges, a metered record is obtained for each route showing the total period of time during which all circuits were occupied. This information may give the first indication of imminent congestion.

Daily Traffic Recording

Following on from a field trial evaluation (Ref. 5), it is proposed to equip crossbar and step exchanges with add-on monitoring equipment which will permit Daily Traffic Recordings to be obtained. Traffic intensity and counts of calls offered/calls lost for selected circuit groups will be recorded daily, and the data will be tele-metered to central locations for logging. This will enable the busy hour carried traffic and call congestion to be measured, and the offered traffic to be estimated accurately (Ref. 4), thus yielding the information needed for supervision of the GOS.

The system is seen as a significant step forward in our ability to accurately and economically monitor traffic on key routes and circuit groups. Our forthcoming SPC local exchanges will have an in-built ability to supply daily traffic data.

Individual Circuit Monitoring (ICM)

Computerised equipment for large-scale monitoring of individual circuits is currently under evaluation by Telecom Australia. The equipment scans the state (busy or idle) of each circuit at frequent intervals, and accurate data are obtained on call seizures, circuit occupancy and average holding time of each device. The primary value of ICM is for maintenance, advantage being taken of the fact that circuits which are faulty or out of service will show markedly different values of holding time and/or call seizures to the expected, or average, values for the circuit group as a whole.

As a by-product, the individual circuits can be pre-grouped in software data tables into routes. At regular intervals (e.g. every hour) a printout can be obtained (remotely if desired) of the number of seizures and traffic intensity for each group. This information can then be used for congestion supervision purposes.

The ability to measure, analyse, and report on live traffic in an on-line mode gives ICM great potential as an instrument for GOS supervision. ICM can be provided as an add-on facility at existing exchanges, but will be built-in to our SPC local exchanges.

MANUAL SERVICE ASSESSMENT OF LIVE TRAFFIC

Telecom Australia has objectives for the performance of its telephone and telex systems as viewed by the users. For example, the target for telephone calls in the local "unit fee" calling area, is that not more than 1.0% of all calls should encounter equipment congestion, and that not more than 1.5% should fail due to switching loss — i.e. call failures due to plant defects. (Switching loss includes calls which are switched to a wrong number; encounter no progress; are cut off; or are simultaneously connected to a third party.) For Subscriber Trunk Dialling (STD) calls the targets are 2.0% for congestion loss and 3.0% for switching loss.

A continuous programme of manual service assessment of live traffic is used to obtain the necessary data. The results are used by upper and middle management as a statistically reliable indicator of overall performance of the telephone and telex systems, and to quantify particular aspects which are likely to cause customer dissatisfaction. The other key indicator of user dissatisfaction is the level of customers' Technical Assistance reports; this indicator is covered later. For the telephone system, the method of obtaining the data is to have manual operators at central locations observe a sample of calls originated from exchanges in each urban area. At ARF and ARE crossbar ex-

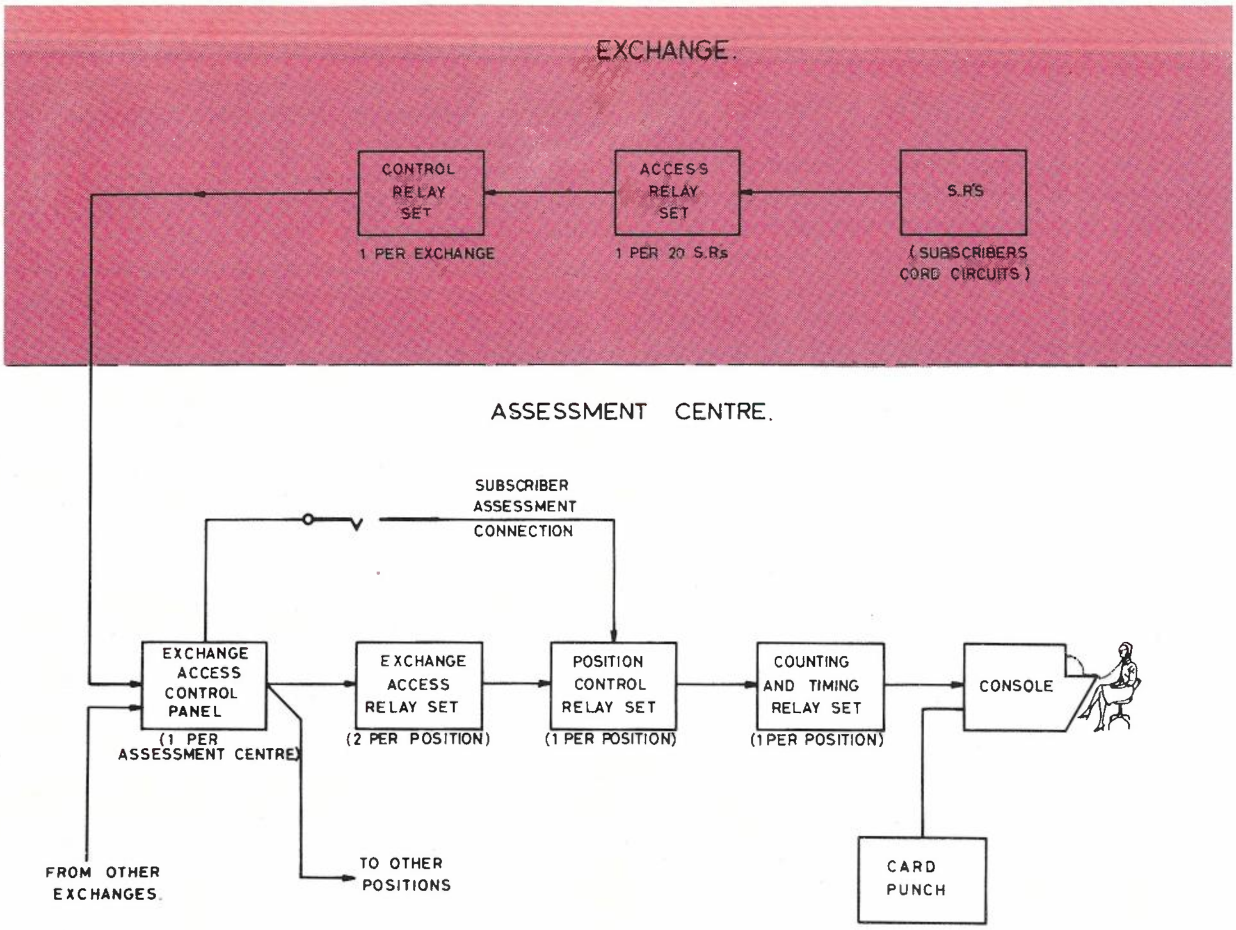


Fig. 1—Local Network Service Assessment Equipment

changes a small number of SR relay sets (i.e. Subscribers' Cord Circuits) are connected via junction cable pairs to the centralised service assessment operators. SRs are utilised because they are in use for the entire duration of a call. The SRs are selected so that an unbiased sample of all originated traffic from the exchange is obtained. See **Fig. 1.**

The sample size used in the large metropolitan networks is 100 originating calls per exchange per four week period. Prior to 1976 the sample size was 200 calls per exchange. Observation of calls occurs from about 0700 to about 2200 hours, five days per week. We aim to sample half the calls for each exchange in the first two weeks of the period and the other half in the second two weeks, the object being to avoid statistical bias being introduced by short term disruptions in equipment performance. Most local calls are observed from the time the subscriber first attaches to the SR cord circuit until the call has been in progress for 15-20 seconds, but 10% of calls are observed until completion or until three minutes has expired, whichever occurs sooner. The objective of the longer observation on some calls is to note cases in which the quality of transmission on the circuit appears to impede the conversation, and to see whether the metering (which takes place at the termination of crossbar-originated local calls) occurs correctly.

With STD calls, metering occurs during the progress of the call, and observation occurs from the seizing of the SR until about four meter pulses have occurred. For STD service assessment the objective in the larger metropolitan networks is to sample 5000 calls per four week period. To get an STD sample of this size it is necessary to supplement the sample obtained as shown in Figure 1 with direct observation of calls which have already been switched to a trunk route; a penalty is that some information about the call is then not obtainable. Post-dialling delay is also measured on STD calls.

The service assessment operators use headsets to listen to the calls chosen for sampling. Information relevant to each call is recorded directly onto punched computer cards. This recording method generally works very satisfactorily, and by avoiding the need for double handling of data, enables a high productivity to be obtained from the operators. Data recorded for each call include: origin exchange, number of the called party, time of day and whether the call was successful. If the call fails the reason is recorded. In Australia, the tone used for calls which fail due to congestion in the public network is different from the tone for calls which are directed to a busy subscriber. This enables the Service Assessment operators to distinguish between the two cases.

The punched cards are processed by computer at the conclusion of each four-week period. As indicated earlier, the prime outputs obtained are:

- the percentages of all observed calls in the network which fail due to equipment congestion or which encounter switching loss, and
- the percentage of calls which fail due to factors which can be attributed to the calling or called parties.

For urban networks, the results have been found to be consistent from one period to the next thus giving confidence that the sample size is adequate for the purpose of providing a network indicator. It is interesting to note that the worse the performance of an exchange, or network, the more extensive is the quantity of data obtained about failed calls without having to increase the sample size. This may assist the maintenance staff in fault-finding activities.

Since only 100 calls are sampled from each originating exchange there is no illusion that the sample should give a statistically reliable picture of individual exchanges. The statistical confidence will depend on the mean and variance of true congestion and switching loss being experienced on calls from that exchange. As these losses are usually small (e.g. in the range 0.5-3.0%) 100 calls will not give a statistically reliable indication of true performance. Even for a full year (i.e. 13 four week periods = 1300 calls) a measured loss of 1.0% will have 95% confidence limits of 0.5-1.5%. Nevertheless, the annual results are useful for management to assess the comparative performance of originating exchanges and to observe the long-term trend for individual exchanges.

With these reservations, the four-weekly data is sorted by the computer program to give an aggregate picture for each originating and terminating exchange, and a matrix is produced indicating losses between individual pairs of exchanges. Since the latter will generally be very small it is better to produce a report showing only those cases where the percentage of unsatisfactory calls exceeds a specified figure. Also, the call sample size between individual pairs of exchanges will vary considerably, and it is necessary to use statistical tables to determine the confidence limits that can be placed on the performance results obtained from the matrix. (However, aggregating the exchange-pair data over a period of a year leads to a higher confidence in the results.) Since the percentage dispersion of calls varies considerably between exchanges it is found that if, in a four-week period, we observe 100 calls originating from each exchange in an urban network the number of calls terminating at each exchange will vary from quite a small number (e.g. 20) to much larger numbers (e.g. 500). Thus, the statistical confidence which can be placed in the data for assessing the terminating performance of exchanges varies a great deal. In order to cater for the smaller sample sizes we generally prefer to see the terminating data aggregated over a period of three months rather than just four weeks.

The network data is also partitioned into the categories of "whole-of-day" and "busy period only", since, although our targets are in terms of whole-of-day performance, there is concern to ensure that busy period performance is also satisfactory. However, the estimates of loss for the busy period (generally 0900-1100 hours), are less reliable due to the smaller sample size. It has been found that the busy period switching loss is generally only slightly worse than the whole-of-day average. This implies that the switching equipment which is mainly crossbar, performs almost as reliably in heavy traffic as in light traffic.

The service assessment operators record metering irregularities but these are events of such infrequent occurrence (typically on less than 1% of calls) that the results do not provide a statistically reliable indicator of the true percentage.

The post-dialling delay for each STD call is recorded as falling within a particular range, and the computer processing gives a percentage in each range so that a comparison with targets is facilitated.

I would like to emphasize that the service assessment monitoring of a small sample of live traffic is primarily aimed at yielding an indication of network performance to upper and middle management. The data is not intended as an actual fault finding tool. Nevertheless measurement data relating to failures is made available on a daily basis to Network Performance and Analysis Centres (NPAC). These centres are continuously obtaining data about network performance from many sources and the service assessment data supplements the other information. Studies are proceeding which, through the use of on-line data logging and analysis by minicomputers, could lead to a greater degree of automisation of the service assessment procedures.

In the telex network similar procedures to the above are used for assessing the performance of live traffic. At IOC trunk exchanges the service assessment process is partly automated. After the operator commences observation of a new call most of the required data is recorded automatically by the exchange's central processor onto magnetic tape. The operator adds the extra information which cannot be obtained automatically — e.g. wrong number obtained, poor quality of transmission, etc. At regular intervals the data is analysed off-line by computer.

ARTIFICIAL TEST CALL GENERATORS

Nearly all of the medium and larger sized telephone exchanges in Australia are permanently equipped with a machine called a Traffic Route Tester (TRT) which can generate calls to predetermined test numbers. In addition, NPACs are also provided with one or more TRTs and these can be connected via junction pairs, or via the switched network and Remote Call Repeaters to originating stages of terminal exchanges. Portable TRT machines are provided for use as required at the small exchanges, (Ref. 7). At ARE-11 exchanges, a permanently installed Automatic Exchange Tester will encompass the facilities found in a TRT, and these machines will be able to be activated from a remote control centre.

A TRT can be set up to establish any desired number of calls to predetermined test numbers, and if the call fails the reason is recorded on a meter and a printer. If desired, the forward connection is held to enable the tracing of the call — this is called the "hold and trace" mode of operation. When using the TRT in the "observe service" mode, after the programme of calls has been completed, the meters can be read to indicate for each destination the number of call attempts and the number of call failures in the different categories. Thus an estimate of the GOS and switching loss to each particular destination may be obtained.

The terminations used on the test numbers are Tone Answer Responding Sets (TARS) which provide automatic answering and identification facilities. (If a TARS is not available at the destination exchange a Test Call Answer Relay Set or TRT will suffice). Test calls from the TRT are injected into the telephone system at the same point as calls from ordinary subscribers. Similarly, the TARS are connected to the equivalent of subscribers' line terminals. The signals used between the TRT and the TARS are the same as would pass during ordinary subscribers' calls. Thus the TRT test calls traverse the same paths through the public network, employ the same signalling facilities, and encounter the same network conditions as normal subscriber dialled calls. A multi-tone detector enables the TRT to recognise the tone sequence of a successful call (Ring Tone, then two pulses of 820Hz tone from the TARS of at least 650msec duration separated by a silent interval of at least 500msec followed by an answer signal), or the service tones which mark an unsuccessful call (Busy Tone or Congestion Tone).

It used to be common practice in Australia to regularly run a programme of TRT test calls between exchanges in each urban network. The dispersion of calls to the various destinations was arranged to approximately coincide with network traffic flows. With this method of testing it is possible to isolate equipments causing failures and to rectify most of the faults thus revealed. The performance of the urban networks was improved considerably as a result of these, and other, endeavours and, as a result, when call congestion and switching loss approached or attained the target levels it was no longer necessary to run test call programmes on a regular basis.

Nowadays, the exchange TRTs are generally used regularly only to generate STD calls since this portion of the network still shows some scope for improvement towards the target. Even so the tendency now is to use a remote TRT (located at the NPAC) to generate the test STD calls. The rationale for this centralisation approach is that the cause of failure of STD calls is generally found to be in the trunk switching or trunk transmission facilities, or particular terminal exchanges, rather than in the local originating exchange equipment. Since trunk exchanges carry large volumes of traffic and considerable revenue is earned from these calls, the Australian trunk switching exchanges (including the Metaconta IOC SPC trunk exchanges) are equipped with TRTs and a regular programme is run to test all out-going trunk routes from each of these exchanges.

When the need is indicated by a deterioration in some other performance indicator the TRTs are used 'as required' to generate test calls. For example, subscribers' complaints may be indicating a high number of calls encountering no progress from one origin to a particular terminal exchange. By generating a stream of calls to the terminal, with the TRT in the hold and trace mode, it is possible to obtain an indication fairly quickly of which equipment item (e.g. a particular outgoing junction) is causing the trouble.

The TRTs currently in use cannot simulate with any precision the calling behaviour of actual subscribers (e.g. inter-arrival times of calls, dispersion of calls, etc.), or of their actual dialling characteristics as received over the subscribers lines (e.g. in terms of distorted dial pulses, short and long inter-digital pauses, etc.). So the results derived from traffic route testing cannot be expected to coincide statistically with the quality of the service assessed from live traffic.

Although the TRTs may be used to gather large quantities of data to yield an indication of the performance of an exchange or of a network there is a growing school of thought amongst engineers in Telecom Australia that when networks are performing satisfactorily, the routine use of TRTs is unnecessary, and that they are best reserved for helping to locate faults which have first come to notice from another reporting source. The increasing facilities for automatic monitoring of MFC signals on live traffic (see next Section), especially in SPC systems, are bound to reduce the overall importance of TRTs.

AUTOMATIC MONITORING OF LIVE TRAFFIC

It is usual nowadays for common control exchanges to be provided with equipment which performs GOS monitoring of live traffic, and with other equipment which supervises the setting up of a sample of live calls. Two particular methods used by Telecom Australia include the use of permanent statistical meters, and devices called No Progress Call Detectors (NPCD). A third technique, called Individual Circuit Monitoring, is under field trial. This equipment uses a minicomputer or microprocessors to supervise, record, analyse and report on the busy/idle state of traffic circuits. More details are included in my companion paper (Ref. 1), and in a previous Section of this paper.

Permanent Meters

Traffic meters are permanently connected to leads from the supervisory units and they record the total number of calls, and the number of calls lost due to faults and congestion. The permanent traffic meters will show long term trends in the performance of the equipment with which they are associated. The meters are read at intervals of two or four weeks, and the percentage of call failures is computed. The trend is compared with the target. Action limits for congestion and time outs are used to detect deterioration of performance which may not have been noticed by other means. The permanent meter reading results can also be analysed for traffic balance between similar items of equipment.

As a particular example, ARF crossbar exchanges have meters associated with each group-selector stage marker to record the total number of calls offered to the marker and the number of calls meeting congestion. It is therefore a straight forward matter to obtain an accurate indication of congestion loss for calls switched by each marker, either in the busy hour or over the whole of day. Furthermore, it is possible to associate this type of metering with each individual final choice junction route in order to obtain an accurate appraisal of the GOS of calls which are offered to the final choice routes. In this case it is usual to time-switch the meters so that they are only turned on for the duration of the busy hour; the figures thus obtained over a period of a week or month represent the average busy hour grade of service for each final route. The figures may be compared with the theoretical probability of loss estimated from traffic measurements on the same final choice routes — see earlier Section.

Of course these measurements do not include the effects of congestion at earlier stages of the switching process, but this is generally quite small.

Similarly, ARE-11 SPC exchanges maintain a record in the memory of the Operations and Maintenance Processor of these types of statistics; the data can be interrogated by command via a computer terminal.

No Progress Call Detector (NPCD)

A sampling method called the NPCD or RKR (Trouble Recording Register) is used at our ARF crossbar exchanges to monitor calls from an earlier stage of the switching process. The NPCD utilises a test register which is inter-connected so that all subscribers in the exchange have access to it. (Note: compelled sequence MFC signalling is used on calls originated from, or in transit through, crossbar or SPC exchanges). The register monitors the progress (through the signalling sequence) of all calls set up by that particular register. All local and trunk call attempts are recorded on separate statistical meters. Call failures are classified into categories and each failure is recorded on the appropriate meter. It is therefore possible to obtain an indication of the GOS being experienced on local calls and trunk (STD) calls, and the figures supplement those obtained from other sources, e.g. manual service assessment.

The MFC forward and revertive signalling system permits registers to keep track of the progress of a call through the stages of switching. The sorts of conditions which cause blocking or no-progress will usually result in MFC call failure, and the status of the P-chain in the register at the time of call failure indicates the stage reached by the call. Therefore, using the NPCD, when a call fails to be established satisfactorily, the destination number of the call and the stage of switching at which the call has failed are transmitted via a data network to a centralised location (the NPAC). Here the information is displayed on a teleprinter, and is also recorded onto punched paper tape for subsequent computer analysis. (Action is nearing completion to have the data collated and analysed on-line by mini computer. This will reduce the time taken to detect fault patterns and will therefore improve the service to subscribers). By these means, fault patterns observed on live calls may be utilised to help locate network trouble spots with accuracy. Naturally, since the network is designed to have some congestion, it is only warranted to initiate investigatory action into causes of congestion when the target levels have been exceeded.

Telecom Australia is about to commence the conversion of a large number of existing ARF exchanges to partial SPC working as ARE-11 exchanges, and these will have the equivalent of the NPCD facility just described. The IOC trunk exchanges also have inbuilt facilities for recording and reporting MFC call failures.

The NPCD supervision of the establishment of live calls, sampled from the total originating call population, and analysed on-line at a central location is a powerful tool, and in many respects is superior in its effectiveness to other methods such as service assessment and subscribers' technical assistance requests.

Nevertheless the NPCD has limitations. As calls are only monitored during the setting up phase, failures such as wrong numbers, triple connections, cut-offs and transmission problems are not identified.

AUTOMATIC MARKER DISTURBANCE RECORDING

The automatic disturbance recording (ADR) equipment is a supervisory system that is provided in many of Telecom Australia's ARF exchanges to collect selected supervisory information from various points within the exchange and from dependent exchanges in the district. The ADR formats this information into individual messages for transmission in telegraph code to a message concentration centre, and distributes the messages to destinations as determined by the information content of each particular message.

In a crossbar exchange, markers are used in the setting up of stages of each call and it is possible therefore to have the markers forward information about calls which do not proceed satisfactorily through the setting up phases. In particular, it is known for each stage of setting up a call what maximum time should be taken by the exchange equipment to perform that function. If the function is not completed within the allotted time it is assumed that there is a malfunction in the equipment being used, and the call is "force released" and is therefore said to have "timed-out". Information transmitted includes the actual equipment items in use and the operated position of the crossbar relays. Normally, the information is stored on paper tape or magnetic tape at a central location (the NPAC) and is analysed by computer at weekly intervals. Detailed reports are distributed to the exchanges and summary reports are sent to middle management. If the rate of time-outs starts to exceed a predetermined level all information is routed to a teleprinter at the control centre responsible for the maintenance of the exchange, thus permitting more immediate attention to the situation. It is therefore an automatically adaptive procedure.

The marker disturbance information is an invaluable aid at common control exchanges to help track down items of switching equipment which are causing calls to fail during the setting up phases. Because of the random fashion in which equipment is selected for each new call, malfunctions of a few out of many items of common switching equipment are not likely to affect individual subscribers to a sufficient degree to cause complaints. Therefore, the marker disturbance recording method has a particular place in pin-pointing faulty equipment.

On the other hand, since the marker disturbance method is not designed to record details of call attempts, the method does not in itself give a GOS indication. Furthermore, as no storage facility is provided at the exchange, if a new time-out occurs whilst information is already being transmitted about a previous time-out, then the information about the later failure will not be recorded. For these reasons, it is usual to examine the trend performance of each marker, and the exchange, over a period of time in terms of "recorded time-outs per thousand lines per week" rather than to attempt to arrive at an actual indication of GOS.

ARE-11 exchanges will be provided with the equivalent marker disturbance recording facility to that just described. ARM exchanges use a device called Centralograph to provide similar information. The IOC trunk exchanges produce many types of disturbance reports which are recorded onto paper tape, and are analysed off-line by computer. Studies are proceeding which could result in the analysing being done on-line by minicomputer.

SUBSCRIBER'S TECHNICAL ASSISTANCE REPORTS

From what I have said so far you can see that Telecom Australia conducts quite an extensive programme of traffic-oriented measurements in order to ensure as far as is economically justified that its customers are receiving a satisfactory service. Notwithstanding these efforts, we are still sometimes dependent upon complaints or requests for technical assistance from users to inform us of congestion or of the presence of some equipment malfunctions.

As the supplier of a product greatly valued by the community we would naturally prefer that our users should be dissatisfied to the minimum possible extent with the services which we provide. Complaints and requests for technical assistance (TA) give a rapid feedback response indicating the instantaneous trend in customer dissatisfaction, but even so, this form of feedback does not give an absolute indication of all problems customers have been experiencing in using the telephone and telex networks. Telecom Australia has set targets for an acceptable level of complaints, and has internal objectives for the maximum delay in rectifying fault situations. For example, the current target for technical assistance reports relating to equipment at the large metropolitan telephone exchanges is that the level should not exceed 2.0 reports per hundred telephone stations per four week period. (TA categories include: cut-off, wrong number, no progress, triple connection (i.e. crossed connection), congestion in switching equipment, call no voice, and answer no voice.) Separate figure-of-merit indicators are used to monitor the degree of user dissatisfaction with public telephones.

Economic studies have not been undertaken by our administration to estimate the additional capital and operating costs which would be incurred if we were to lower the objective to say 1.0 TA requests per hundred telephone stations per four week period, but it does seem unlikely that the sum of the marginal revenue plus savings in the fault recording and investigation areas of our operations would offset the marginal costs. With the present-day emphasis on "equality", a cause for some concern to us is the consideration of whether, in averaging the TA complaints for each exchange as a whole in order to arrive at the figure of merit on a per hundred stations basis, we are perhaps concealing from our attention some factors which might result in groups of subscribers receiving a relatively poor grade of service. At first glance one might say that all that is necessary is to check the number of complaints made by each individual subscriber. There would, however, be many pitfalls in analysing the results from this indicator. For example, the usage habits of subscribers vary enormously so even if there was no bias in exchange equipment performance against any particular group of subscribers, and if the propensity to complain was quite uniform among all subscribers, then we would still expect an uneven distribution of complaints, more or less in proportion to their calling rates.

A special complaints number ("1100") is published in the telephone directories so that callers are connected immediately to operators who are skilled in handling complaints. These operator positions are equipped with basic line test facilities, and for some types of difficulties the operators can connect the complainant directly to the desired called party. If exchange equipment or the junction network appears to be the cause, the complaint is treated as a technical assistance report and is passed to the NPAC for analysis. (If, on the other hand, the problem is associated with the subscriber's line or subscriber's equipment, details are transmitted by the operator to a Fault Despatch Centre, and the complaint is classified as a subscriber's repair report). With regard to exchange and network faults, the NPAC looks for patterns in the complaints, also making use of other information (e.g. NPCD output). If a pattern is detected (e.g. no progress on all calls on a particular group of junction circuits) then the appropriate exchange or transmission centre is advised and action is then taken to locate and correct the cause of the trouble.

Surprisingly, it is estimated that less than 1% of call failures are reported. Nevertheless, the customer TA reports, supplemented by reports from manual assistance operators, combined with speedy centralised analysis at the NPAC reveal serious trouble spots more quickly than would generally be expected from normal maintenance supervision. This reporting process is of special value in the trunk network which is vulnerable to interruptions because of staff activity on equipment comprising the telephone circuits between exchanges.

The TA complaints are recorded onto punched cards or paper tape for computer analysis. Fault patterns thus revealed are immediately advised to the exchanges affected. At the end of each four-week period the number of complaints per 100 telephone stations for the preceding four weeks is computed. This figure of merit indicator is computed separately for originating calls and for terminating calls for each exchange. The information is used by the officers in charge of exchanges, and by middle management, to check performance against the targets.

It is generally found that the level of complaints is greater directly after "cut-over" of new exchanges and is also high when large scale exchange installation activity is occurring at a working exchange. At other times it is not difficult to consistently keep the performance at about the target level.

The NPCD monitoring of call failures and the on-line analysis of this information by minicomputer may result in less emphasis being placed on the analysis of TA reports in the future.

Call attempt failure reports from manual assistance operators who handle trunk calls supplement the customer complaint information about the trunk network. The reports are analysed by the NPAC staff and when sufficient information is available to indicate a pattern of faults the diagnosis is passed on to the appropriate exchange or transmission centre.

The level of TA reporting is the prime indicator of customer dissatisfaction. A weakness, however, is that the frequency of complaints in the different categories is not an accurate representation of faults in the network, since customers have a higher propensity to complain about faults for which call rebates are credited (e.g. wrong number).

SOME REMARKS ABOUT GOS

Overload Traffic Situations

A point can be reached under overload conditions where even a slight further increase in offered traffic can cause a very marked deterioration in the effective GOS due to the influence of repeated call attempts, and because many of the circuit groups are probably already heavily loaded. The more efficient a system, the more easily does it go into overload. This is significant for common control (e.g. crossbar and SPC) systems, as each ineffective call attempt occupies the common control equipment for approximately the same time duration as an effective call. Under traffic overload conditions in an exchange or network, a longer time than normal is spent searching for a suitable free circuit at each stage of the switching process, and the average holding time of common control equipment therefore increases, the upper limit extending to the pre-set time-out period. A high proportion of ineffective calls, followed by repeat attempts, may easily result in an increase in congestion in the switching stages to an unacceptable level. Special cases of this nature occur with "phone-in" quiz contests conducted by radio stations. A very large number of subscribers make call attempts to the same number at the same time. This of course has the unfortunate side effect of causing a general congestion for subscribers at many exchanges.

International Implications of Unsatisfactory GOS

The GOS performance of each country's network is of interest to other administrations since a poor quality of service will increase their own overhead on outgoing international calls. Telecom Australia uses service assessment methods (see earlier Section) to measure the effective call rate, congestion loss, switching loss, metering error rate and other aspects of the performance of International Subscriber Dialled (ISD) calls, and in particular analyses the failure rates into each country. All administrations will probably agree that it is in our mutual interest to have satisfactory quality of service within our own country in order to reduce the proportion of call failures on incoming international calls to minimal acceptable levels. In this regard, CCITT Recommendation E541 (Overall GOS for International Connections) notes that at present the only practical way of ensuring an acceptable overall GOS on international calls is to specify an upper limit to the design loss probability per connecting link in the national network (as is done for links in the international network in Recommendation E540). Consequently, Recommendation E541 suggests that "the links in the national network should be designed for a loss probability not exceeding 1 per cent per link in the final choice route during its applicable busy hour" . . ."Although the worst overall GOS would be approximated by the sum of the loss probabilities in tandem, on most calls the overall GOS will be significantly better due to factors such as the use of alternative routing, non-coincidence of traffic peaks and the fact that circuits are generally provided in advance of the design traffic being reached". However, it should be noted that Recommendation E541 only relates to congestion as a result of traffic flow. A user's assessment of service quality is also influenced by the number of call attempts which fail due to equipment faults (i.e. the switching loss), or wanted subscriber busy, etc. or which encounter unsatisfactory transmission quality.

CONCLUSION

Faced with the ever increasing cost of labour, there is a necessity for telecommunications engineers to examine from time-to-time the need for measurement data in terms of the end use to which it is put. In addition, they need to ensure that the recording equipment, measurement procedures and processing methods are engineered so as to produce data to the required degree of accuracy at the minimum overall cost, i.e. the total system must be considered rather than the individual aspects in isolation.

It is considered within the Telecom Australia administration that the assortment of measurement techniques which I have described are adequate in most instances to provide all levels of management with timely and sufficient information to oversight the grade-of-service and switching loss performance of the Australian telecommunications system. Nevertheless, new developments are imminent (e.g. daily traffic recording, individual circuit monitoring and automatic service assessment at SPC exchanges) which will bring welcome improvement to the availabiilty and accuracy of some of the data items dealt with in this paper.

By varying the resources expended on measurements in an adaptive way, an attempt is being made to match the costs of the measurement programme to the potential benefits obtainable from applying the results of the measurements. It will be noted that the adaptive approach to measurement fits in well with the controlled corrective maintenance approach to the maintenance of telecommunications equipment.

This paper has emphasised in a number of places that for collecting data about the performance of our network the trend is away from generating test traffic, and towards the monitoring of live traffic by computerised equipment which can assist considerably in the necessary processes of measurement, recording, analysis and reporting.

REFERENCES

1. Farr, J. P.: 'Telecommunications Traffic Measurement and Processing Methods used by Telecom Australia'; U.R.S.I. Symposium on Measurements in Telecommunications, France, October 1977. (To be reprinted in the next issue of the Telecomm. Journal of Aust.)
2. Hayward, W. S.: 'The Reliability of Telephone Traffic Load Measurements by Switch Counts'; B.S.T.J., Vol. 31, No. 2 (1952), pp 357-377.
3. Kuczura, A. and Neal, S. R.: 'The Accuracy of Call-Congestion Measurements for Loss Systems with Renewal Input'; B.S.T.J., Vol. 51, No. 10 (1972), pp 2197-2208.
4. Descloux, A.: 'On the Accuracy of Loss Estimates'; B.S.T.J., Vol. 44, No. 6 (1965), pp 1139-1164.
5. Marlow, G.: 'CENTOC — Towards Centralised Traffic Measurements'; Telecomm. Journal of Aust., Vol. 26, No. 1 (1976), pp 72-81.
6. Caroll, B. J. and Rubas, J.: 'Supervision of Plant Congestion'; Telecomm. Journal of Aust., Vol. 18, No. 1 (1968), pp 54-58.
7. Mitton, L. M.: 'Recent Developments in Traffic Route Testers in the Telecommunications Network'; Telecomm. Journal of Aust., Vol. 24, No. 2 (1974), pp 136-143.

J.P. FARR is Senior Engineer (Switching Standards), Regional Operations Branch, Western Australia. (See Vol. 28, No. 1, page 9.)

ERRATUM

WIDEBAND CRYSTAL FILTER DESIGN by O. TENEN

The paper on this subject, published in volume 27, No 1, had some errors in the formulae in Table 1, page 75.

The expressions for $\overline{C}$ and R_L should be replaced by:

$$\overline{C} = \frac{1}{\omega_o \overline{R}}$$

$$R_L = k^2_{n-1,n} q_n P_N \overline{R}$$

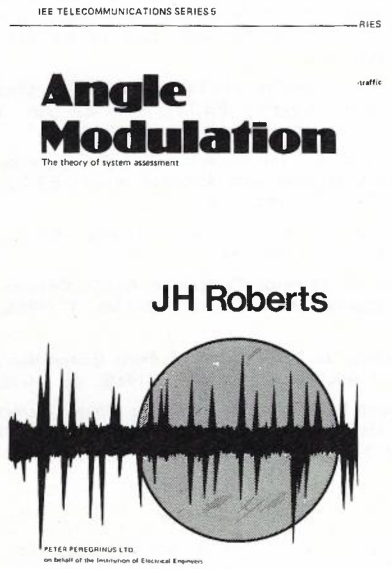
and the expression shown for $C_{N,\ N-1}$ should be replaced by:

$$C_{N,N+1} = \frac{a}{k^2_{n-1,n}}\left(1 - \frac{r k^2_{n-1,n}}{a^2}\right)\frac{\overline{C}}{P_N}$$

Book Review

ANGLE MODULATION: The theory of system assessment.

J. H. ROBERTS; Peter Peregrinus Ltd.



Towards the end of the last decade, a group centred around the late R. G. Medhurst at the Hirst Research Centre undertook a systematic examination of outstanding problems in the analysis of frequency modulation. Their motivation was the then intensive development of analog FM terrestrial radio and satellite communication systems and their published results combined a high degree of analytical competence with a sound appreciation of the need for sensible approximations usable by the system design engineer. J. H. Roberts, the author of this book, made an important contribution to these studies. He has now drawn together the threads of this work and more recent developments in a survey aimed at the communication systems analyst.

It is really only possible to comprehensively survey a field which has become established and in which research interest has somewhat declined — as in the case of analog modulation. Nevertheless, the subject remains a daunting one in which the treatment of many important questions (e.g. the filtering of an FM signal) leads to an algebraic morass and in which progress has been achieved by manipulative ingenuity. The theory of analog modulation is not constructed on broad lines of development but is rather a collection of competing techniques — each valid in a particular area. The amorphous nature of the topic might be described by likening it to a bush as distinct from a tree. Moreover fundamental steps often rely on particular algebraic features, for example, the important relation between the distribution function of the phase and the characteristic function of the modulated signal (eqn (2.17)) relies on an integral property of Bessel functions.

In view of this it may be unreasonable to ask the writer to emphasise what basic techniques there are; but they could be elucidated in the context of their applications. In particular, techniques for determining the spectrum of the modulation in the presence of noise, interference, etc., might be treated before analog modulation applications are discussed, leaving the question of the distribution of the angle until the digital modulation section. The task of the reader is made more difficult by occasional awkward writing and the use of different symbols for the same quantities (the low-pass components of narrowband noise are denoted by X, Y and I_c, I_s, etc.). More importantly, the author more than once misses the valuable opportunity to give the reader a physical understanding of what is happening — contenting himself instead with making a mathematical point.

The comments made, the book is a fairly comprehensive treatment of frequency and phase modulation in which the first two chapters lose no time in confronting the computational difficulties involved. Chapter 3 evaluates the instantaneous frequency of a signal, using the technique of counting zeros. Chapters 4 and 5 are more system oriented and discuss filtering and distortion due to noise or interference; the graphical presentations are helpful yet some specific results for large-capacity FDM systems would be useful. The effect of amplitude to phase conversion could be treated at this stage since expression of the resultant waveform in the form exp $[\alpha(t) + j\beta(t)]$ often enables the converted amplitude and phase components of the total distortion to be calculated in a similar manner.

Chapter 6 deals with the probability distribution of the instantaneous frequency and the next chapter continues with the question of filtering, including the use of pre-emphasis. In this area one has the powerful but complex Volterra series expansion and the crude but effective Monte Carlo technique flanking the useful quasi-stationary approximation. The limitations of these methods are discussed — the main disadvantage of the first two approaches is the lack of any insight into the effect of a parameter variation on the system design.

The first-order approximation (Ch. 7) is applicable where the distortion is small, which will usually be the case with working systems. The author then examines threshold extension devices and the last quarter of the book is devoted specifically to the spectrum and error rates for digital modulation. This monograph contains much material which will be sought out by the more meticulous system designer.

Reviewed by John MURPHY, Telecom Australia Headquarters.

Hybrid Transformers — Part 2

A.H. FREEMAN, M.I.E. Aust.

This is the second of two articles designed to inform the reader of the properties of hybrid transformers and present simple methods of designing or analysing circuits in which they are used. It examines variants of the circuit dealt with in the first article "Hybrid Transformers — Part 1" (Vol. 27, No. 3 of this journal) and illustrates the varied application of hybrids in telecommunication plant by a number of specific examples.
An appendix gives further mathematical details useful in the design of circuits using hybrids.

INTRODUCTION

Part 1 of this article dealt in some detail with a specific two transformer hybrid circuit. For convenience the circuit is repeated here as **Fig. 9** with minor changes. This is the circuit most frequently used in a terminating set, but is only one of a very large number of possible circuits using one, two or three transformers. The rest of this article discusses these other circuits, their relationships with the circuit of **Fig. 9,** and applications of hybrids.

OTHER CIRCUITS

Skew Hybrids

In the circuit of **Fig. 9** in the balanced condition power fed to one port was output from the two adjacent ports with equal power in each port. Circuits can be designed and are sometimes needed in which the power division is unequal and these are known as "skew hybrids". This can be done by altering the turns ratio so that $N_1 : N_2 : N_3 = 1 : \sqrt{a} : \sqrt{1-a}$

Using the same methods as before it can be shown that the circuit still has identical requirements for balance, but that power is divided unequally. The following table gives details for power input to each port.

Input Port	Balance Condition	Relative Power at Port 1	Port 2	Port 3	Port 4
1	$Z_2=Z_4$	1	a	o	(1-a)
2	$Z_1=Z_3$	a	1	1-a	o
3	$Z_2=Z_4$	o	1-a	1	a
4	$Z_1=Z_3$	1-a	o	a	1

It can be seen that the turns ratio of **Fig. 9** is obtained by setting a=0.5 so that **Fig. 9** could be regarded as a particular case of the more general skew hybrid. However, the skew hybrid circuit is considerably more difficult to analyse and since it is only required in a limited number of special applications nearly all published data refers to the symmetrical case, and the skew case is treated specially when necessary.

If a skew hybrid is used as a terminating set, the loss between 4 wire receive and 2 wire line is —(10 log. a)dB, and between 2 wire line and 4 wire send is —(10 log. (1-a))dB, so that the sum of these two losses is —(10 log. a(1-a))dB, which is greater than 6dB, so that more gain is needed in the 4 wire path than for the symmetrical case.

The trans hybrid loss with impedance Z_2 at the 2 wire line port and Z_1 on all other ports is $-(10 \log. (a(1-a))+20 \log.((Z_1-Z_2)/(Z_1+Z_2))$dB. Thus the cross hybrid loss is increased by the same amount as the 4 wire gain must be increased and the echo and stability conditions are the same.

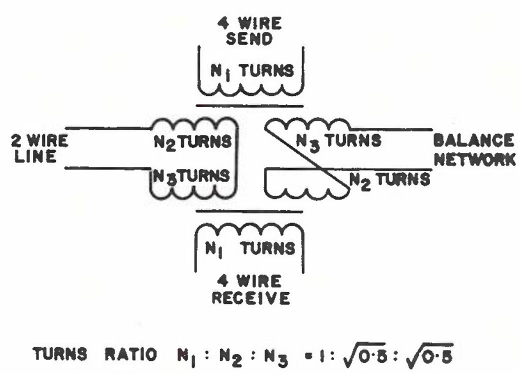


Fig. 9 — Basic Hybrid Circuit.

Impedance Transformations

In the circuits of **Figs. 9 and 10,** each port is designed for the same nominal impedance, often 600 ohms. However, other impedances are sometimes required and since each port is associated with a separate winding or windings the turns ratios can easily be adjusted to give any desired impedance ratios.

A common requirement arises when the 2 wire line is a loaded cable of nominally 1200 ohms impedances while the 4 wire ports are connected to 600 ohm equipment. This is possible if the turns ratio of **Fig. 9** is changed to $N_1 . N_2 : N_3 = 1 : 1 : 1$. Obviously, if appropriate allowance is made for the impedance transformations, all the characteristics already quoted apply to this circuit.

On occasions hybrids have even been built to perform also as the input and output transformers of the 4 wire amplifier, with impedances at those ports designed to feed directly to transistors or valves.

Different Transformer Connections

All the circuits so far described are variants of the one basic pattern. There are other circuits which have the same properties, using one, two or three transformers. These can all be shown to be identical in their transmission characteristics to a circuit of the type already discussed. They usually have some limitations or some special properties which are incidental to their operation as hybrids, but are of particular value to the application in which they are used.

One such circuit, which is widely used in impedance measuring bridges is shown in **Fig. 10.** At first sight there is little resemblance between this circuit and **Fig. 9,** but in this case a series of simple transformations can show that they are almost identical.

In **Fig. 10,** ports 1 and 3 share a common terminal so the circuit can only be used if the external circuit conditions allow this. Therefore, the circuit of **Fig. 9** could be used with two terminals strapped as shown in **Fig. 11A.** This joins the start ends of two identical windings on T2, so that the finish ends are also at the same potential and can also be joined as shown in **Fig. 11B.** The two parallel windings can then be replaced by a single winding as shown in **Fig. 11C.** Finally, by redrawing the circuit, as in **Fig. 11D,** we get the circuit of **Fig. 10.**

The properties quoted earlier for the circuit of **Fig. 9** are unaffected by the connection between ports 1 and 3 and therefore these properties all apply to **Fig. 10.**

This transformation is only possible because the

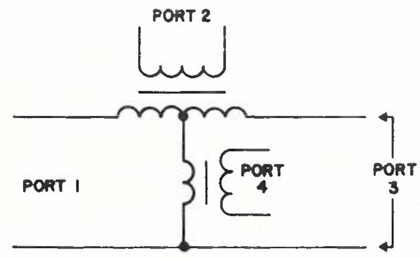


Fig. 10 — Alternative Circuit.

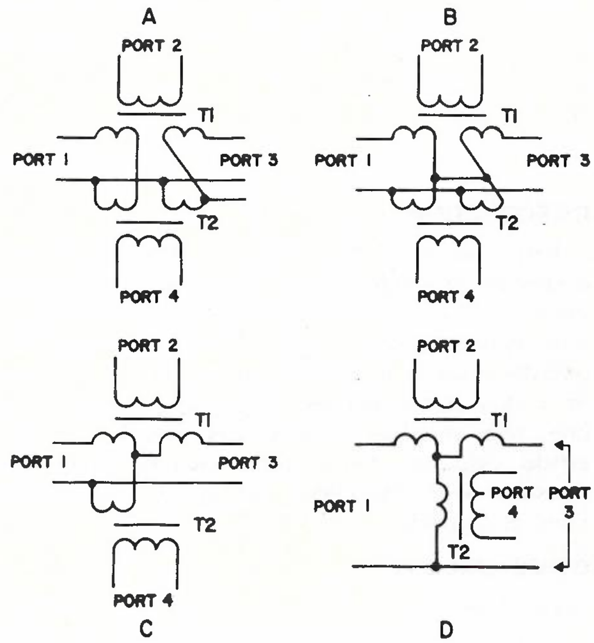


Fig. 11 — Equivalence of Figs. 9 and 10.

two windings on T2 had equal numbers of turns, and the same transformation is not always possible for the variants of **Fig. 9** having different impedance and power ratios. The reason is that there are simply not enough transformer windings which can be independently varied to give the flexibility of **Fig. 9.**

Other hybrid transformer circuits will be referred to later for particular applications. In most cases they use a limited number of windings or only one transformer. Such circuits are used because they are simpler and more economical, and the application is such that the loss of flexibility is of no significance. There are many thousands of circuits of this kind, and little point in enumerating them all. In the appendix a test is given which can decide whether a particular circuit is in fact a hybrid.

APPLICATIONS

2 Wire/4 Wire Terminating Sets

This is one of the largest and most important applications of hybrid circuits and has already been introduced in Part 1 of this article. **Fig. 12** shows a connection involving a 4 wire amplified section, with 4W/2W terminating sets at each end of the 4 wire section. The cross hybrid loss must be controlled in order to ensure stability and reduce echoes to an acceptable level. This must often be done with the 2 wire port being switched to a variety of junctions and subscribers lines of differing impedances. The control of echo and stability in these conditions is a complex topic which cannot be fully treated in a general article of this kind.

The circuit of **Fig. 9** is generally used for 2W/4W terminating sets, except for a few very old carrier systems. It is usual to provide the hybrid as an integral part of a line relay set, and a plug-in circuit board is used. The 4 wire ports may have centre taps to provide signalling circuits. Earlier practice was to associate them with the carrier equipment and this arrangement is still used fairly widely.

Telephone Induction Coils

By far the largest number of hybrids are located in telephones, disguised under the designation of induction coil. The requirement of a telephone induction coil is essentially that of providing a 2W/4W termination. Power must be fed from the transmitter to line and from line to receiver, but power fed from transmitter to receiver should be minimised to reduce sidetone.

However, in a telephone there are other considerations:

- Costs are important because of the large numbers involved.
- In automatic telephones the transmitter current is fed over the line from the exchange.
- Dialling, ringing and switchwork signals must be provided.

Fig. 13 shows the speech path circuit of a magneto telephone, and it is obvious that it is similar to the hybrid circuit of **Fig. 12,** except for the omission of transformer T2. The effect of this omission is that the design impedances of the line, network and receive ports cannot be adjusted independently, and the impedance ratios line : network : receiver are fixed at 1 : 1 . 0.5. However, the receiver can be wound to any reasonable impedance, and the network can also be designed to suit this condition, so a single, three winding transformer is adequate in this case. The microphone winding is designed to match the low impedance of a magnetic transmitter insert.

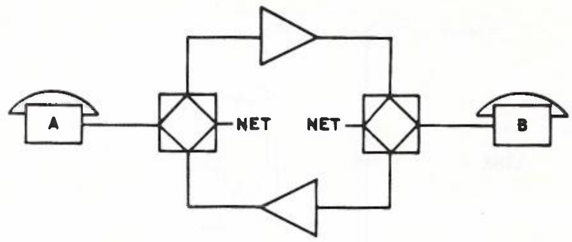


Fig. 12 — Terminating Sets.

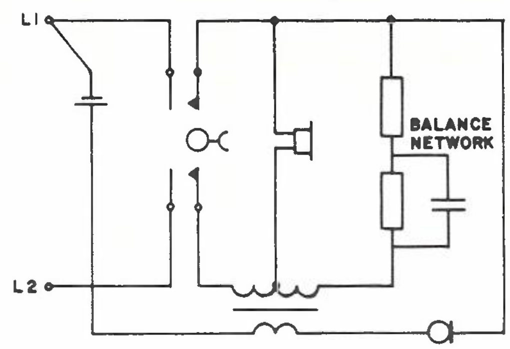


Fig. 13 — Speech Circuit Telephone MT400.

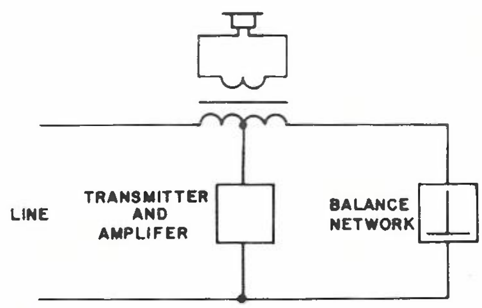


Fig. 14 — Speech Circuit Telephone 804.

Fig. 14 shows the speech path circuits of long line 804 type telephones. It is similar to **Fig. 13** except that the position of the receiver and transmitter are interchanged. This is done to allow the transmitter to be powered from the line current. In this telephone the transmitter is a combination of a receiver insert and a transistor amplifier and is designed so that its output impedance is the appropriate value for this circuit (approximately half the line impedance).

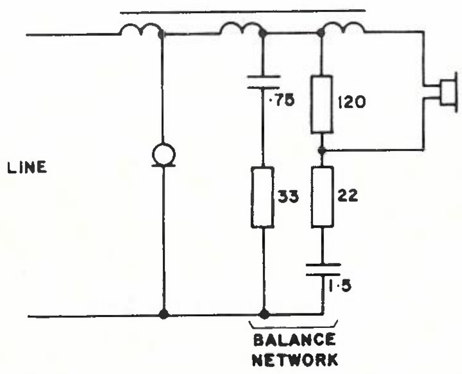


Fig. 15 — Speech Circuit Telephone 801.

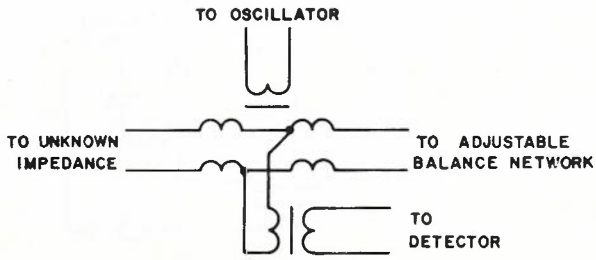


Fig. 16 — Impedance Bridge for Balanced Circuits.

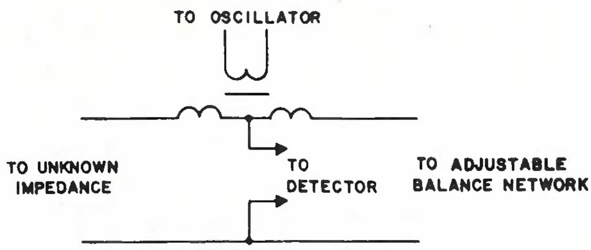


Fig. 17 — Impedance Bridge for Unbalanced Circuits.

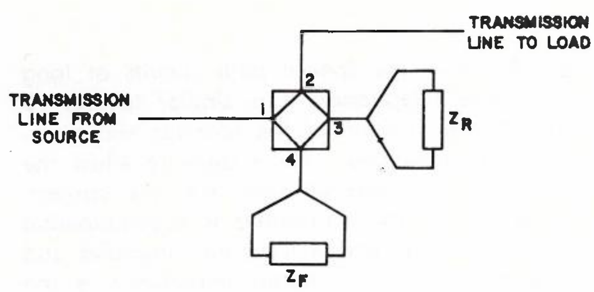


Fig. 18 — Measuring Power Flow and Return Loss.

Fig. 15 shows the speech path circuits of the 800 series telephone, with the regulating varistors omitted. The induction coil is again a three winding transformer and its operation as a hybrid is discussed in the appendix. This type of circuit was first used in Australia in the 400 series telephone. The receiver of this telephone was considerably more sensitive than earlier types but the transmitter was almost the same. Therefore, a skew hybrid was used which gave about 1.9 dB extra transmitting gain at the expense of losing about 3.4 dB of the increased receiver efficiency. Being only a single three winding transformer, it is not possible to adjust all impedances and the design was selected to give the desired power ratios, and match the transmitter to the line. The receiver and network were then designed to match the impedance conditions imposed by the three winding transformer.

Measurements

Hybrids are extensively used as impedance measuring bridges, particularly at audio and carrier frequencies. The most widely used circuits are shown in **Figs. 16 and 17, Fig. 16** being used for balanced circuits and **Fig. 17** for unbalanced, i.e. grounded circuits. They are used like any other bridge, with the balance arm being adjusted for minimum signal in the receiver. At balance the impedance being measured is equal to that of the balance arm. For this application carefully designed and accurately constructed transformers are needed and special arrangements for screening are usually included. It is also possible to use this circuit to measure return loss. In this case the balance arm is set to a specified value such as 600 ohms and the received signal level is measured.

A similar application is monitoring power flow and impedance on a transmission line carrying high frequency power. In this case a highly skewed hybrid is inserted in series with the transmission line as shown in **Fig. 18.** Terminations Z_F and Z_R, equal to the transmission line characteristic impedance terminate ports 3 and 4. For the purpose of this example it is assumed that of the power applied at port 1 99% is transmitted to port 2 and 1% to port 3, giving losses of .04 dB and 20 dB respectively.

The power in Z_F is therefore 20 dB less than that in the line and a meter may be used here to monitor the power level. In addition, if the input impedance of the line at port 2 is different from Z_F some of the input power will be transferred to Z_R.

The power measured in Z_R can be interpreted as a measure of the power reflected back along the line from the load, the return loss or the standing wave ratio. Meters of this kind are often called SWR meters or directional couplers and are widely used in radio transmitters. At low frequencies they may be constructed using transformers with toroidol cores, but at VHF and UHF frequencies it is more common to assemble them from length of coaxial cable or wave guide components. However, regardless of the constructional details the principle is the same.

Splitting and Combining Circuits

Hybrids are often used in transmission circuits to minimise interaction between different transmission paths when they are branded or combined. A typical application is when several filters are used to separate different frequency bonds and the principle is illustrated in **Fig. 19.** In this case an amplifier feeds a high pass and a low pass filter, with a hybrid used to isolate them. If the balance network impedance exactly matches that of the amplifier each filter behaves as if it were fed from a separate amplifier of half the power and the same impedance as the actual amplifier. Thus each filter can be designed independently, which simplifies the design and often allows better performance. Where a bank of bandpass filters is required, as in channel modems, it is usual to use a hybrid and to connect odd channels to one side and even channels to the other. This gives sufficient separation between the pass bands of the filters on one side to reduce the interaction almost to zero. A single 3 winding transformer similar to **Fig. 17** is usually used.

Fig. 20 shows two amplifiers connected to a common load via a hybrid. Again, if the two impedances at ports 2 and 4 are equal, the amplifiers do not interact. If the two amplifiers are delivering outputs of identical wave form and phase, all the output will be delivered to one of the loads.

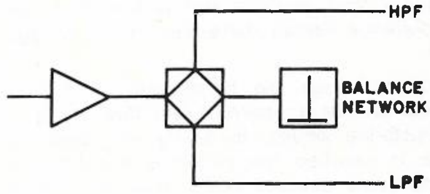


Fig. 19 — Hybrid Used to Isolate Filters.

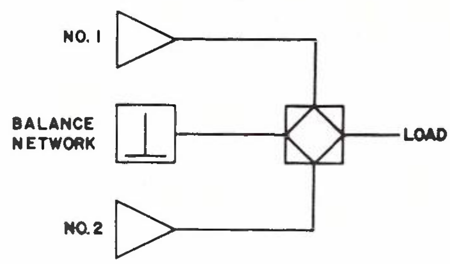


Fig. 20 — Hybrid Used to Combine Amplifier Output.

This kind of circuit is used in sound and television broadcasting transmitters, and again, in the case of VHF transmitters coaxial cable circuits are used which are electrically identical to a hybrid.

CONCLUSION

In this second part of a two-part article, some of the variations to the basic hybrid circuit used to meet specific requirements have been explained. Hybrids are used as circuit elements in a variety of applications where one or more of their properties are exploited; a selection of such applications has been described.

APPENDIX

PROOFS AND DESIGN HINTS

Common Properties of Hybrids

Design and analysis of circuits including hybrids is greatly helped by the fact that all hybrids constructed from transformers are members of a single family. Unfortunately, the only proofs of this either rely on network theorems with which few of the readers of this article would be familiar, or are very tedious and difficult to follow. For this reason, no proof will be given here.

Recognising a Hybrid

To confirm that a particular circuit is a hybrid, two tests must be satisfied. The first is that under some condition there is no power transfer between two of the ports. The easiest way to do so is to use one of the arrangements shown in **Fig. 21.** In each of these, two of the ports are terminated in resistors and an oscillator is connected to a third. In the first case, the fourth

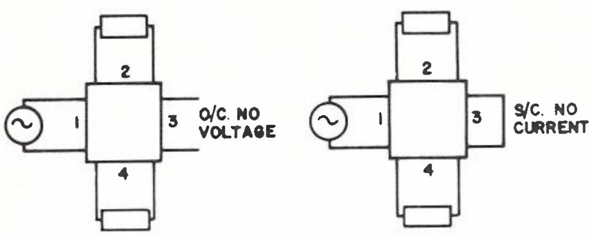


Fig. 21 — Two Tests to Prove a Four Port is a Hybrid.

port is open circuit and the test is that for a particular pair of resistance values there will be no voltage at the open port.

In the second case, the fourth port is short circuited and the test is that no current will flow for a specified pair of resistance values. In nearly all cases, if one of these tests is satisfied the circuit is a hybrid. However, to eliminate some unusual cases, it is also necessary to prove that power can be transferred between the same two ports with a different set of terminations. A combination of open and short circuit conditions is usually the easiest.

As an illustration, take the circuit of **Fig. 15** which is the basis of the 801 series telephone. **Fig. 22** shows the transformer used in this telephone with resistors terminating the line and network terminals, the receiver terminals open circuit, and an oscillator applied to the transmitter terminals. Voltages and currents at various points are shown on the diagram.

We want to show that for some values of R_L and R_N the voltage V_R is zero. Clearly, if this is so, then $V_L > V_T > V_N$, and this will occur for some combination in which $R_L < R_N$. This shows that the circuit satisfies the first test. The second test is almost a formality, since the network terminals short circuited and the line terminals open the circuit is a simple two winding transformer. In the actual 801 telephone circuit the receiver is connected to a point near the bottom of the balance network. This is done to allow a 1.5μF capacitor which is part of the balance network to be used also as a spark quench, and to block DC from the receiver. It has only a small effect on side tone.

The preceding discussion has been non-mathematical, but is easily extended to give numerical values for the impedance and power ratios of the circuit.

Firstly, since the ampere turns in windings 1 and 2 of the transformer must balance:

$$900\, I_L = 540\, I_N$$

$$\therefore\ I_L = \frac{3}{5} I_N$$

$$\text{Also } I_T = I_L + I_N = \frac{8}{5} I_N + \frac{8}{3} I_L$$

Secondly, if $V_R = 0$, the voltage ratios of the transformer give:

$$\frac{V_N}{315} = \frac{V_T}{855} = \frac{V_L}{1755}$$

i.e.

$$\frac{V_N}{7} = \frac{V_T}{19} = \frac{V_L}{39}$$

Now

$$\frac{R_L}{R_T} = \frac{V_L}{V_T} \cdot \frac{I_T}{I_L} = \frac{39}{19} \cdot \frac{8}{3} = 5{\cdot}47$$

$$\therefore\ R_L = 5{\cdot}47\, R_T$$

Also

$$\frac{R_N}{R_T} = \frac{V_N}{V_T} \cdot \frac{I_T}{I_N} = \frac{19}{7} \cdot \frac{8}{5} = 4{\cdot}34$$

$$\therefore\ R_N = 4{\cdot}34\, R_T$$

Again the power ratios

$$\frac{P_L}{P_T} = \frac{V_L}{V_T} \cdot \frac{I_L}{I_T} = \frac{39}{19} \cdot \frac{3}{8} = {\cdot}77 = 1{\cdot}1 \text{ dB}$$

and

$$\frac{P_N}{P_T} = \frac{V_N}{V_T} \cdot \frac{I_N}{I_T} = \frac{7}{19} \cdot \frac{5}{8} = {\cdot}23 = 6{\cdot}4 \text{ dB}$$

As they should, these add to unity.

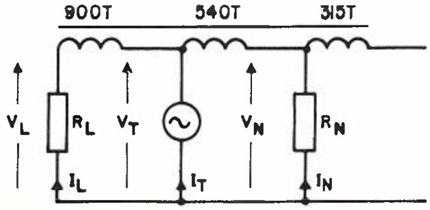


Fig. 22 — Test of Hybrid Circuit of 801 Telephone.

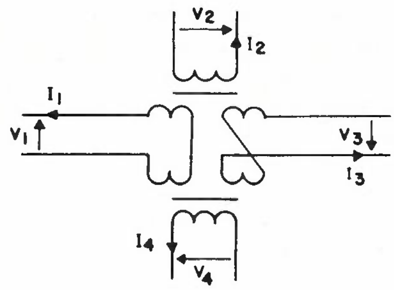


Fig. 23 — Currents and Voltages in a Hybrid.

These results give all the impedance and power ratios of the circuit, except for the impedance associated with the receiver port. This is the input impedance of this port in the condition shown. To calculate this it is useful to recognise that since there is no coupling between the transmitter and receiver ports, this impedance is unaffected if the transmitter port is short circuited. This gives a simpler circuit, and standard calculations give $R_R = 0.536\, R^T$.

Circuit Calculations

To calculate the currents, voltages and impedances in a circuit with a hybrid, particularly in the unbalanced state, is difficult. It is usually best to use one or more of the equivalents shown in Part 1. For those who are interested, the method of deriving them is described here.

As a network element, a hybrid has four ports, with four voltages and currents associated with them, as shown in **Fig. 25.** The effect of the hybrid is represented by four equations, representing the conditions the external currents and voltages are forced to satisfy by the two transformers. These equations are:

$$\begin{aligned}
V_1 + \sqrt{{\cdot}5}\, V_2 \quad & \quad + \sqrt{{\cdot}5}\, V_4 = 0 \\
- \sqrt{{\cdot}5}\, V_2 \quad & + V_3 + \sqrt{{\cdot}5}\, V_4 = 0 \\
\sqrt{{\cdot}5}\, I_1 \quad & - I_2 + \sqrt{{\cdot}5}\, I_3 \quad = 0 \\
\sqrt{{\cdot}5}\, I_1 \quad & - \sqrt{{\cdot}5}\, I_3 \quad - I_4 = 0
\end{aligned}$$

In addition, the external circuits connected to the four ports establish other relationships between the currents and voltages, providing one additional equation per port. These eight equations are sufficient to specify all currents and voltages in the circuit. However, this procedure is of little practical value without the assistance of a digital computer and meticulous accuracy in ensuring that all signs are correct.

It is usually far easier to use one of the equivalent circuits shown in Part 1 of this article. These can be derived by the use of a more general equivalent shown in **Fig. 24.** This circuit containing a hybrid, two positive impedances and two negative impedances is electrically identical to the hybrid alone. A proof is given in Ref. 2. This equivalence can be used by setting the negative impedance equal to the external impedance of a port, allowing that port to be deleted from the circuit.

To illustrate this, consider the problem of determining the input impedance of port 1 in **Fig. 25A.** Adding impedances equal to $+ Z_2$ to ports 1 and 3, and $-Z_2$ to ports 2 and 4 does not affect the external conditions, and this gives **Fig. 25B.** This gives a total impedance in port 2 of zero and the corresponding transformer, having one winding shorted, can be deleted from the circuit, giving **Fig. 25C.** The input impedance of port 1 is now that of Z_2 in series with a transformer; this becomes the network of impedances shown in **Fig. 25D.** This equivalence was quoted without proof in Part 1. The other equivalents shown there, and many similar ones, can easily be derived in this way. Each such equivalence gives only one or two properties of the hybrid, but their ease of use is of considerable advantage, particularly where only a few of the properties of the circuit are of interest in a particular case.

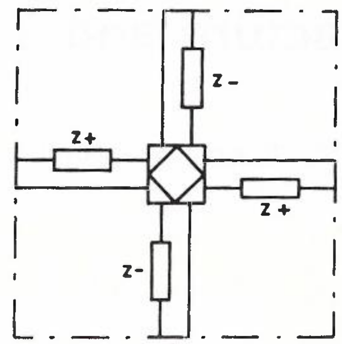


Fig. 24 — An Equivalent Circuit.

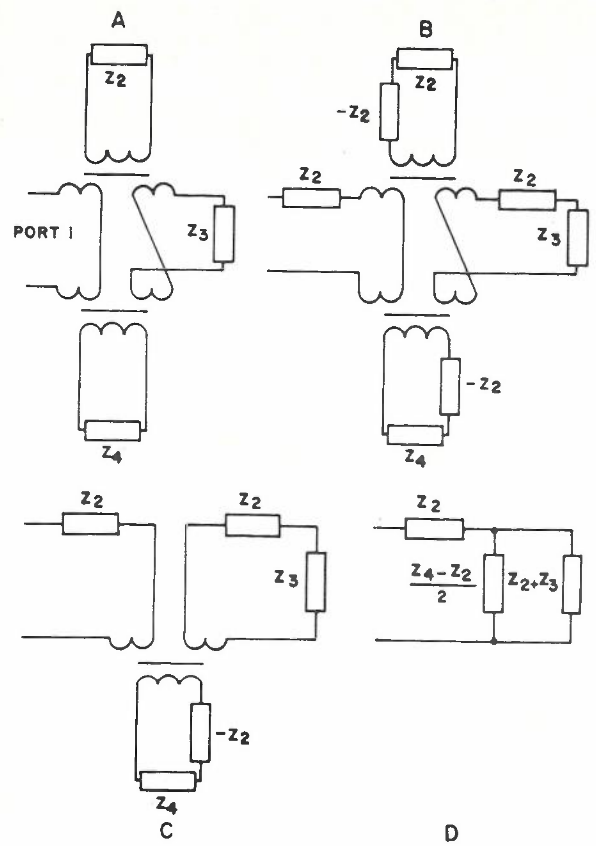


Fig. 25 — An Application of Equivalence of Fig. 24.

REFERENCES

2. Freeman, A.H. : "Hybrid Coil Amplifiers", Australian Telecommunications Research, Vol. 3, No. 2, November 1969.
3. Friedham, H.O. : "On Hybrid Transformers", A.T.E. Journal, 1958, 14, 218-228.
4. "Operation and Application of Hybrid Junctions", Lenkurt Demodulator, 1953, Vol. 2, No. 9.

A.H. FREEMAN is Supervising Engineer, Switching and Facilities, Country Section, Planning and Programming Branch, NSW See Vol. 18, No. 3.

Manufacture and Test of ARE-11 Equipment

C. O'REILLY, Dip. E.E. and B. J. McMAHON, B.E.

Previous articles have introduced the ARE system and described a new installation at Elsternwick, Victoria, and the conversion of a working ARF exchange to ARE at Salisbury, South Australia.

This article explains the production and installation testing procedures used to preserve the ARE system's capacity to operate to the standard of reliability for which it is designed.

INTRODUCTION

Previous articles in this series have provided an introduction to the system (Ref. 1) a review of the equipment and project activities for the new exchange at Elsternwick, Victoria (Ref. 2) and a summary of the experience in cutover of a working ARF exchange to ARE 11 at Salisbury, SA (Ref. 3).

In this paper, the authors will concentrate on two closely related aspects of the system; the reliability criteria and how these are met in production, and the system characteristics which have been developed to ensure an efficient procedure for production testing and for installation and commissioning of the ARE-11 exchanges.

RELIABILITY

The reliability of a Stored Program Controlled (SPC) system such as ARE-11 depends on a number of factors including the control system architecture, the diagnostic and switchover mechanisms of the central devices, and the purity of the software. All of these factors have been well considered in the ARE-11 system and are treated in some detail in other articles (Ref. 4, 5). Fundamental to the system reliability there remains the correct choice of components in printed board and shelf assemblies and control during the manufacturing processes so that the delivered hardware will fulfil the long term reliability criteria on which the system performance relies.

In the design of the electronic equipment for ARE-11, the starting point for the detailed design work has been an approved range of component types. This range has been established after extensive testing, and includes large scale integrated (LSI) circuits, semiconductor memories of both random access (RAM) and read-only (PROM) types, and ferrite memories for the central stores.

The equipment practice uses the component boards of L. M. Ericsson's type ROE which are pluggable in the BCH 300 shelves, which are in turn plugged into jacks in the side of the electronic racks of type BDH. The hardware design is then based on a stringent set of rules related to this equipment practice, incorporating a number of standards which have been developed as a result of manufacturing experience. Among these may be noted the range of standards applying to the printed board layout design which are aimed at ensuring an economical and reliable design for manufacture and field use.

An indication of the effect of the compliance with these design rules can be seen in the behaviour of the system under extreme environmental stress. During the system evaluation by Telecom Australia, the ARE-11 model exchange in Melbourne was subjected to an ambient temperature of 35°C for a period of 4 hours after the temperature build-up. The control equipment continued to function without failure. In this context another noteworthy result was the measured temperature increase within the shelves. This was in all cases less than half of the worst-case allowed values, which in turn are usually a restriction of the working temperature range of the components as compared to the range allowed for by the component manufacturers.

In the following chapters it will be shown how the production process includes a series of check procedures all aimed at delivery of a product in which these fundamental design requirements are fulfilled for the long term of service that the equipment is to provide.

MANUFACTURE OF ARE-11 IN AUSTRALIA

Production

The introduction of ARE-11 into production in Australia meant that the production articles became much more complex. This meant that many existing manufacturing policies had to be studied and changed as well as the purchase of expensive new equipment. Previous to ARE-11 some printed board assemblies (PBAs) had been produced of the type ROA for crossbar exchanges. Over the recent years a number of PBAs type ROE for traffic signalling systems and tariff control systems have also been produced. Generally, the production system used with the ARE-11 production can be illustrated in **Fig. 1.**

Component Testing

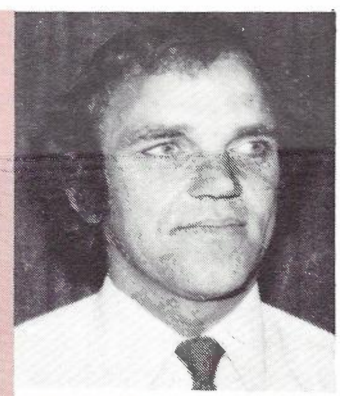
With the introduction of more complex articles it became essential that all faults were eliminated at an early stage of manufacture. This meant that the traditional incoming inspection via sampling needed review and in some cases 100% inspection has been introduced. In addition, to achieve the required reliability of the overall system certain environmental stresses have to be applied to components. This is the case for ICs where MIL STD 883 is followed. A summary is given in this military standard, **Fig. 2.** All acceptable components pass into store where stringent storage and handling procedures are followed.

Manufacture of PBAs, Shelves, Racks and Cables

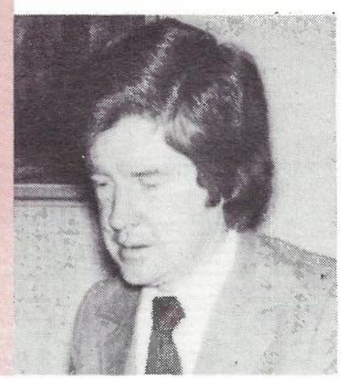
Most of the assembly work on all articles is performed manually. On shelves and cables the direct wiring principle is used, where the wire is located and terminated in the one operation. Assembly of PBAs is performed with utmost care as the simplest error can be extremely expensive to locate at a later stage. Soldering of racks and shelves is also a manual operation. PBAs are soldered in a wave soldering machine where output and quality are improved. After all soldering operations, 100% visual inspection is performed to achieve the desired quality levels.

COLIN O'REILLY joined L. M. Ericsson in 1964 as a test technician in their final test department. Over a number of years he worked in production testing, test equipment maintenance and test engineering. He was promoted to his present position of Quality Assurance Manager in 1973.

He holds a Diploma Certificate in Electrical Engineering from the Ballarat School of Mines. At present he is a member of SAA Committee MS 29 (Quality Control).



BRYAN McMAHON joined L. M. Ericsson in 1967 after working with the PMG's Department in Queensland and at the Research Labs at Headquarters. With L. M. Ericsson he has worked with the parent company on AKE and CCITT No. 6 development, and on AKE project work in Mexico. As Systems Engineering Manager, he is now in charge of the design and development activities of L. M. Ericsson in Australia.



Testing of PBAs, Shelves, Racks and Cables

Not all production processes are fault free and therefore 100% final testing is performed on all products.

Racks, shelves and cables are tested on an automatic-tester. The tester is an electro-mechanical device controlled by coded punched tape that tests continuity and leakage of all

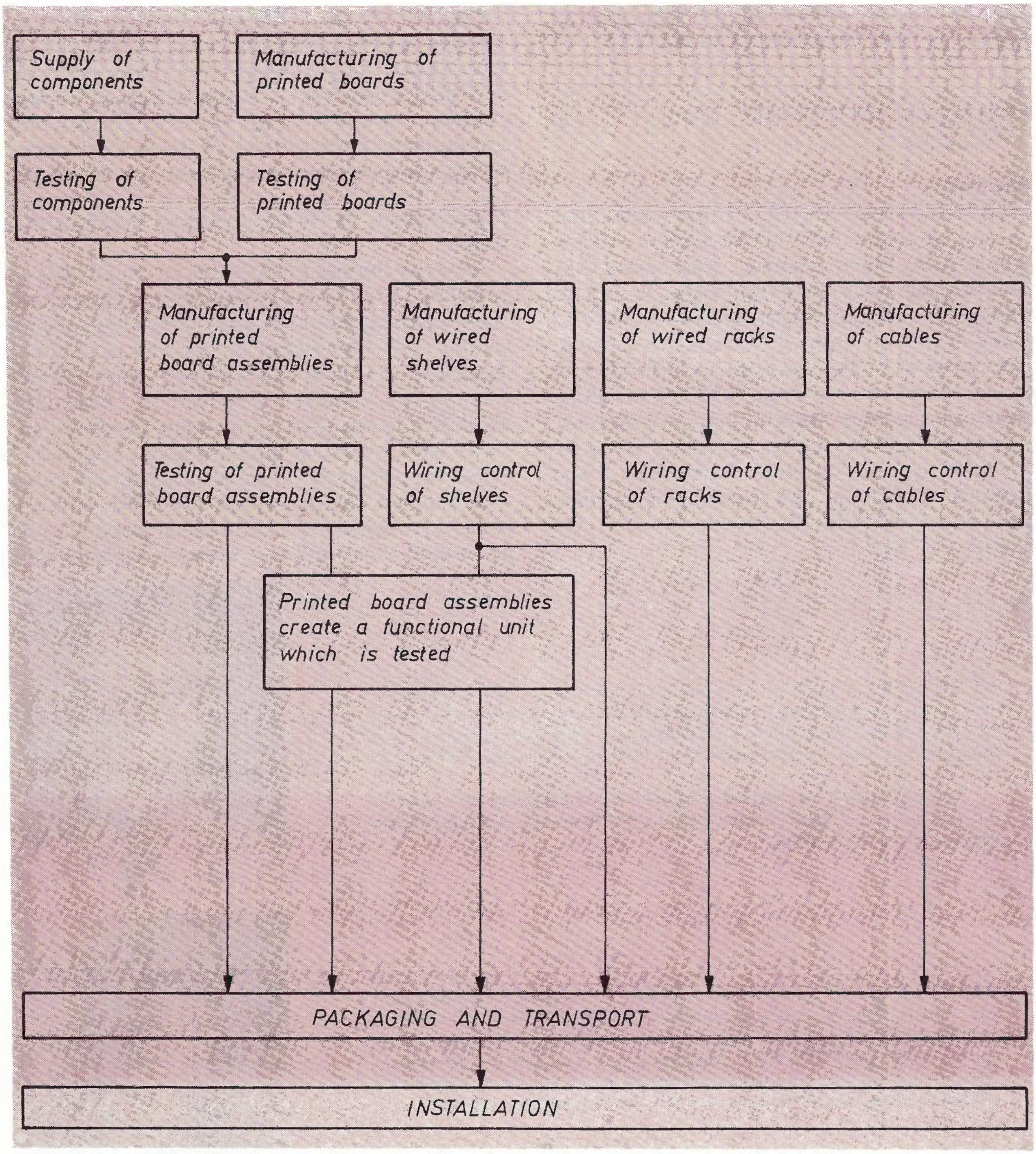


Fig. 1 — Outline of Production System for ARE-11.

circuits. During testing, faults are noted on a printer for analysis. All faults are repaired and all devices are retested.

Printed board assemblies range in circuit type and complexity from simple attenuation pads to digital processing units. Basically, they can be divided into 2 categories, Digital and Analog.

Digital Boards

Digital boards usually require large amounts of test data which must be executed at a fast rate. To achieve this LME have designed their own computer-controlled test equipment, LPA 101. The functions of this tester are to:

- Check the test object against its truth table
- Check any static or dynamic measurement critical in the design
- Communicate with the tester via a test screen or a printer.

The LPA is a modular design with a processor controlling a number of test stations. The processor consists of a mini-computer PDP11, a teletype, a cartridge tape recorder and a disc memory. A system program, loaded from the cartridge recorder controls the computer during the read-in, editing translation, storage and executing of the test programs.

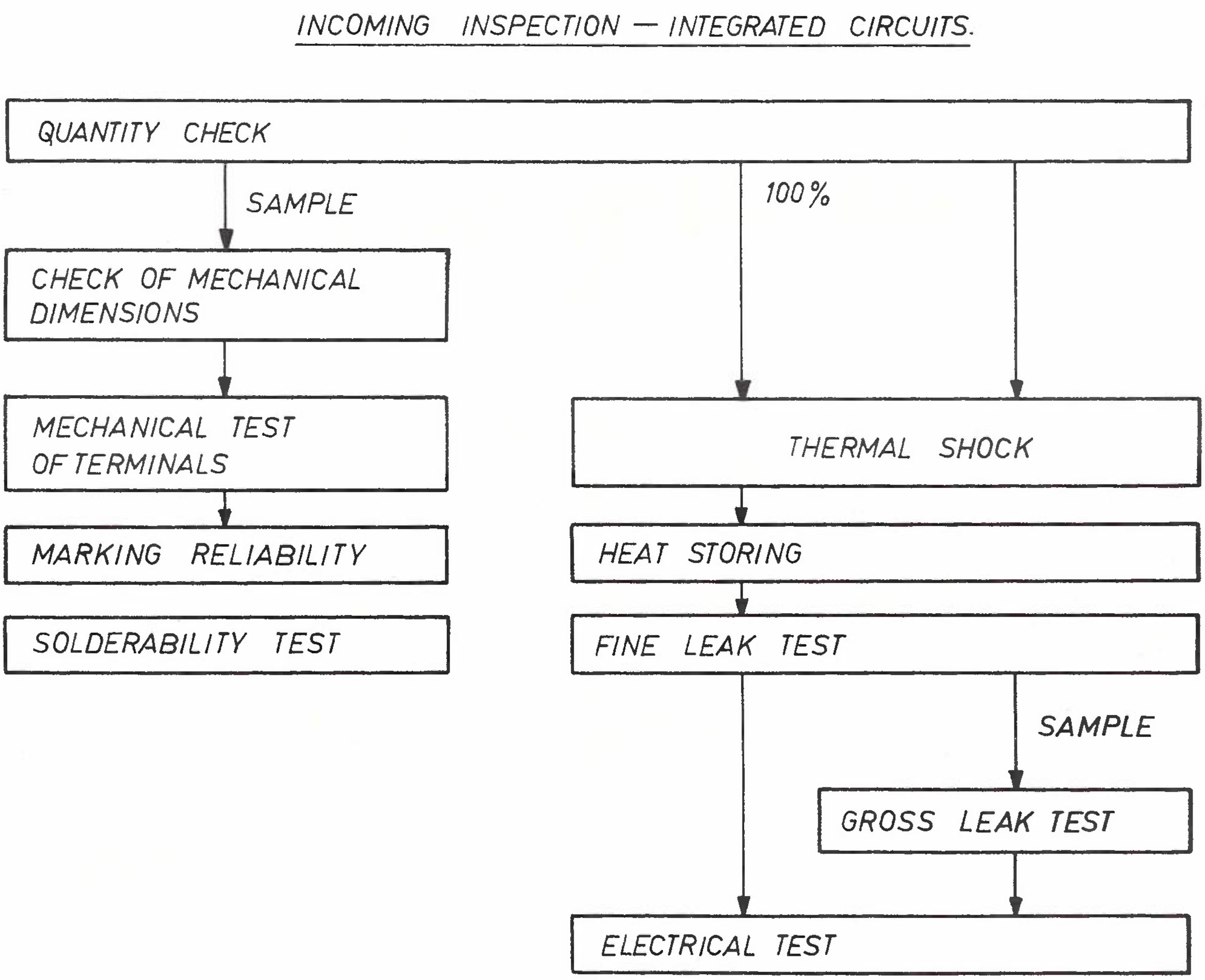


Fig. 2 — Summary of MIL-Standard for IC-Testing in ARE-11 Production.

The test programs are written in a high level language, similar to Fortan but application oriented. Several programs can be stored simultaneously in the memory and they can be edited or executed from one or two test stations.

Testing is performed by placing the PBA in the test fixture and pressing a start button. The test result is displayed on an alphanumerical display. Faults on boards can be isolated by the assistance of a fault tracing probe. The probe can be either operator guided to locate the fault or the operator can be directed by system software.

Analog Boards

Analog boards can be tested in a similar way to digital boards with computer controlled equipment. In this case a number of signal generators and sensing instruments are controlled by a processor. Fault localisation is more difficult with analog boards. To assist the tester a number of test points are incorporated in the design of the board. Thus the test equipment can nominate that the fault is in a small functional unit.

Equipped Shelves

After the boards and shelves have been tested they are integrated together to form a complete functional unit. These units are tested before delivery. The testing on distributed devices such as STU-L, KMK, KMT, is performed in an ARE-11 exchange with a simulated switching environment. Special test programs are stored within the CPU and when executed simulate exchange traffic on the unit under test. Faults within each unit are isolated to boards or shelf level. The faulty board or shelf is returned to PBA or shelf test for retesting to locate the fault.

The advantage of testing the units by this method is that the shelf is tested with test data, patterns and test speeds simulating the environment in normal operation.

Central devices such as CPU, Program Store (PRS), Data Stores (DAS) and Central Stores are tested by means of special diagnostic test programs run in the ARE-11 processors. This is done because it is virtually impossible to exercise every branch in every program normally resident in Traffic Control Processor (TCP) or Operations and Maintenance Processor (OMP). The correctness of each program in PRS is established in the diagnostic routines by calculating a so-called check sum whereby all instruction words are added together and the check sum value is printed out for each program.

In addition to the diagnostic tests, the normal operating system consisting of Monitor and Data Refresh programs is run and checked to respond normally to various conditions such as power failure.

INSTALLATION TESTING

Hardware Testing

The delivery of electronic equipment from the factory follows the testing as described above of each fully-equipped shelf in a master test environment. An important aspect of the development of the ARE-11 system is the provision of more automated testing at the installation site. For testing of the installed hardware, the method is very similar to that used in production testing, the main difference is that an access switch (ACS) is used in the production test plant, and access to the device under test is achieved in installation testing by moving the gaffel-tag plug from one position to the next.

In addition a remote control unit (RCU) is used by the operator in installation testing to communicate with OMP from the racks where the shelves under test are located.

To start a series of tests on hardware units the operator issues an appropriate command from an I/O device; the green lamp on RCU will then be lit to indicate that OMP is ready to start the test. The operator gives one pulse on the RCU-button to begin the test sequence; when OMP completes a fault free test run on a device, the green lamp is again lit while OMP waits for an order from the operator. Normally the operator will move the test connections to the position for the next device and give two pulses on the RCU to cause the OMP to test the next device.

When a test finds a faulty device, a fault printout is received, and the red lamp on the RCU will be lit, and the operator has two options. The test can be repeated by pressing the RCU-button once, or the next device can be tested after moving the connections and giving two pulses from RCU.

It is not necessary to exhaustively test all electronic shelves in an installation in this way, since the fault risk for some shelf types is low, and they will be tested during subsequent activities in the commissioning of the exchange. At present, it is intended that this hardware testing at site be performed on all device types except Multiplexer (MUX), though Digit Controller Identifier (IDS) and TCP-PBX Test Interface (PBXE) are not tested in isolation but together with Digit Controller (DCI) and PBX Line Test and Connect Relay Sets (PBXR/PBX-C) respectively. Further exceptions may be added as experience is gathered from the installation activities.

This hardware testing requires the basic functions of both OMP and TCP, and some additional programs in OMP which are used both for production and installation testing. Further, a standard set of Translation Store (TRS) data has been developed which with minor adaptions, can be used at all installation sites so that this testing can be performed independent of the data preparation for a particular exchange.

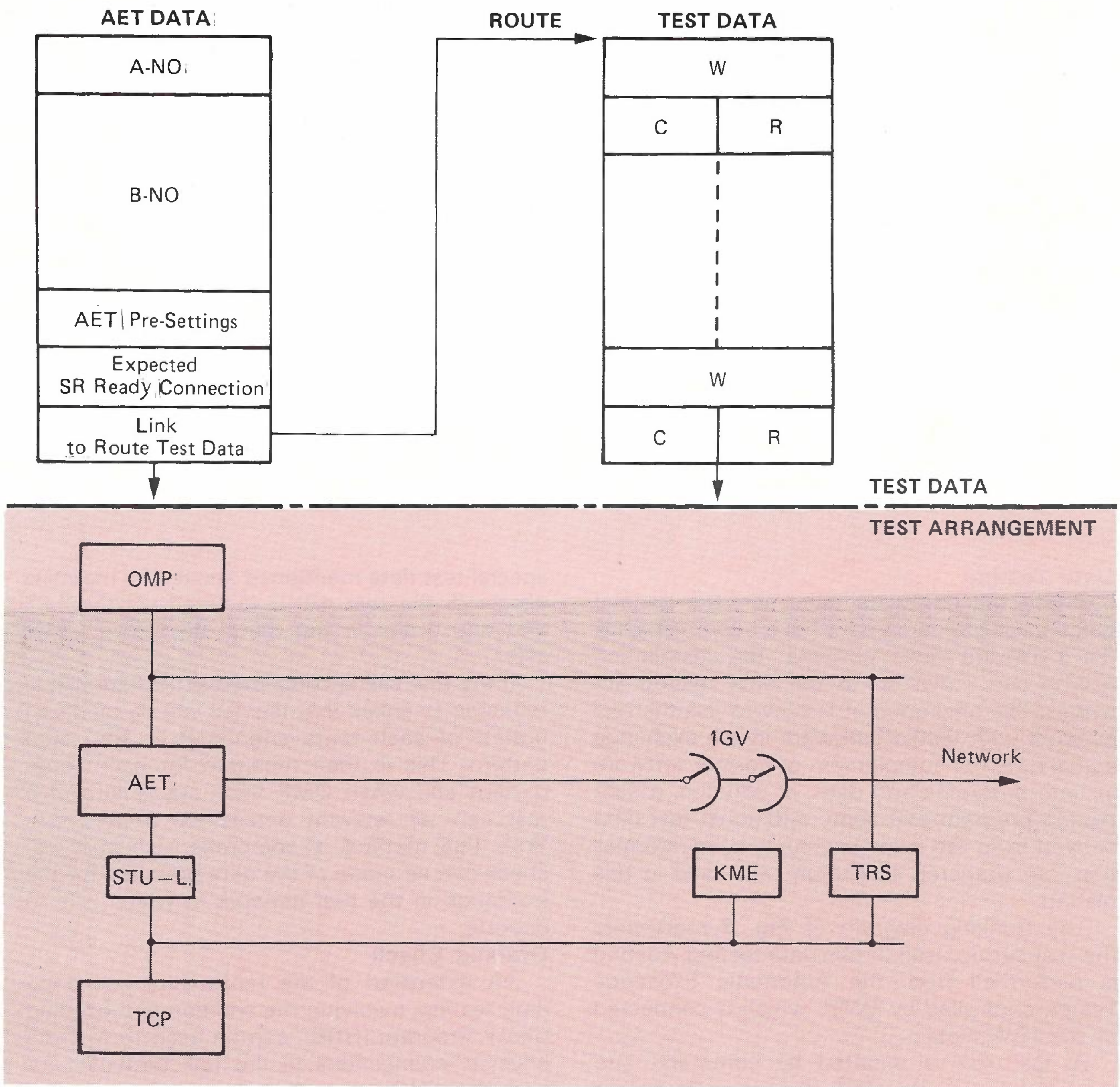


Fig. 3 — Trunking Diagram for Exchange Data Testing

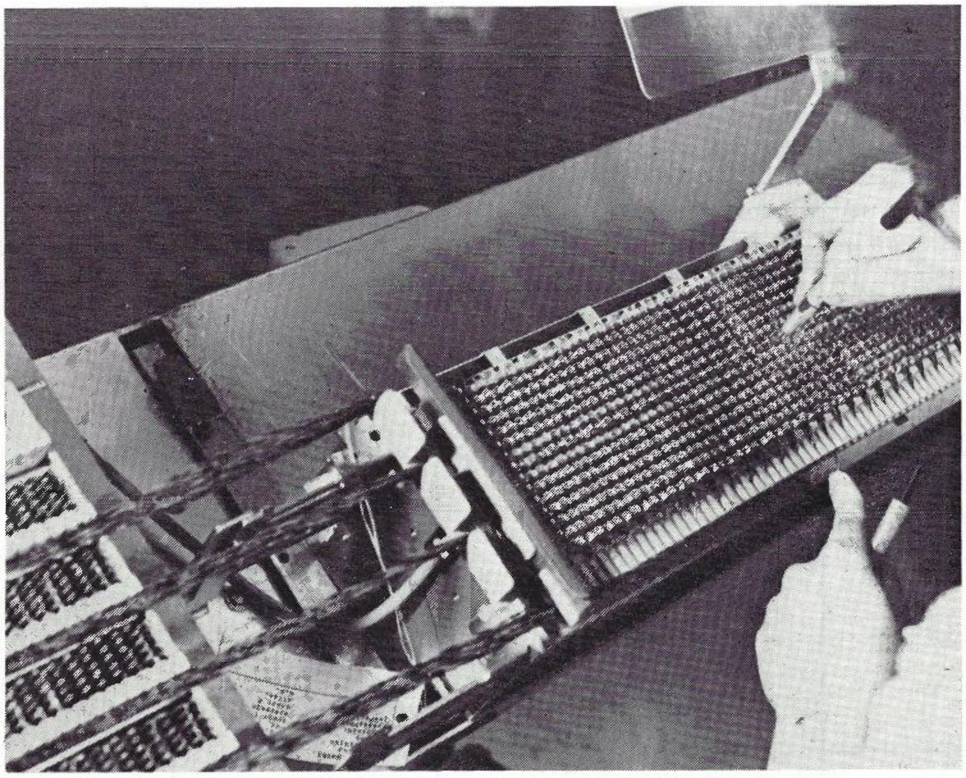


Fig. 4 — Direct Wiring of a BCH 300 Backplane. The unit being wired is a single-height shelf and the operator is guiding the wire to a terminating tag using a special wire-feeding tool.

Data Testing

When the hardware units and the general function of the equipment have been tested by the hardware tests outlined, the installation testing can move on to the data testing activities. The environment is now to use the real network with tested hardware in the exchange against the full complement of normal software in both programs and data. In addition, a data testing program and some additional test data derived from the same exchange base information, but prepared separately, are used in this testing.

The trunking diagram of **Fig. 3** represents the test set-up used in this data testing. Testing is performed from the Automatic Exchange Tester, controlled by OMP, which is connected to the IGV inlets.

A test call is initiated by command and started through the AET. Program Data Test (DAT) compares GV routing data against the special test data mentioned above. If a match is obtained, the test call is initiated via the AET and one outlet in the route alternative under test.

If the test call is completed satisfactorily it is repeated to check that the call can be made on outlets of each route alternative in the route pattern. This is then repeated for each route pattern and when OMP finds any failure of a test call, all relevant details are printed out. With this method, a comprehensive and real check can be made of the data prepared for the exchange in the real network in which it is to operate.

Grading Check

An extension of the method of exchange data testing, involving the addition of a Grading Check Program (GRC), can be used to test the physical connections in the IDF between GV and the FURs, and also between switching stages.

The method also exploits the capability in ARE-11 of individual selection of an FUR, and consists of establishing a series of calls from AET to each outlet on one route. The calls are terminated in the AET and in this way checked that they pick up the correct wires and connections through the grading. The wires within the one outlet are checked for correct poling.

OMP OPERATING SYSTEM (OMPOS) AND MAINTENANCE FACILITIES

After the testing and acceptance of the Telecom model exchange, the need for more extensive operation and maintenance facilities was seen by both Telecom and L. M. Ericsson. Some special solutions were studied, but it was decided in mid-1976 that an improved operating system for OMP, together with an expanded program and data store for OMP, should be adopted as the basis for the ARE-11 exchanges in Australia. These and associated hardware enhancements to the CPU and some interface devices ensure that the ARE-11 system now being introduced in Australia conforms to the standard LME system. They also give the capability of providing specific Telecom facilities now, and additional maintenance facilities developed by LME or specified by Telecom at a later stage.

Among the functions which will be provided in addition to those available at Elsternwick and Salisbury are the following:

- Interface and Transmission of alarm and test data to Automatic Disturbance Recording (ADR) network.
- Marker supervision including Marker Disturbance Recording.
- Improved hardware routine test facilities.
- Remotely controlled Exchange Tester.
- External communication between processor groups.

Future developments associated with the new OMP operating system will allow the introduction of facilities such as:

- Interworking with centralised maintenance systems.
- Electronic Charging.

Fig. 5 — General View of the ARE-11 Delivery Testing Equipment at the Broadmeadows Plant of L M Ericsson. The test positions for the testing of equipped shelves are at a height suitable for easy access and handling during the test.

CONCLUSION

The quality control and testing procedures outlined here provide a sound starting point for the operation and maintenance of ARE exchanges, which will be the subject of a further article.

REFERENCES

1. Close, W.: "ARE-11 System Appreciation"; Telecom Journal of Australia, Vol. 27, No. 1, 1977.
2. Dougall, C.: "Elsternwick ARE-11 Exchange"; Telecom Journal of Australia, Vol. 27, No. 2, 1977.
3. Douglas, K.: "Converting a working ARF 102 Exchange to ARE-11"; Telecom Journal of Australia, Vol. 28, No. 1, 1978.
4. Morlinger, R. and Viktorsson, O.: "ARE-11 System Description"; Ericsson Review, No. 2, 1977.
5. Hemre, A. and Hagard, G.: "Software and its handling in the ARE-systems"; Ericsson Review No. 2, 1977.

The Papua New Guinea Telecommunications Network

F.A. COATES, M.I.E. Aust.

The brief but remarkable history of the development of the telecommunications network of Papua New Guinea spans, in just two decades, the transition from H. F. shout-down trunks and manual switchboards, to virtually complete automation, ISD and Stored Program Control switching equipment.

The web of telecommunications is a vital factor in the coalescence of an emerging new nation.

Telecom men, (many of them Australians) with the determination to get things done often at great personal risk, have aided in the spread of telecommunications across the ruggedly beautiful face of Papua New Guinea.

A CAPSULE HISTORY OF PAPUA NEW GUINEA

The mainland of what is now Papua New Guinea was probably first sighted by Portuguese and Spanish navigators en route to the East Indies in the early part of the sixteenth Century. Following his chance discovery around 1526, Don Jorge de Meneses is thought to have named the island Papua after the local name describing the inhabitants' appearance. Another early traveller fancied he could see a resemblence between these people of the South-west Pacific and the inhabitants of the African Guinea Coast and adopted the term "New Guinea".

Europe's need for coconut oil, a natural product in Papua New Guinea, provided the stimulus which ultimately ended the country's isolation. In 1884 Germany and Great Britain claimed the island's northern and southern segments respectively. At the outbreak of World War I Australian troops occupied German New Guinea and it remained under military administration until 1921 when the League of Nations conveyed a mandate upon His Britannic Majesty for and on behalf of Australia. British New Guinea, as Papua was then called, was placed under Australian Authority in 1905. Following the disruption to civil rule caused by combat action of World War II, the United Nations General Assembly approved a Trusteeship Agreement which established New Guinea as a Trust Territory and in 1949 the territory of Papua and New Guinea became a single Australian administrative unit.

Formal self government, on December 1st 1973 transferred responsibility over all internal matters to the Papua New Guinea House of Assembly. Independence followed a short time later when on September 16th, 1975, Papua New Guinea became a fully independent State within the British Commonwealth of Nations.

English is one of the three official languages and is widely used in this country of over 700 different language groups. The other official languages are Melanesian Pidgin and Hiri Motu.

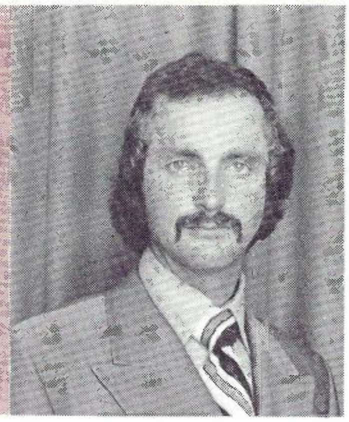
Papua New Guinea's main export is copper from the world's largest open-cut copper mine on Bougainville Island. Other major exports are gold, coffee, copra, cocoa, coconut oil, timber and rubber.

THE TELECOMMUNICATIONS ADMINISTRATION

Early History

The first telephone exchange in Papua New Guinea was installed in 1910 for the benefit of 30 subscribers in the Port Moresby area. Long distance communications commenced in Rabaul during 1912 when the German ad-

FRANK COATES commenced his career in 1960 as a Technician-in-Training with the PMG Department. After various appointments in the technical ranks he won a Trainee Engineer place and graduated from RMIT in 1970. Following network planning and traffic engineering positions in Planning Branch, Victoria he was seconded to Postal and Telecommunications Services, Papua New Guinea in 1974 as a Senior Engineer in the newly formed International Telecommunications Division. He has represented PNG in a number of international forums on network planning and operations in pursuance of the Country's search for telecommunication autonomy. In 1976, as Supervising Engineer of the Technical Services Branch, he headed a group to investigate the Department's requirements in traffic data collection, forecasting and the supply of basic planning information for the orderly development of the telecommunications network of Papua New Guinea.



ministration established a morse radio station to communicate with her warships in the South Pacific. In the following year the Royal Australian Navy established a morse station at Port Moresby. This was followed by stations in the eastern islands of Samarai and Woodlark.

The telephone service also had an early beginning on New Britain Island with a service between Rabaul and Kokopo (about 25 kms) before World War I. It was later taken over by the Australian Government at which time it attracted an ordinance proclaiming that all calls would be free. By one of those curious anomalies that seem to so often haunt bureaucracies, this was not rescinded until 1951.

In a post-war reorganization the administration of the country's telecommunications was placed under the control of Amalgamated Wireless (Australia), a private company operating what became known as the Islands Radio Service. This arrangement persisted from 1922 until shortly after the outbreak of war in the Pacific.

As with many aspects of human activity, the Second World War stimulated the development of the country's telecommunications. Manual telephone exchanges were established by the Australian and United States armies in Lae, Finschhafen, Port Moresby, Madang, Wewak, Kieta and the northernmost island group of Manus. With the exception of Port Moresby and another at Samarai, all closed following the Japanese occupation of most of the country.

Post-War Period

With the peace came the necessary reconstruction of the country's services and industries. This was greatly hampered by inadequate cross-country communications. The remnants of the army system were handed over to the Australian administration but were in a poor state of repair.

Papua New Guinea's external communications including ship-to-shore, were the responsibility of the Overseas Telecommunications Commission (Australia) from 1946 until 1973.

Up until 1952 there was a strong but unsuccessful move to have the services of posts and communications controlled by the Australian Post Office since it was considered that the Administration lacked the necessary finance, personnel and materials to promote an efficient service.

With this daunting prospect the A.P.O. Divisional Engineer, Parkes, N.S.W., was appointed as the first Director of the Department of Posts and Telegraphs (P&T) in October, 1954. W. F. (Bill) Carter, O.B.E., arrived in the Territory of Papua and New Guinea shortly after his 30th birthday and was to guide the department through it's first 21 years of existence. His initial budget of about $800,000 for both operational and capital requirements was to be used to improve the efficiency of the postal and telecommunications facilities of the Country. On the telecommunications side this consisted of 15 telephone exchanges, about 2400 subscribers and a combined P&T staff strength of 152 Europeans and 364 Papua New Guineans.

The Emergent Nation

From these humble beginnings P&T has successfully progressed throughout a period of burgeoning demand, internationally negotiated capital investment and now operates on a commercial accounting basis, repaying dividends on the Government equity in the business.

On 10th December 1975 the responsibilities and functions of the Department of Posts and Telegraphs were incorporated in the Postal and Telecommunications Services of the newly formed Department of Public Utilities.

At the end of the financial year 1975/76 P&T held Telecommunications assets of the order of K40,000,000 ($A40,100,000) and showed a profit on this side of the business of over K4,676,000 (**Fig. 1**).

From the inception of P & T the Department has pursued a vigorous localization policy in spite of considerable training difficulties associated with a rapidly changing technology. Of the 1028 people employed in the telecommunications field at June 1976, over 70% were PNG nationals. The P&T senior administration has nearly 80% of its positions filled by nationals, one of whom is Mr Carter's successor, Mr Israel Edoni, Secretary of the Department of Public Utilities.

Unfortunately, the PNG educational system is unable to cope with the demand for professional and semi-professional manpower required by the telecommunications industry. Engineering graduates from the Papua New Guinea University of Technology are hotly pursued by both Public and Private sectors alike. It is not surprising therefore that the greater proportion of the expatriate staff in P&T are engineers and senior technical officers. Without drastic changes in the present tertiary educational policies this situation is unlikely to change for many years.

In December 1973 Papua New Guinea assumed responsibility for International Telecommunications and the Coastal Radio services by

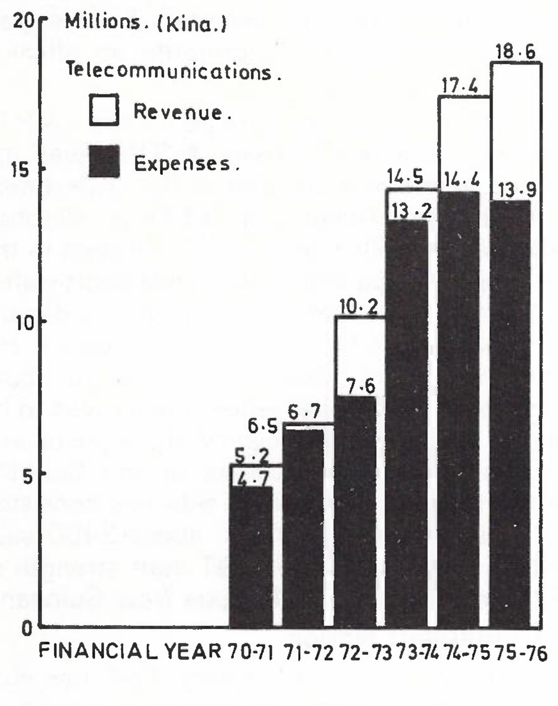


Fig. 1 — P & T's Telecommunications Business shows Healthy Profit.

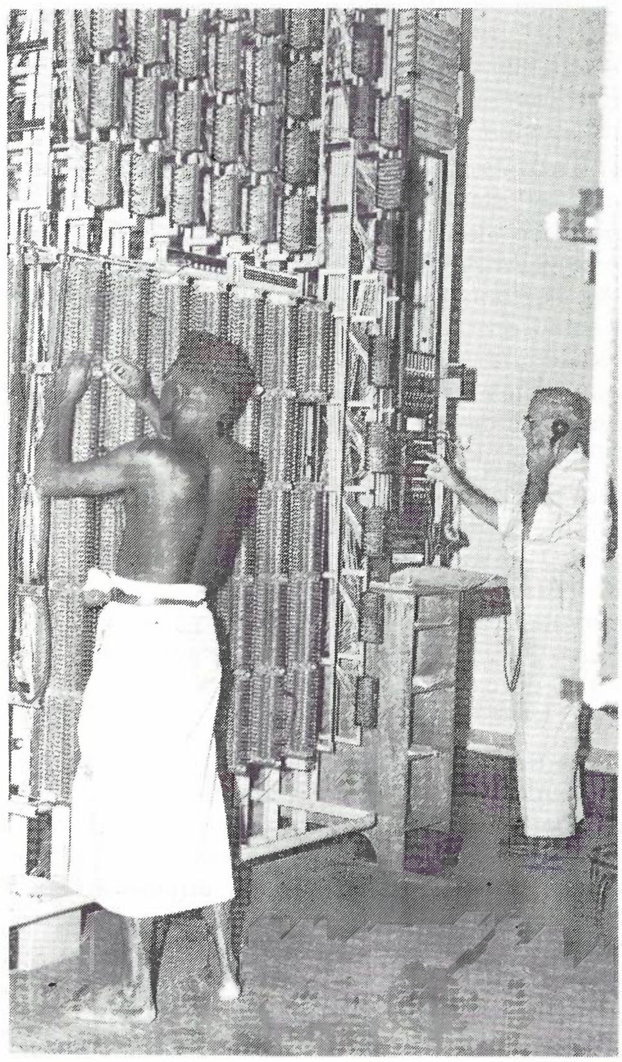


Fig. 2 — Rabaul SxS Exchange 1957. From Earliest Days P&T have Pursued a Vigorous Localization Policy.

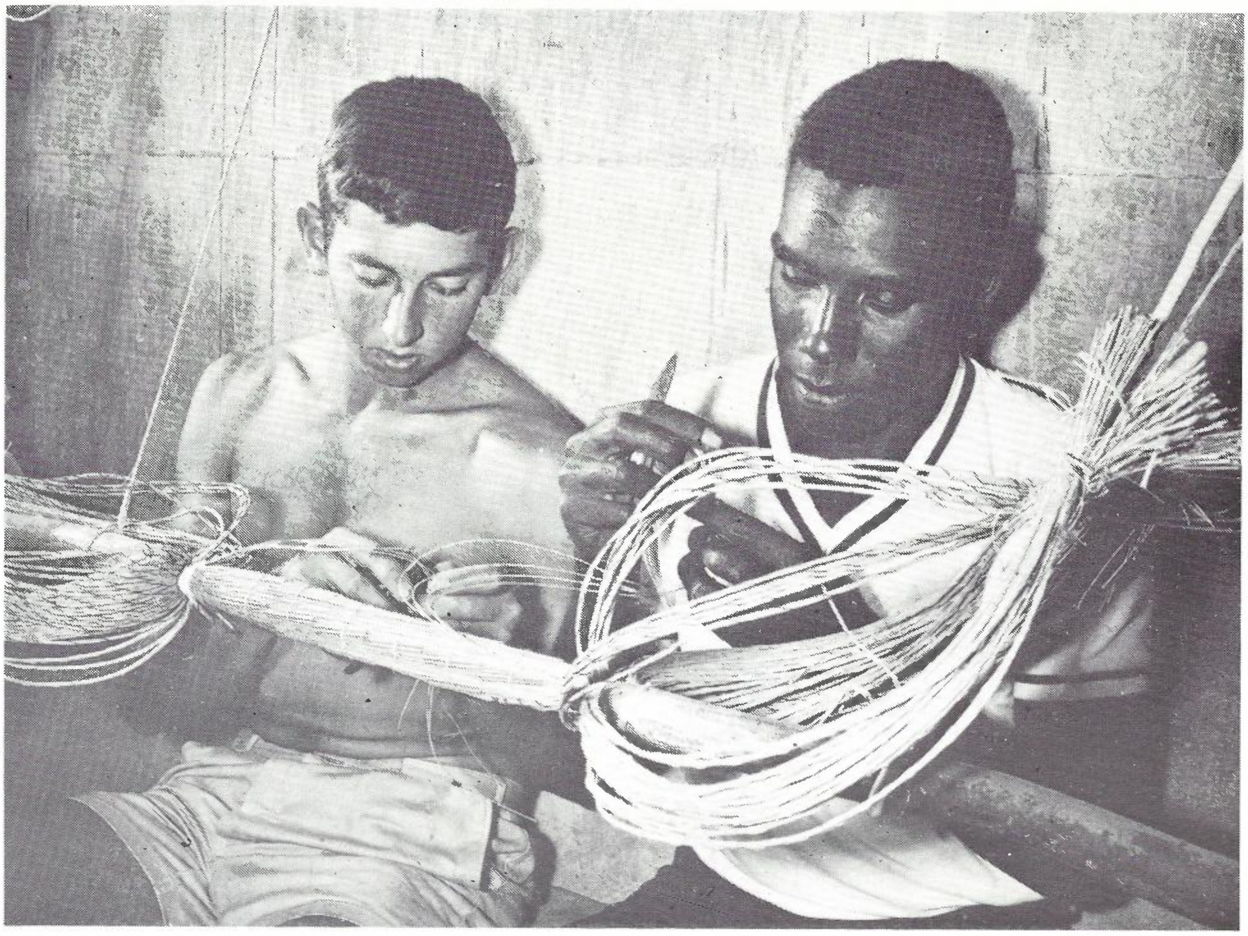


Fig. 3 — Linesman Training in the Field, Port Moresby

use of an Australian Government loan ($1 Million), and grant-in-aid ($0.5 Million) respectively to purchase the Overseas Telecommunicatons Commission (Australia) (OTC(A)) assets.

TELEPHONE DEVELOPMENT

The manual telephone exchanges handed to the Administration by the military at the end of World War II were in poor condition but with perseverence and cannibalization a basic service was maintained.

Planning commenced in 1952/53 for the introduction of automatic step-by-step exchanges. The period 1956 to 1958 was to see automatic exchanges installed at Port Moresby, Konedobu, Boroko (two suburbs of Port Moresby), Lae and Rabaul.

By 1969 additional automatic exchanges had been commissioned at Bomana and Sogeri (near Port Moresby), Kokopo and Toleap (near Rabaul), the old gold-mining towns of Bulolo and Wau south of Lae and on the North Coast, at Boram and Madang.

The Madang ARF was installed to L. M. Ericsson (Sweden) specifications and was the first of its type in Papua New Guinea. Toleap, Wau and Bulolo were Ericsson ARK's also provided to Swedish standards but incorporating modifcations to bring them into line with APO installations. The later Crossbar installations adopted APO standards.

Many new automatic exchanges followed but these remained within isolated automatic enclaves, there was no long distance communications of any significance. In mid 1968 there were still only 18 telephone trunk routes. But by then an exciting and ambitious expansion program had begun on the trunk network.

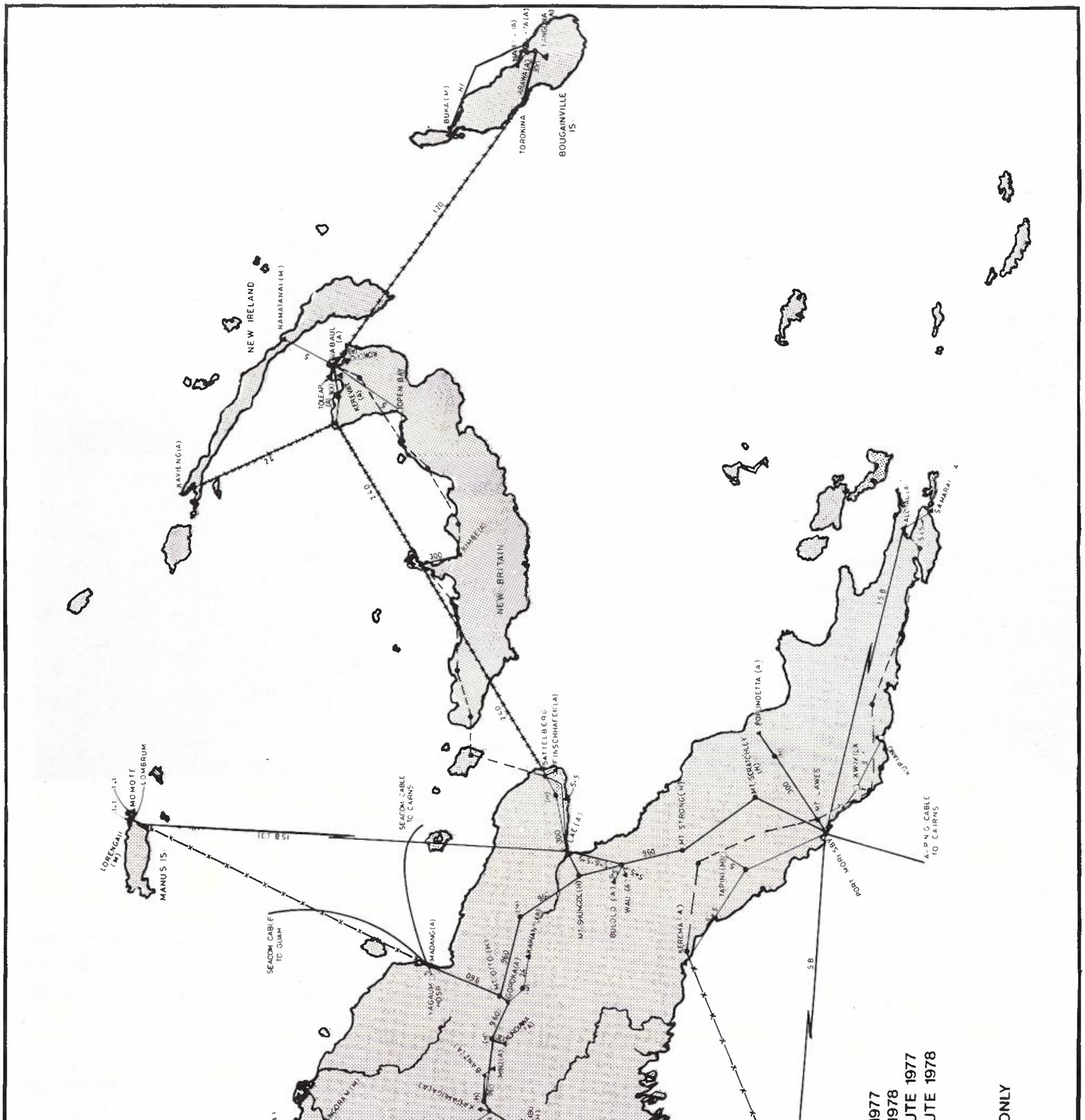


Fig. 4 — Papua New Guinea Telecommunications Network.

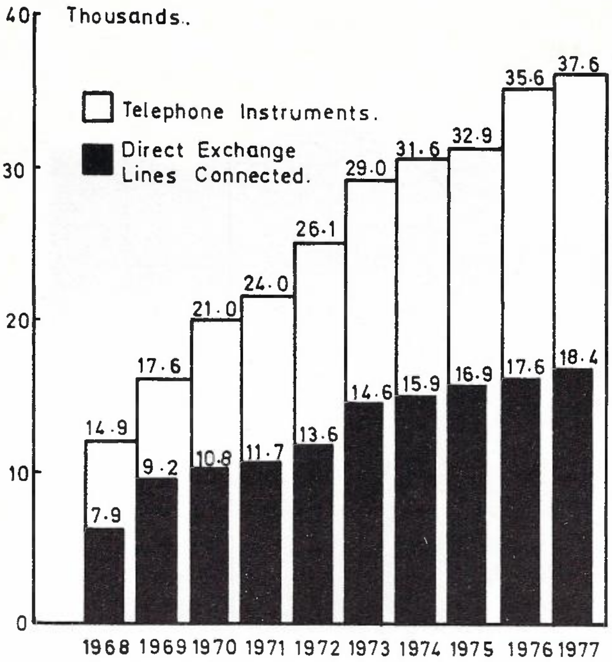


Fig. 5 — Telephone Subscriber Development. Average Growth of Over 10% per Annum Until Recent Recession.

TRUNK DEVELOPMENT

In the early sixties there were only 10 trunk line channels serving the Country's long distance telecommunications requirements. Many of the connections involved omnibus H. F. trunks giving poor transmission quality and low traffic capacity.

The trunk usage rate of about 14 calls per telephone per year, although very small was nevertheless sufficient to plunge the system into long delays. A modest improvement to the, service between Lae and Port Moresby was achieved with the installation, in the early 1960's, of two low power 5 channel VHF links via Mt Lawes and Mt Kaindi. It was 'diffraction all the way' but proved that if capital funds could be made available a commercially viable long distance network was a decided possibility.

A 24 channel system, installed in 1967, connected Lae to the SEACOM cable access point at Madang giving some PNG telecommunications customers access to new international facility provided by various Commonwealth countries.

In 1963 the International Bank for Reconstruction and Development (World Bank) was asked to make an investment survey of the whole country. Posts and Telegraphs was the only department to satisfy the Bank's criteria and the 1967 World Bank Loan of $US7 Million was made specifically for the development of telecommunications.

Then commenced an extraordinary broadband microwave installation project. Field surveys carried out on foot through some of the world's most rugged terrain gave many mountain villagers their first sight of white men outside the tiny isolated missionary stations. The field teams levelled suitable helicopter landing pads for later repeater installations by literally blasting off mountain tops.

The topography of the repeater sites presented system planners with rather unusual economic considerations. In the final analysis a system using high reliability, low power repeaters was chosen to minimize repeater maintenance visits which usually involve expensive helicopter hire charges or prohibitively costly access roads. A courageous decision was taken to purchase state-of-the-art micro-wave equipment whose power requirements (30 watts for a 1+1, 960 channel system) were such that they permitted a primary cell power source. The Italian Company, Telettra produce the 2GHz equipment which makes use of thin-film devices retransmitting the received signals directly at microwave frequency thus avoiding an intermediate frequency (IF) stage. P&T's latest plans to use Solar cells as the primary power source put the country as a forerunner in the use of this energy source.

TELEX

For many places and for many years the telegraph was the only means of contact with the outside world. In 1961 there were 13 zone centres that could accept telegraphic messages from 359 outstations, many of which were the only means of communication with the administrative centres of remote districts.

In the overall fabric of the Papua New Guinea telecommunications plan, the telegraph/telex service was also reviewed. Tenders for the supply of automatic Telex equipment for operation over the new broadband system were called in November 1971. The successful Contractor, Frederick Electronics Corporation, supplied a processor controlled exchange (ELTEX) in May 1974 for about $400,000 which is used as the

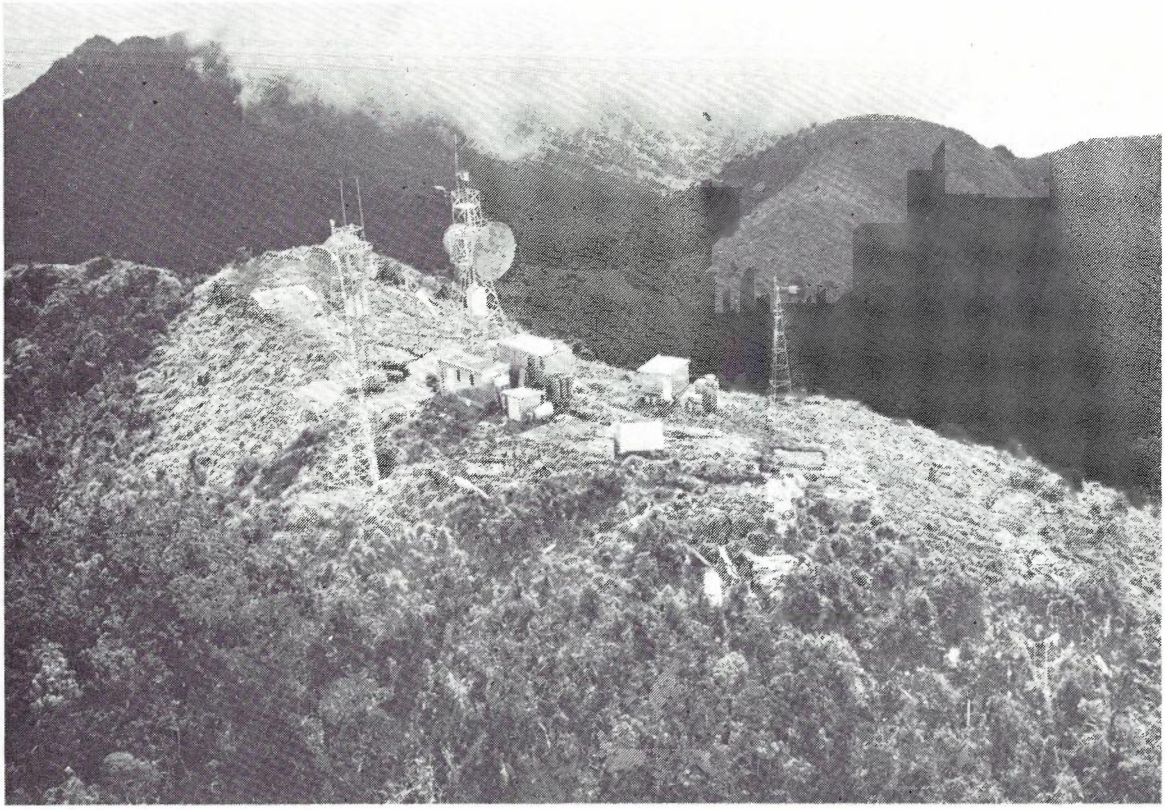


Fig. 6 — Mt Otto Repeater. Pivot Point of 960 Channel System for Goroka to Lae and Madang

national and international telex exchange. Also a similar system to the European "Gentex" service, where telegrams are transmitted by telex, is in operation from telegraphic offices throughout the country.

INTERNATIONAL

Except for a brief period following the second World War the Overseas Telecommunications Commission, Australia (OTC) and its predecessor, A.W.A., were responsible for all international services until self Government in December, 1973.

International Facilities

In 1967 the South East Asian Commonwealth Telephone (submarine) Cable System (SEACOM) was commissioned. The Papua New Guinea landing point at Madang provides 160 good quality channels both to the South, terminating at Cairns, and to the North and West with landing points at Guam, Hong Kong, Malaysia and Singapore. Papua New Guinea was able to purchase a 5% equity of this cable when, following Australian Government sponsorship, she became a partner in the Commonwealth Telecommunications Organization (CTO). The CTO is a unique partnership involving the free access to partnership facilities on a cost-by-usage basis. Technical co-operation stems from membership of various specialist groups within the Organization.

To gain access to SEACOM circuits OTC(A) installed an Ericsson ARM20 Gateway exchange at Madang in 1972. The exchange interested P & T Planners as a possible combined International and Main Trunk Exchange. The financial advantages to be won by removing one tier of the trunk switching hierachy were obvious **(Fig. 7)** however, two major problems arose. Firstly there was the question of economically combining these two functions in one switching machine. Expert assistance offered by OTC(A) and the APO differed in their respective assessments of the matter. Secondly, to efficiently carry the combined national and international traffic for Papua New Guinea the nodal switching point would need to be situated 250 kms to the south-east, at Lae. The decision of the day was to proceed with the Madang installation. Later, when the Madang Gateway was purchased (along with other OTC(A) assets), it was decided to close the exchange and move the international facility to the new multi-storey communications complex at Lae.

The Second International Bearer

In 1973 serious discussions began between P&T and OTC on the provision of a second broadband bearer between the two countries. Traffic growth rates were astronomical following the enthusiastic response to International Subscriber Dialling (ISD) from Papua New Guinea to Australia in late 1972 **(Fig. 8)**.

The alternatives that were considered were:

- an island-hopping microwave route from West Papua to Cape York
- a submarine cable
- a satellite earth station

The microwave route was attractive to P&T as it would have allowed development of the domestic network in a part of the country poorly served by telecommunications. However APO charges for the lease of bearers to OTC, the Australian international carrier, made this alternative financially unattractive. It is worth a speculative moment to ponder the changed course of telecommunications development in Papua New Guinea in this and other major projects had OTC and the APO been a single organisation.

The economics of the remaining alternatives were traffic sensitive with a low traffic situation favouring the earth station.

Traffic predictions were difficult to make during this period because of the step-function in the traffic volume data caused by the ISD service. A

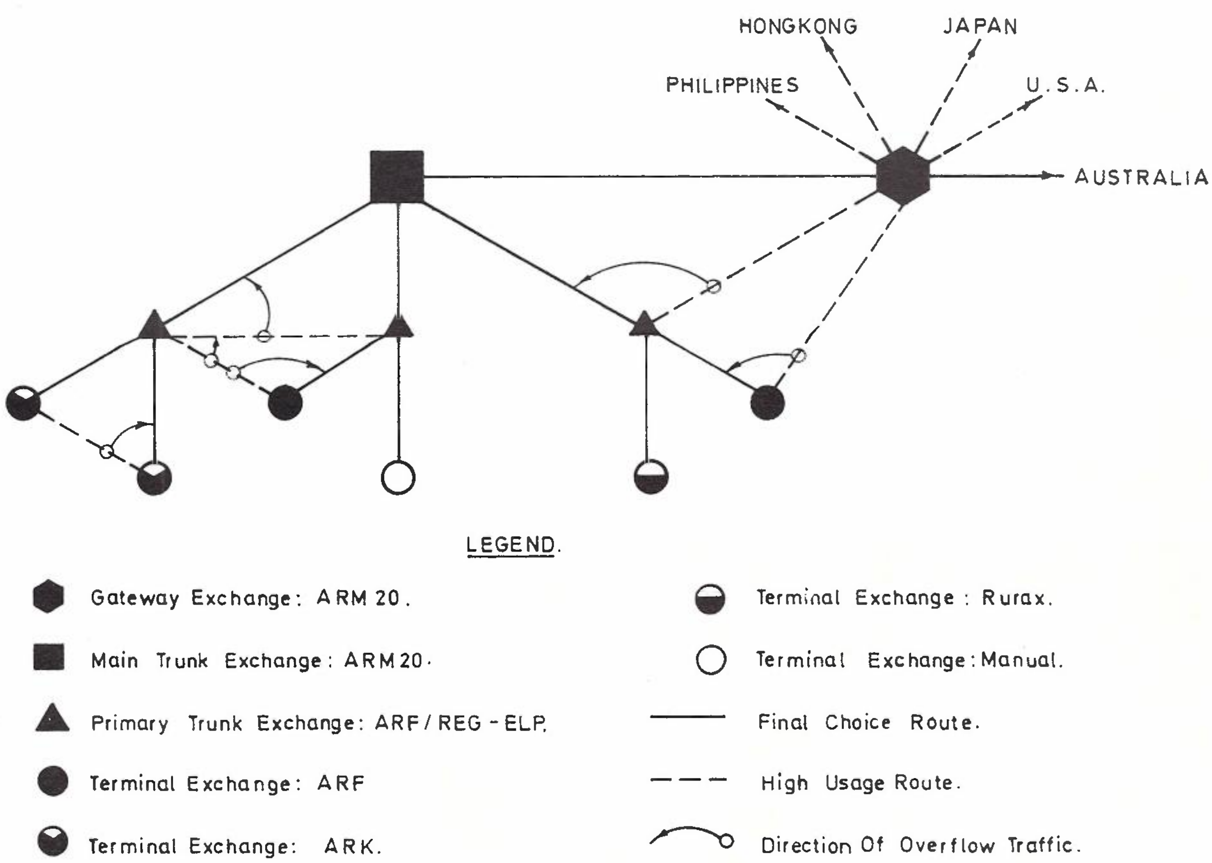


Fig. 7 — PNG Switching Hierachy and Possible Routing Patterns.

further difficulty prevailed due to the differing corporate objectives of P&T and OTC. Papua New Guinea favoured retaining known techniques instead of the new satellite technology which would place further demands on training and limited skilled manpower.

It is now history that in October 1974 a contract was placed with Standard Telephones and Cables (London) for the laying of a $A7 million cable between Cairns and Port Moresby. The jointly owned cable came into service in July 1976. It has a capacity of 480, four kHz channels.

THE NETWORK

Although it would be pretentious to imply that the network was conceived and developed in accordance with some all-encompassing philosophy, it is true to say that the early Planners had a vision of the Papua New Guinea Network as one that would be,

- simple to engineer (for Planning)
- simple to manage (for Operations)
- simple to use (for Customers)

In many ways Papua New Guinea's timing in entering modern telecommunications was awkward. The industry was braving new technologies during the sixties and it was at this time that P&T were looking for the systems to provide facilities into the latter part of the century.

Some bold decisions like the choices for broadband trunk facilities and the processor controlled telex exchange were unqualified successes which used techniques that even today are not commonplace.

In the switching field manufacturers were ex-

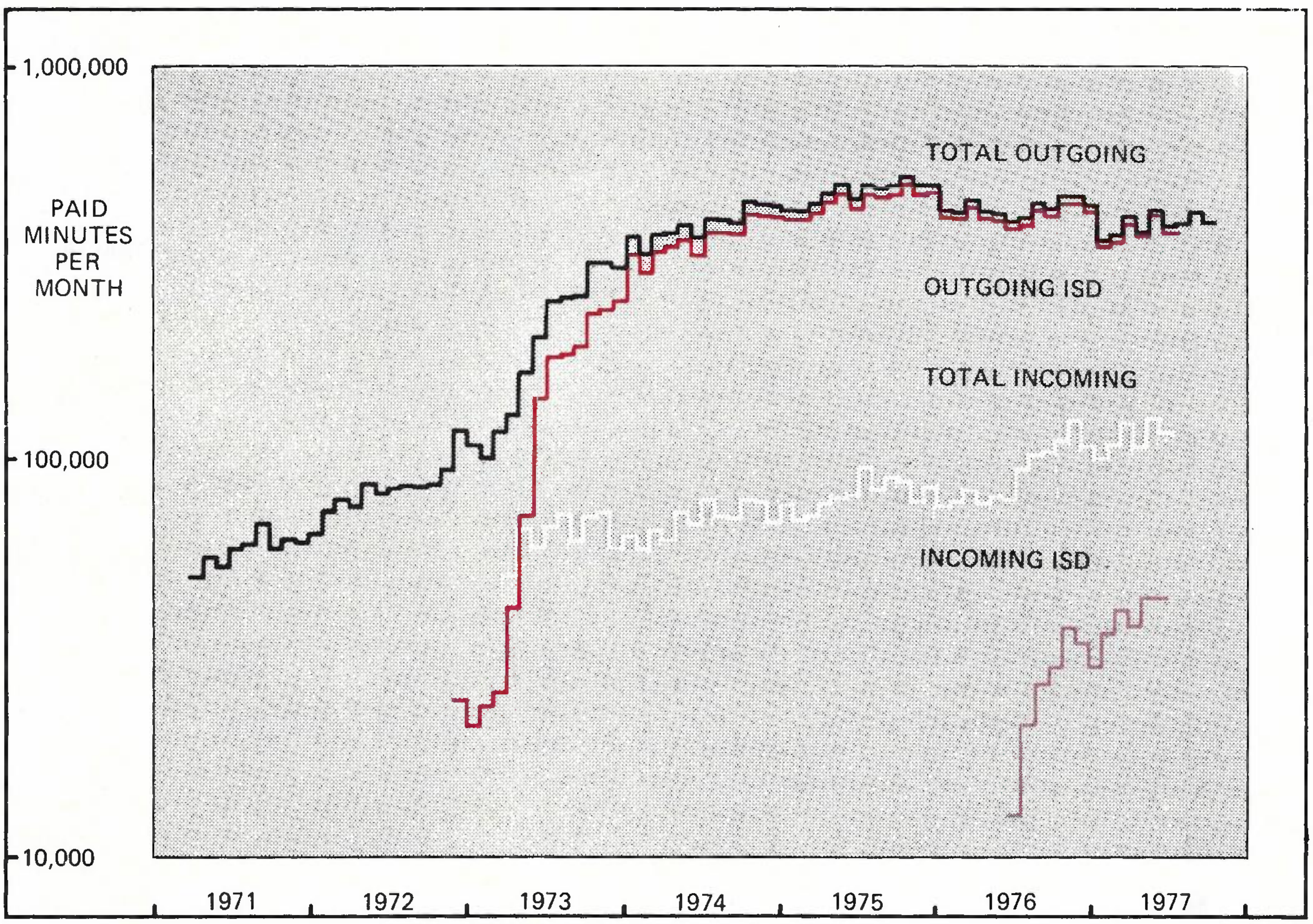


Fig. 8 — Growth in Revenue Traffic Between PNG and Australia.

perimenting with stored program controlled exchanges but had not installed significant equipment quantities at the time that P&T were searching for replacements for the step-by-step equipment. In any case the crossbar equipment ultimately chosen has adequately performed its functions whilst offering the advantages of:

- readily obtainable supply of equipment
- a nearby recruitment pool of trained personnel for manpower or training requirements (Australia)
- proven technology that is widely adopted.

There is substantial evidence that the resultant telecommunications network of transmission, switching and control is performing very efficiently indeed, particularly considering the difficulties to be faced in a developing country.

Switching

Fig. 7 illustrates the telephone switching hierachy and possible routing strategies in the PNG national network. Primary trunk exchanges are situated at Wewak, Madang, Lae, Rabaul, Arawa, Goroka, Mt Hagen and Boroko. There is a wide-spread meshing of inter-Primary trunks with Lae and Boroko having direct routes to all the Primaries whilst the remaining centres only have routes to major communities of interest at present.

All Primaries are equipped with the Register type ELP which provides trunk charging facilities and control of rural ARK terminals. The two largest Primaries at Lae and Boroko have extended availability by means of 3-stage group selectors (GVC).

In May 1975 one of the remaining step-by-step exchanges closed down completing the integration of all PNG telephone numbers into a single six digit closed numbering network. In mid 1977 the Port Moresby exchange closed and with it the era of step-by-step in the PNG trunk network.

The major manual assistance service is centred at Lae with facilities provided by AFM equipment. The Operators can directly dial to subscribers in most parts of the world. As stated earlier, ISD is available to Australia only, at present using the multi-metering system of billing.

With such a compact and tidy network the management of it is relatively simple. A network performance centre exists in Lae to coordinate maintenance effort and collect management information for all national and international traffic. Service observations are carried out and continuous monitoring of the grade of service on the major trunk routes is achieved by a unique traffic surveillance system.

Traffic Management

Until 1975 the traffic facilities installed around the Primary exchanges and Main exchange consisted of traffic measuring leads which extended an analogue signal representative of the traffic on a selected group of devices to a moving coil DC meter. The system required manual recording of sampled traffic values and was generally considered to be cumbersome and of dubious accuracy due to human errors.

The replacement equipment using a combination of electronic Erlang-hour meters (EEHM) and solid state scanning, counting and storing devices offers a flexible, accurate and economical alternative.

Racks and relay sets are installed at all Primary exchanges to accommodate the printed circuit boards which are rotated around the network following a regular programme of traffic measurements. The ARM's have permanently installed facilities.

Ancillary equipment residing at the Primaries facilitate basic but accurate traffic measuring capabilities for use by local staff. **(Fig. 9).** This EMMA equipment (Erlanghour meter Manual Measuring Arrangement) is also involved in a bi-annual trunk network traffic study. During a ten day period the EMMA facilities at each centre simultaneously record the entire trunk traffic during the network busy hour. This network "snapshot" provides excellent planning and management information.

Like the network that it monitors, the traffic reading equipment supplies a facility eminently capable of meeting the requirements but with no expensive and potentially troublesome frills attached.

With fairly minor additions the system can be easily extended to perform a real-time network management function. Such extensions will be considered when the network traffic and/or complexity warrants.

TRAFFIC GROWTH

The physical features of Papua New Guinea consist largely of lush tropical coastal areas and precipitous mountain ranges to 4800 metres. Either topography renders roadmaking a difficult and expensive task. As a consequence road transport is quite restricted.

The capital, Port Moresby, for instance, has no roads connecting it to other major centres. Transportation needs are mainly met by air or coastal shipping although the recently developed and improving Highlands Highway system is now providing some alternative means of conveyance between the major centres of Lae, Goroka, Mt Hagen and Madang.

Telecommunications is therefore of vital importance in carrying out the business of government and to promote industrial and agricultural development.

Trunk and Overall Usage Rates

The importance of telecommunications is reflected in the high usage rates for the telephone service.

Boroko is the largest terminal exchange having 9000 installed lines of ARF Crossbar equipment. The overall originating rate is 0.068 and terminating rate is 0.047 Erlangs per direct exchange line. Lae with some 2300 lines has an originating rate of 0.055 and terminating rate of 0.049 Erlangs per subscriber.

The overall average trunk originating rate is 0.017 Erlangs per exchange line. Originating trunk usage rates range from 0.010 Erlangs per line (Boroko) to 0.024 Erlangs per line (Goroka, which has about 1000 subscribers in the area). This is inclusive of the small operator assisted traffic; STD comprises over 95% of all trunk traffic.

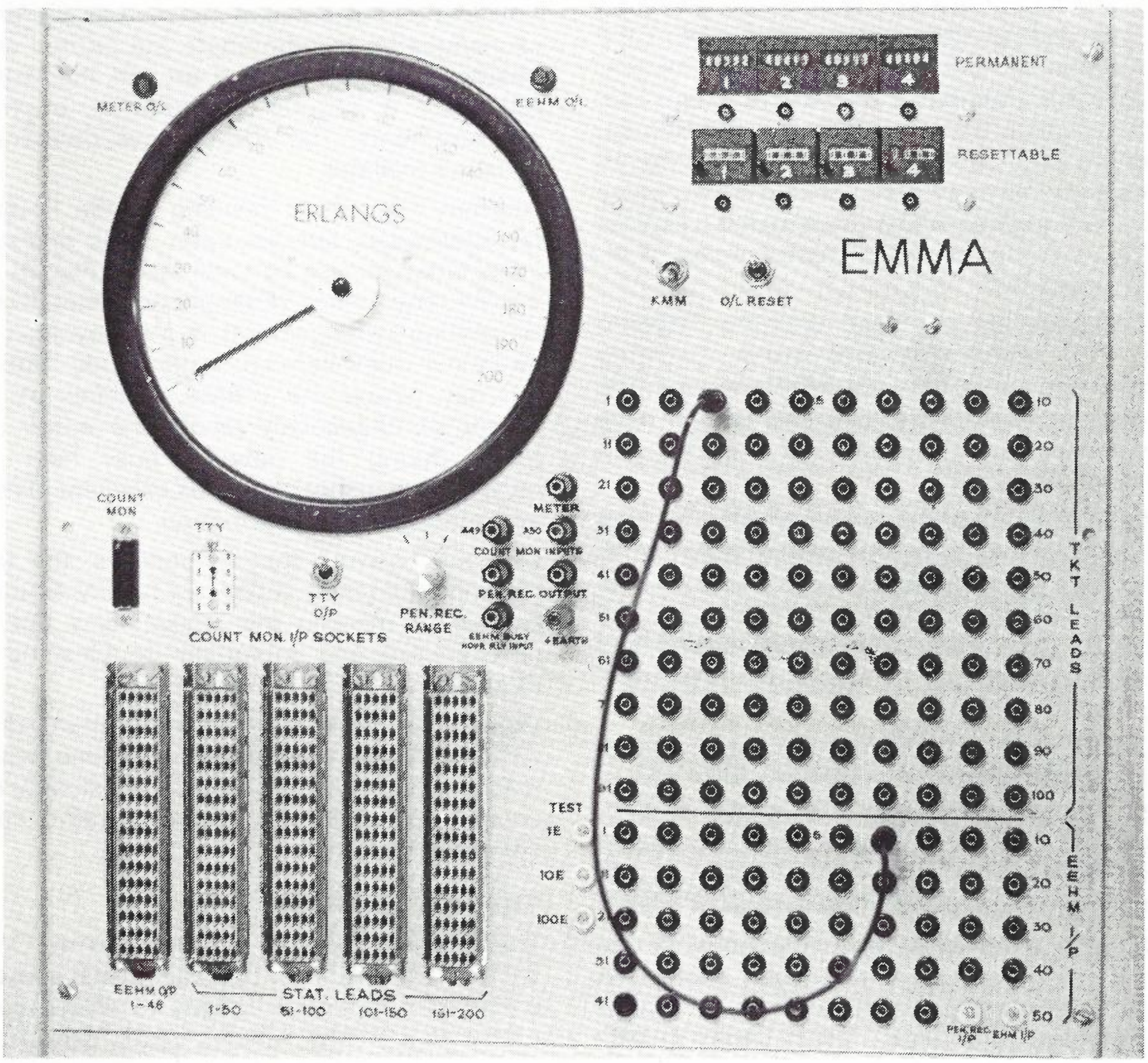


Fig. 9 — EMMA — Flexibility and Accuracy of Manual Traffic Studies.

International Usage Rate

During the period from December 1972 to February 1974 nearly 98% of the telephones in Papua New Guinea were progressively given access to ISD for calls to Australia. In this time the total revenue traffic from PNG to Australia increased fourfold to 400,000 paid minutes of telephone traffic per month. A little over a year later it had passed the half million minutes mark. Virtually all of this traffic was ISD.

The economies of the move to ISD can be gauged from the fact that revenue traffic increased five times with a corresponding circuit increase of only 22%. This is due to the much higher circuit efficiency with ISD. Also Operator costs were reduced with the closure of four Regional Manual Assistance centres following a 60% reduction in operator traffic.

At its peak in 1975 the ISD traffic to Australia represented 91% of all outgoing international traffic. The overall international originating rate (to all countries) was 30 paid minutes per subscriber per month. This is of the order of 100 times the Australian originating rate and 50 times that of the UK which has extensive ISD throughout the world.

The Flow of Traffic and Money

It will be realized then that the establishment of ISD was an extremely profitable move. However whilst P&T and subscriber alike were thrilled with the new service it was to bring grief to the Department of Treasury.

This arose because of the international accounting arrangements which provide that traffic revenue is shared evenly between the terminal partners regardless of the traffic direction. This is fine when the two traffic directions have equal volume but results in an outward flow of cash from a country under traffic imbalance conditions similar to the conditions of trade imbalance. By the end of 1975 there were over 5 minutes of paid traffic leaving Papua New Guinea to every one incoming from Australia. The drain on foreign reserves was of the order of $US 2 million per year. The situation was clearly intolerable for the economy of a developing country.

The means of redressing the situation had as their extremes the possibilities,

- establish unbarred ISD from Australia
- discontinue ISD from Papua New Guinea

The former was in contravention of established Telecom Australia policy until automatic message accounting became available. The latter would be financially disastrous to P&T.

Telecom Australia responded to Ministerial directives and Papua New Guinea calls were given special consideration. Shortly after announcing the unbarred service Telecom reported over a million telephones had access to the service. This has apparently had the desired effect with a traffic turn-around from one direction to the other. Imbalance is now down to about three to one and shows signs of further reduction if recent trends continue.

'GURIAS' AND OTHER HAZARDS

Earthquakes

Just before midnight on Sunday 20th July 1975, the technical assistant stationed at the Torakina troposcatter radio terminal on Bougainville Island was awakened by a strong earth tremor centred somewhere out in the Solomon Sea. He packed some possessions and his sleepy family into the P&T Landrover and drove them inland, for experience told him that the beach-front site would likely be covered by the surging tidal wave following the tremor.

At forty minutes after midnight the tidal wave swept through the station swamping the rectifiers, power amplifiers, generators and everything else under one and a half metres from floor level.

The initial tremor or 'guria' as they are called in Pidgin, had snapped the antennae feeders cutting off all communications with the island. In the morning an airborne inspection showed the likely extent of damage and emergency repair operations commenced immediately under very difficult conditions.

The building and diesel fuel storage tank had sunk one metre into the wet sand which had assumed the consistency of porridge because of repeated aftershocks. The Landrover, having been returned during the dark of the early hours of the morning, had sunk below the level of the wheel hubs.

The fresh water tanks were shattered as was the septic tank, making life decidedly unpleasant particularly at high tide whose level now inundated the subsided beachfront.

Difficulties aside, service was restored within 48 hours.

Lethal Debris

In spite of the widespread publicity given to tribal fighting in Papua New Guinea, P&T people have frequently been the unwitting but unharmed spectators to these occasional skirmishes. There have been cases where hostilities were temporarily suspended to allow the P&T people to pass. Far more dangerous however is the debris of an earlier conflict.

Whilst laying cable in the Sogeri area some 20 km from the end of the Kokoda Trail of World War 2 fame, the cable plough lifted a 'live' 200 pound bomb. Sobered by this incident, bomb clearance crews were used when laying cable between Lae and Nadzab, another area of heavy combat action.

Other debris resulted in a call for help to the Royal Australian Navy mine clearance teams when making the landing point of the Australia-PNG cable safe for cable laying operations. Many large mines left sitting on the floor of Bootless Inlet, a few kilometres down the coast from Port Moresby, were detonated by the RAN men.

Helicopters

Unfortunately not all the incidents were without tragedy.

Helicopters were indispensible during the installation of the trans PNG microwave link. Mr Vern Hodgson, a senior P&T engineer and Carlo Naggi of Telettra were returning to Goroka by 'chopper' after visiting the repeater site on top of Mt Otto (3,730m) when the main rotorblade drive mechanism failed. They plunged into the moss forest 500 metres below the summit, two hundred metres short of an emergency landing pad. It was two days before the search parties could find the three bodies in the dense scrub.

Although other minor helicopter incidents did occur the several thousand trouble-free flying hours during the project attested to the overall good record particularly considering the hazardous conditions of altitude, terrain and weather experienced over the period.

CONCLUSION

Papua New Guinea, the land, has kept Papua New Guinea, the people, separated for many hundreds of years. Telecommunications is of fundamental importance in the search for national unity.

Although small in comparison to telecommunications networks in Australia and other larger nations, the Papua New Guinea network was not developed without overcoming problems that were significant when measured against any standard. The resultant service is one employing some of the most modern equipment of its type in the telecommunications world.

The next stage of development is to take the telephones to the people. At present only about 11% of the population has reasonable access to the telephone. In other words a concentrated effort will be made to expand the network into the rural areas, providing basic telecommunications facilities in the villages.

ACKNOWLEDGEMENT

The author would like to thank Mr Bill Peckover, Acting First Assistant Secretary (Telecoms) whose first hand experience of the development of the telecommunications network of Papua New Guinea over more than 20 years proved invaluable in substantiating historical facts.

A Method of Providing Full STD Facilities for Subscribers in Remote Areas

G.J. STEVENS, B.Tech., Grad. I.E. Aust.

A relay set has been designed to enable selected number ranges in an ARF cross bar exchange to be identified as a "pseudo" terminal exchange in a tariff charging zone other than the one in which the exchange is located. Small groups of subscribers at such designated exchanges in "foreign" charging zones can then be connected to the ARF exchange and both originating and terminating STD calls involving these subscribers can be charged correctly.

This article describes briefly the operation of the relay set, and the circumstances under which it finds application in the South Australian and Northern Territory network.

INTRODUCTION

A feature of the Australian telephone network is the extremely low telephone density over much of the area of the nation. For example, in South Australia and the Northern Territory alone, there are in excess of 70 exchange areas having 20 subscribers or less, and the forecast development for many of these indicate that the installation of an automatic terminal exchange of the types currently in use in the Australian network could not be justified solely on economic grounds.

The concept of Remote Controlled Electronic Equipment (RCEE) exchanges has been used in a number of instances to provide service to subscribers in remote areas. An RCEE exchange is a 'notional' exchange location which provides a reference point from which applicants can be quoted, and which can be used in the determination of charges to be applied to trunk calls in accordance with the call charging arrangements in use in Australia. Currently under this policy, the subscribers are extended to a suitable manual exchange where they have individual jack appearances, and calls are switched in the normal manner. However, special attention must be given by the operator to the charging of such calls. A special problem arises then when the parent manual exchange is converted to automatic working since the RCEE exchange cannot continue to function in its existing mode in the absence of a manual parent.

Two possible approaches to the solution of the problem came to mind, viz:

- Design a small, simple, inexpensive switching system for use as a terminal exchange;
- Extend the remote subscribers to a suitable, established automatic switching point either collectively by means of a line concentrator or separately by means of either physical or carrier derived circuits.

DEVELOPMENT OF THE RELAY SET

The latter approach appears to be the more attractive, since very little development work is needed, and the full range of facilities of the parent exchange are available to the remote subscribers concerned. However, it does not provide for correct charging of STD calls, either originating or terminating if the RCEE exchange to which the subscribers are connected is in a tariff charging zone other than the one in which the ARF exchange is located.

The correct charging of terminating calls can readily be arranged by suitable analysis in the terminating GV stage of the parent ARF exchange as explained later, but for originating STD, the remote subscribers must be allocated a separate 'zone of origin' to that of the Parent exchange to which they are connected. A preliminary investigation indicated that the implementation of such a procedure in ARF Reg ELP exchanges would be a relatively simple matter, and so, in September 1976, a Design Concurrence Request was submitted to Equipment Design Co-ordination South Australia on this subject. A survey of all States and Headquarters by EDC showed that no such design existed, and authorization was given for detailed design work to commence. Subsequently, the project was also included in the national Research, Development and Innovation (RDI) Programme.

Design work on the relay set commenced in November 1976, and finally led to the manufacture of a prototype relay set in January 1977. This was installed at Port Augusta ARF exchange in South Australia, initially only as a field trial, but as it proved to be quite successful in operation it was accepted as a standard means of providing full STD facilities for remote subscribers in the area. In particular, automatic service to Roopena terminal exchange, situated in a "foreign" charging zone approximately 50 km south west of Port Augusta has been provided by this means since March 1977.

OPERATION OF THE RELAY SET

Fig. 1 is a functional block diagram of the relay set (nominally designated ZAN), and shows the relationship between the relay set and other items of equipment within the ARF parent exchange.

When a call is originated, the hundreds and tens digits of the calling subscribers number are made available to ZAN by means of cabling from the category analyzer (KAN). These digits are analyzed into zone of origin information in ZAN, encoded into the same '2 out of 6' code used by Reg ELP for storing zone of origin information, and temporarily stored on miniature relays. The SR selected for the call is subsequently connected to a free register via RSL, and information regarding the identity of the register is read out of RSM by ZAN. This information allows ZAN to steer the zone of origin information to the correct register via multi-coil relays in a manner which is very similar to the operation of the DIR relay set. Note that numbers within a 1000 line group are analyzed and allocated to a zone of origin in blocks of ten numbers, and that any block of ten numbers not so analyzed assumes, by default, the zone of origin of the parent exchange.

GV ANALYSIS REQUIREMENTS

The example of Roopena will serve to show the GV analysis required to prevent incorrect charging of terminating traffic when incompatible code combinations are dialled. The ten numbers allocated to the Roopena charging zone are xxx271 - xxx270 out of the 424xxx thousand line group at Port Augusta, and the C,D and E digits allocated to Roopena are 465xxx. Thus we have a requirement

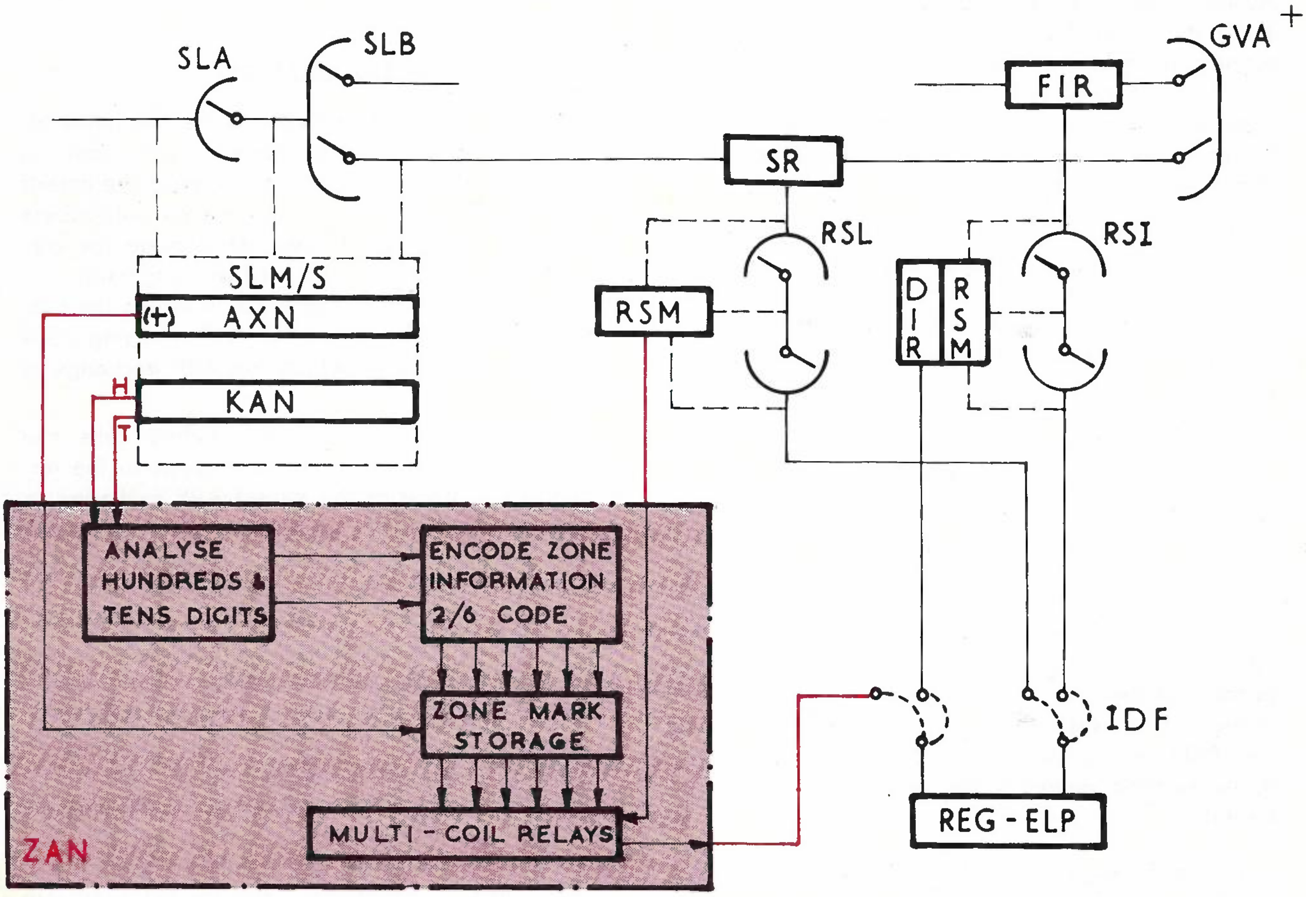


Fig. 1 — Functional Block Diagram of ZAN Relay Set.

to prevent callers from dialling 42427x numbers as this would give access to Roopena at the charging rate applicable to Port Augusta. Also, we must ensure that the only 465xxx codes that can mature are 46527x as any other combination will give invalid access to Port Augusta subscribers.

From **Fig. 2** it is seen that five digit analysis is required to separate all of the illegal code combinations and connect them to 'Number Unobtainable Tone' (NUT). The correct code combinations are connected to the SLD route of the thousand line group concerned, and a 3A10 route revertive (send previous digit MFC) is used to ensure that the SL stage receives the last three digits of the called subscriber's number.

CONCLUSION

At an estimated cost of $300, the ZAN relay set provides a very economical method of variable zone marking within a complete 1000 line SL group with minimal modification to installed equipment, and opens up the possibility of a number of methods of providing service to remote subscribers. Chief among these are the use of line concentrators (on both physical and derived circuits), subscriber's radio (both individual and group systems), and new types of party line systems.

A further development of this theme foresees subscribers of RCEE exchanges in different charging zones being connected to a single ARK exchange, but being switched onto separate routes between the ARK and its parent exchange as the means of conveying to the parent exchange the differing zones of origin. A prototype of a relay set to perform this function has been constructed and successfully tested.

In the future, it is possible that SPC exchanges will provide the facilities required to service remote subscribers, but until that time it is expected that the approach outlined in this article could play a significant role in the Australian telecommunication network.

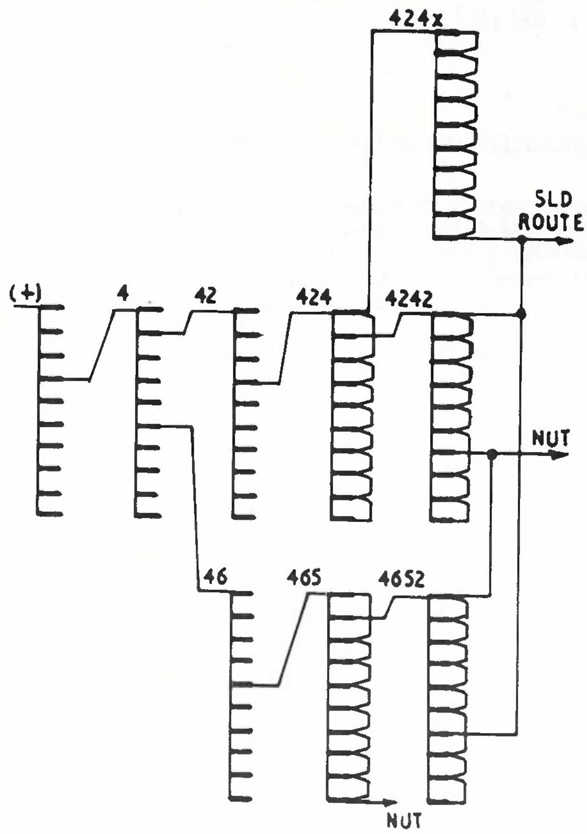


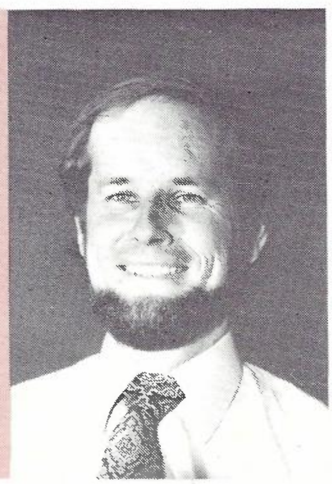
Fig. 2 — Simplified GV Analysis Showing Barring of Illegal Code Combinations.

REFERENCE

BERGMAN, D. F., 'The ARF Minor Switching Centre'; Telecom. Journal of Aust., February 1970, Vol. 20, No. 1, page 50.

G.J. STEVENS is an Engineer Class 3 with the Internal Plant Installation No. 1 Section, Construction Branch in South Australia.

He joined the PMG Department in South Australia as a Technician in Training in 1959. He completed his Engineering course in 1967 and from 1968-1970 he worked as an Engineer Class 1 in the Long Line and Country Installation, and Bearer Utilisation Sections of the South Australian Administration. In 1970 he was promoted to Engineer Class 2 in Long Line and Country Installation where he was involved in the installation of all types of switching and transmission equipment in both country and metropolitan areas until promoted to his present position in 1975.



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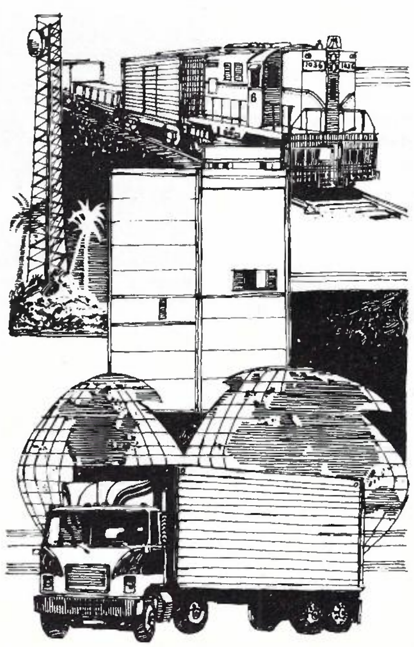

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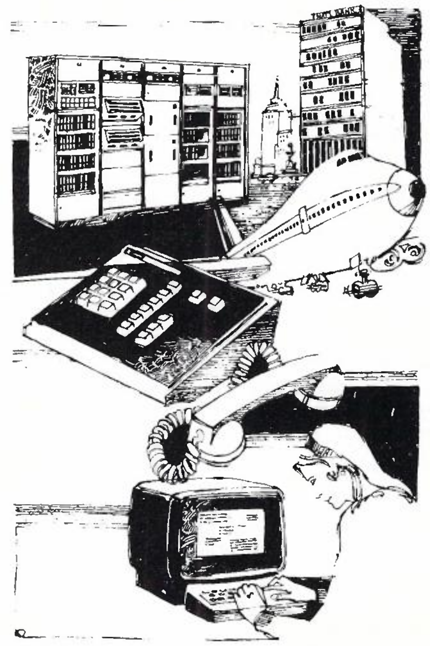

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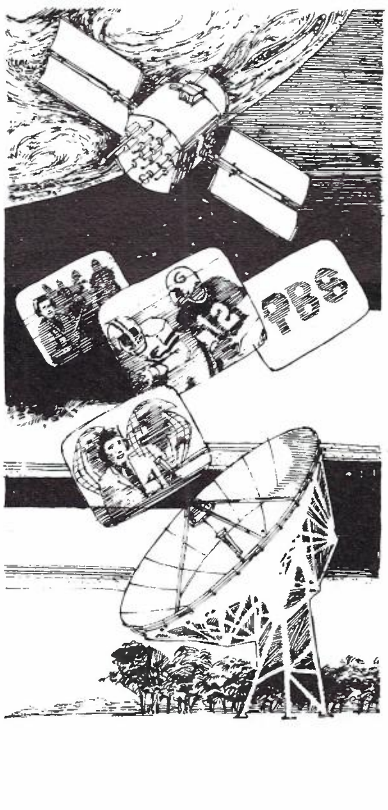

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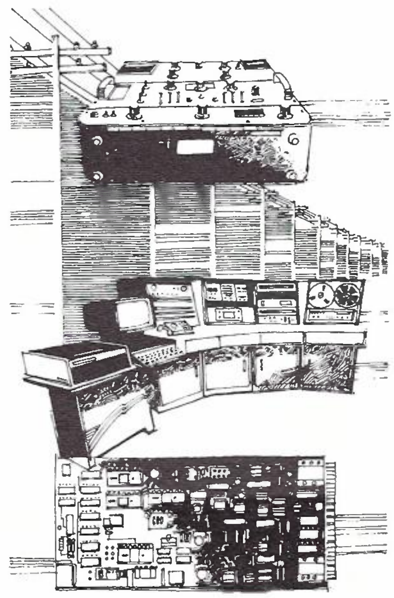

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The Telecommunications Journal of Australia

ABSTRACTS: Vol. 28, No 2

COATES, F.A.: 'The Papua New Guinea Telecommunications Network'; Telecomm. Journal of Aust., Vol. 28, No. 2, 1978, page 182.

The brief but remarkable history of the development of the telecommunications network of Papua New Guinea spans, in just two decades, the transition from HF shout-down trunks and manual switchboards, to virtually complete automation, ISD and Stored Program Control switching equipment. The web of telecommunications is a vital factor in the coalescence of an emerging new nation. Telecom men, (many of them Australians) with the determination to get things done often at great personal risk, have aided in the spread of telecommunications across the ruggedly beautiful face of Papua New Guinea.

DERRICK, L. J.: 'Multicoupler Performance Specifications'; Telecomm. Journal of Aust., Vol. 28, No. 2, 1978, page 103.

This paper reviews the Telecom Australia requirements for antenna multicouplers in the VHF and UHF frequency range and shows how some of the important performance specifications are set. Some of the circumstances in which it would be advantageous to use such devices with single antennas rather than the use of separate antennas for each transmitter or receiver are also discussed.

FARR, J. P.: 'Grade-of-Service and Performance Monitoring of Traffic in the Australian Telecommunications System'; Telecomm. Journal of Aust., Vol. 28, No. 2, 1978, page 153.

This article outlines the measurement techniques used by Telecom to assess grade of service and switching loss performance in the telecommunications system. It includes methods of undertaking traffic recording on final choice circuit groups, service assessment of live traffic, artificial traffic call generation, automatic monitoring of live traffic and the analysis of subscriber trouble reports.

FREEMAN, A. H.: Hybrid Transformers — Part 2'; Telecomm. Journal of Aust., Vol. 28, No. 2, 1978, page 167.

This is the second of two articles designed to inform the reader of the properties of hybrid transformers and present simple methods of designing or analysing circuits in which they are used. It examines variants of the circuit dealt with in the first article in Vol. 27, No. 3 of this journal and illustrates the varied application of hybrids in telecommunication plant by a number of specific examples. An appendix gives further mathematical details useful in the design of circuits using hybrids.

GRAY, R. L.: 'Meeting Specifications with Practical Filters'; Telecomm. Journal of Aust., Vol. 28, No. 2, 1978, page 120.

An essential element of the better couplers is the frequency-selective filter. This paper sets out some principles in a quantitative way for the assistance of radio system designers who may wish to examine the cost or feasibility of various coupler proposals. It discusses a theoretical relation between stopband rejection, frequency separation and loss for a given choice of elements and complexity and suggests an optimum trade-off. This theme is further developed to show the extent to which performance can be improved, or complexity reduced, by matching the filter stopband response more closely to the requirement.

McDONALD, N. A.: 'A Building Block Approach to Multicoupler Fundamentals'; Telecomm. Journal of Aust., Vol. 28, No. 2, 1978, page 110.

This paper is an introduction to the techniques used in the design and construction of aerial couplers. It introduces first the components commonly used in multicouplers and then describes how these components may be assembled to make a variety of configurations to suit given requirements. The configurations described are encountered in VHF and UHF mobile radio systems.

O'REILLY, C. and McMAHON, B. J.: 'Manufacture and Test of ARE II Equipment'; Telecomm. Journal of Aust., Vol. 28, No. 2, 1978, page 174.

Previous articles have introduced the ARE system and described a new installation at Elsternwick, Victoria, and the conversion of a working ARF exchange to ARE at Salisbury, South Australia.
This article explains the production and installation testing procedures used to preserve the ARE system's capacity to operate to the standard of reliability for which it is designed.

ROBINSON, B. E.: 'The Telecomm. Telefinder Radio Paging Service'; Telecomm. Journal of Aust., Vol. 28, No. 2, 1978, page 127.

Since its introduction in 1973 in Sydney and Melbourne the Telecom Telefinder radio paging service has been in high demand and has been expanded to include Canberra and all State capital cities. The service will be extended to serve many of the larger regional cities and will be improved to offer additional facilities.

STEVENS, G. J.: 'A Method of Providing Full STD Facilities for Subscribers in Remote Areas'; Telecomm. Journal of Aust., Vol. 28, No. 2, 1978, page 196.

This article describes briefly the operation of a relay set which has been designed to enable selected number ranges in an ARF crossbar exchange to be identified as a "pseudo" terminal exchange in a tariff charging zone other than the one in which the exchange is located. Small groups of subscribers at such designated exchanges in "foreign" charging zones can then be connected to the ARF exchange and both originating and terminating STD calls involving these subscribers can be charged correctly.

THURMAN, W. H.: 'Digital Transmission in National Telecommunication Networks'; Telecomm. Journal of Aust., Vol. 28, No. 2, 1978, page 140.

An overview is presented of the application in national telecommunications networks of transmission systems making use of digital techniques and of equipment to transmit signals originating in digital form over analogue transmission systems. The paper includes an outline of factors influencing present and future application together with analyses of current application including that in the Telecom Australia network.

THE TELECOMMUNICATION JOURNAL

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Volume 28, No. 2, 1978

CONTENTS

COVER

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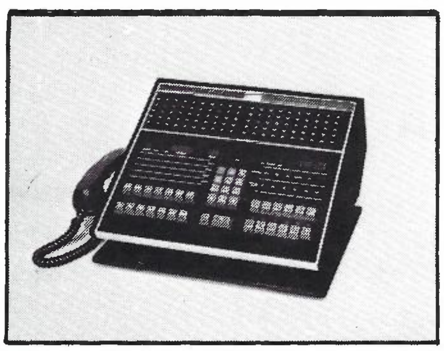

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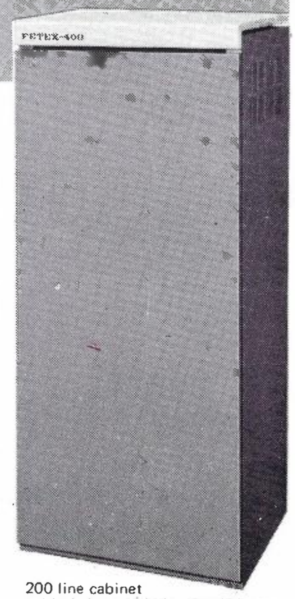

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