REQUIREMENTS FOR TRUNK CIRCUITS

1. INTRODUCTION.

1.1 The telephone system should provide a service which is satisfactory to all subscribers The aim of the Department is to make the telephone service as good as possible but at a reasonable cost, so the main consideration is to strike an optimum balance between service performance and costs.

1.2 The telephone user is subjective in his evaluation of a speech communication circuit. The standards laid down for the various aspects of trunk circuits are designed to give a satisfactory service to the average subscriber. At the time of writing some service standards are not stipulated but the figures quoted in this paper can be regarded as a suitable guide.

1.3 National and commercial broadcasting and television stations make use of audio and video programme networks provided throughout Australia. To ensure a satisfactory standard of reception, each audio and video programme channel in the network must conform with relatively strict requirements. These are detailed in the E.I., PLANNING, Transmission and Line Systems 0 2010 and in the Course Paper, "Standards of Australian Television Service", respectively.

1.4 Service Indicators. The service performance of trunk circuits is checked in a fault recording and analysis programme designed to indicate trunk circuit outage from traffic, and also service availability.

On some routes equipment is added to automatically record the outage time of some carrier systems. In certain cases automatic level recordings are made on carrier systems to help gauge the service performance.

2. TRANSMISSION NETWORK TERMS.

2.1 Before considering the service standards for trunk circuits it is necessary to know the transmission network terms and the basic methods of providing trunk circuits.

2.2 Terminal Exchange (Local Exchange). A switching point which:-

(i) Connects subscribers' telephone circuits to subscribers' telephone circuits.

(ii) Connects a subscriber's telephone circuit to a junction or trunk telephone circuit.

2.3 Transit Exchange. A switching point which interconnects trunk telephone circuits or junction telephone circuits. In the network, transit exchanges are used for switching centres designated as minor, secondary, primary or main.

2.4 A Link. That facility in a network which provides a circuit, (or a group of circuits) switched at both ends in transit or terminal exchanges. A link begins and ends at the exchange reference points. (The exchange reference point is arranged to be as close as possible to the end of the circuit. All circuit levels are expressed with relation to this point).

2.5 Terminal Exchange Reference Points. The exchange reference point is immediately beyond the transmission bridge (on the exchange network side). Typical exchange reference points are expressed for:-

(i) Outgoing Circuits. For crossbar exchanges the reference point is the G.V. selector bank. For other automatic exchanges the reference point is the exchange M.D.F. For manual exchanges the reference point is the exchange switchboard jack.

(ii) Incoming Circuits. For all automatic exchanges the reference point is the M.D.F. For manual exchanges the reference point is the exchange switchboard jack.

2.6 Transit Exchange Reference Points. Once again the exchange reference points are expressed for:-

(i) Outgoing Circuits. For all automatic exchanges the reference point is the selector multiple. For manual exchanges the reference point is the exchange switchboard.

(ii) Incoming Circuits. For all automatic exchanges the reference point is the selector multiple. For manual exchanges the reference point is the exchange switchboard jack.

2.7 Telephone Channel. A means of one-way telephone communication between two exchanges. It comprises the outgoing and incoming terminal equipment appropriate to the speech transmission path between the exchanges.

2.8 Telephone Circuit. A means of both-way telephone communication between two exchanges or between a subscribers telephone and local exchange. It comprises all the outgoing and incoming terminal equipment of the speech transmission paths permanently connected between the exchanges. In the case of subscriber's telephone to local exchange it includes the transmission bridge.

A telephone circuit can be further classified by the number of conductor terminals at the exchange reference points. These classifications are:-

(i) A two-wire telephone circuit. At the terminal this consists of two conductors providing a "go" and "return" channel in the same voice frequency band.

(ii) A four-wire telephone circuit. At the terminal this consists of four conductors, one pair providing a "go" channel and the other pair a "return" channel in the same frequency band.

(iii) A two-wire - four-wire telephone circuit. At one terminal this consists of four conductors and at the other terminal, two conductors.

2.9 Subscribers' Telephone Circuit. A means of bothway telephone communication between a subscriber and a terminal exchange. It comprises the subscribers line and all the outgoing and incoming terminal equipment of the speech and signalling equipment.

2.10 Subscribers' Line. The line facility, however provided, which connects the subscribers equipment with the terminal exchange equipment.

2.11 Junction Telephone Circuit. A circuit for carrying telephone traffic between exchanges in the same or adjoining charging zones.

2.12 Junction Line. The line facility, however provided, which connects exchanges within the same or adjoining charging zones.

2.13 Trunk Telephone Circuit. A circuit for carrying telephone traffic between exchanges not in the same or adjoining charging zones.

2.14 Trunk Line. The line facility, however provided, which connects exchanges not in the same or adjoining charging zones.

2.15 Types of Trunk Telephone Circuits. In para. 2.8 telephone circuits are classified in three categories. These classifications are determined by the number of wires at the terminating exchanges. The line facility which connects the exchanges can be provided by physical wires in cables or on poles, or by circuits of carrier systems.

Trunk circuits are equipped for use as "one-way" or "both-way" circuits. A one-way circuit provides signalling (calling) in one direction only. A both-way circuit provides signalling in either direction.

Fig. 1 shows a typical two-wire telephone circuit. The outgoing and incoming exchange equipment is designated to relate to direction of signalling. To obtain the required transmission performance a V.F. repeater or repeaters (type 22 or N.I.R.) may be added on physical lines at the terminals or at intermediate stations. Circuit stability is a problem when V.F. repeaters are added, and in these cases circuit losses, return losses, and stability of connections, must be carefully controlled.

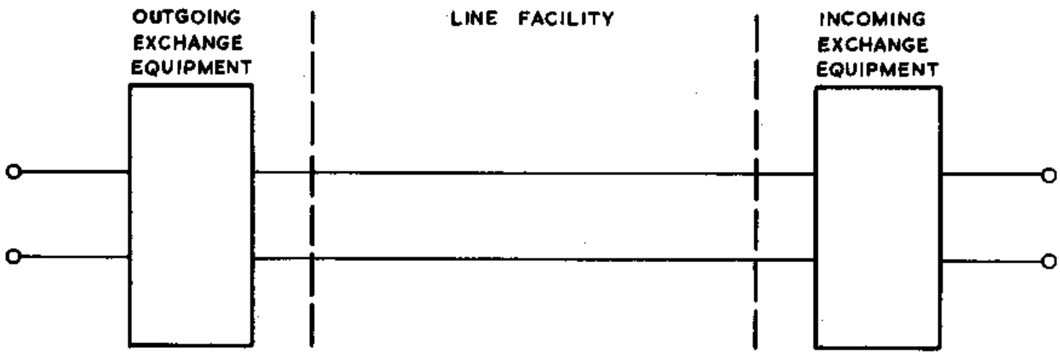


FIG. 1. TYPICAL TWO-WIRE TRUNK TELEPHONE CIRCUIT.

A typical four-wire trunk telephone circuit is shown in Fig. 2. To obtain the required transmission performance when using physical lines, four-wire V.F. repeaters can be added at the terminals or at intermediate stations. At the terminal exchanges, hybrid equipment is added to enable the circuit to be used for speech communication.

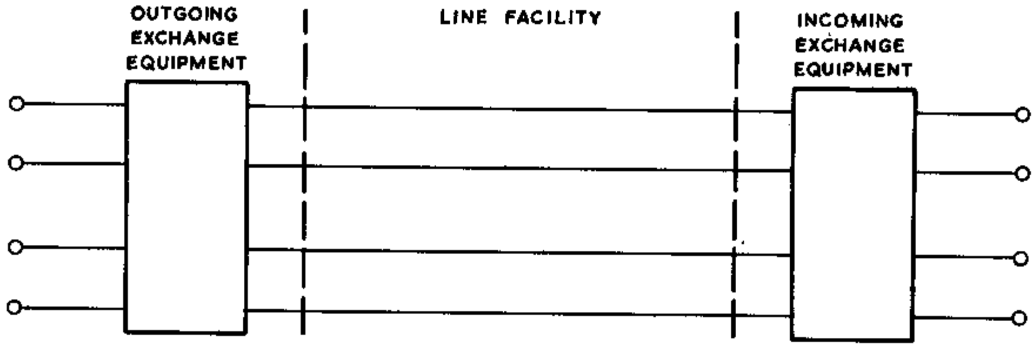
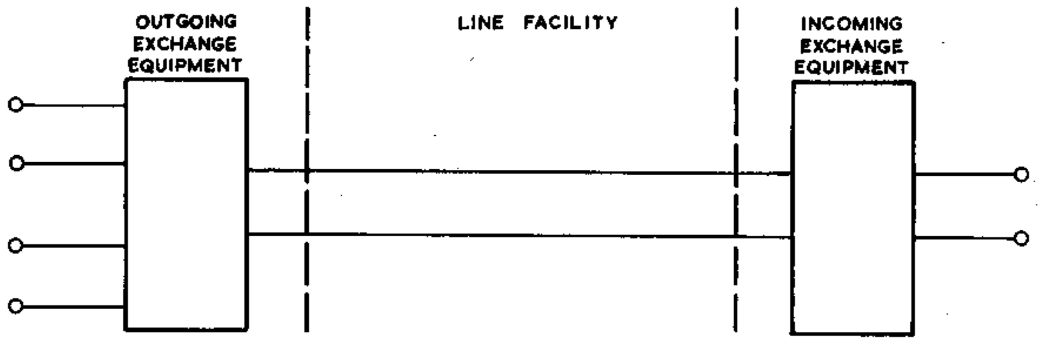
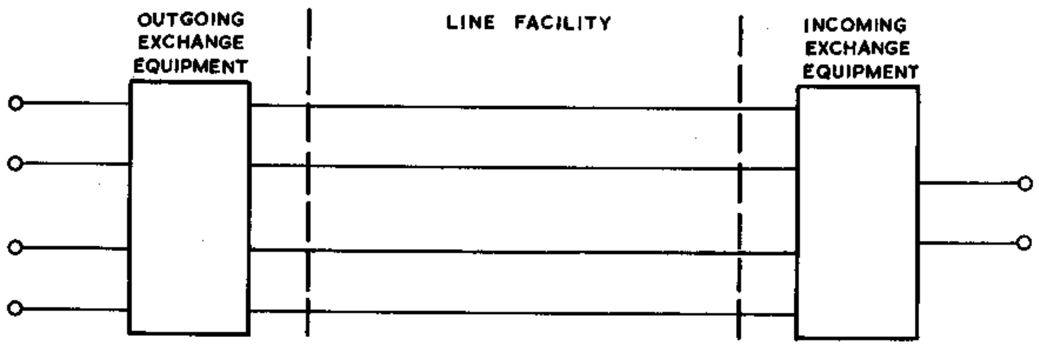


FIG. 2. TYPICAL FOUR-WIRE TRUNK TELEPHONE CIRCUIT.

Fig. 3 shows examples of typical two-wire - four-wire type circuits. The trunk circuit is a two-wire type at one switching point and a four-wire type at the other. In Fig. 3(a) the line facility is two-wire and conversion to four-wire is made with a hybrid at one terminal. In Fig. 3(b) conversion from two-wire to the four-wire line facility is made at one terminal.



(a) TWO-WIRE LINE FACILITY.



(b) FOUR-WIRE LINE FACILITY.

FIG. 3. TYPICAL TWO-WIRE - FOUR-WIRE TYPE TRUNK TELEPHONE CIRCUIT.

3. GENERAL REQUIREMENTS.

3.1 A speech communication circuit should offer a subscriber more than just a means of transferring intelligence from one point to another. It should give the subscriber an acceptable alternative to direct face-to-face conversation.

In direct conversation, communication is emphasised in a number of ways, in variations in speech amplitude and inflection, facial expressions, and gestures. In a telephone conversation the listener is forced to rely on word context and voice inflection for the transfer of meaning.

In speech communication, we are not only interested in transmitting information which can be interpreted as words, but we are also interested in conveying shades of meaning through variations in voice amplitude and inflection. The ideal speech to communication circuit is one in which the feeling of presence that exists in face-to-face conversation is obtained.

When voice transmission is considered for trunk circuits, the factors that affect the intelligibility of the transmitted voice are:-

(i) Frequency range.

(ii) Volume range.

(iii) Level variations.

(iv) Distortion.

(v) Crosstalk and noise interference.

(vi) Frequency stability.

3.2 Frequency and Volume Range (Dynamic Range). The restrictions with regard to frequency and volume range that can be placed on a speech circuit without incurring serious degradation are best considered jointly. In direct face-to-face conversation, the sound intensity (amplitude) and the frequency (pitch) of the sound waves can vary over wide limits. Sound intensities range from the threshold of hearing, a whisper, to very high levels. However, in a normal conversation the range for the average person is about 30dB.

But since many different people use the telephone circuit, the relationship between the sound intensity range used by these different people must be considered. The intensity range between the weakest syllable of a soft talker and the loudest syllable of a loud talker (that is, the two extremes) can be as great as 60dB. Under the same conversational conditions, the frequency range of sound can vary from about 50Hz to about 10kHz depending on the individual.

Within this scope, it would be difficult to construct a multi-channel carrier system that could include all ranges of sound intensity and frequency without restricting the ultimate channel capacity.

From the listener's point of view the quality of a voice circuit can be assessed in terms of intelligibility and intensity. These determine the clarity of reception of sounds transmitted over the circuit. Most of the speech energy, and therefore the intensity, is concentrated in the lower frequencies (vowel sounds), and the higher frequencies (consonants) contribute mostly to the intelligibility.

This means that any voice circuit should include both the low frequencies and the high frequencies. In practice a compromise is necessary because the available bandwidth is limited.

For trunk circuit working the range in speech volume is restricted to be about 50dB, and the normal voice channel bandwidth is restricted to about 3kHz. Typically, the range of transmitted frequencies is from about 300Hz to about 3,400Hz.

3.3 Level Variations. In any transmission medium, the loss in signal strength is not constant, but varies from instant to instant. These variations are a result of changes in circuit loss caused by such things as varying temperatures and other weather conditions. This means that unless some type of level control is used, the signal level at the receiver will also vary. The manner in which level control is accomplished depends on the transmission system. It is desirable to keep level variations which may occur over a short time interval to a minimum.

3.4 Distortion. Distortion is the general term used to describe any change in waveform of a signal. Even where noise and crosstalk requirements are met, distortion may reduce the intelligibility and identification of the speaker. The three basic types of distortion are:-

(i) Frequency distortion.

(ii) Non-linear distortion.

(iii) Delay distortion.

Frequency distortion is the selective attenuation of some frequencies with respect to the overall frequency spectrum. If frequency distortion appears within a voice channel and is excessive, the effect is readily apparent. Where low frequencies are greatly attenuated, the resulting speech will sound "tinny"; if the high frequencies are greatly attenuated, the resulting speech will have a "booming" sound.

Non-linear distortion is caused by non-linearities in the circuit. This type of distortion is characterised by the generation of harmonics which are multiples of the speech frequencies being transmitted. In addition, intermodulation occurs between frequencies, and this results in new frequencies which are sum and difference products of the original speech frequencies and harmonics. Because of the possible interfering effects of these new frequencies, non-linear distortion is kept to a minimum in carrier equipment design.

When non-linear distortion occurs in the common equipment associated with a multi-channel carrier system, the new frequencies produced can cause inter-channel interference. This interferring effect is known as "intermodulation noise" and is a limiting factor to the maximum number of circuits that can be obtained on a carrier system.

Delay distortion is the result of differences in the velocity of propagation for the various frequencies in a complex wave. It is sometimes termed phase distortion because of the phase shift that occurs. For a speech circuit, delay distortion is not a problem because the ear is relatively insensitive to phase variation. However, on voice frequency circuits used for high-speed data transmission, delay distortion is an important factor.

In a typical channel the frequency with minimum delay is approximately 1600Hz and the maximum delay occurs at the extreme frequencies. This is illustrated in Fig. 4 which shows approximate relative delay times versus frequency.

At the time of writing, data transmission rates in the order of 600 bauds and 1200 bauds are in use. For 600 baud operation the transmitted energy is concentrated between 1200Hz and 1700Hz and for 1200 baud operation the energy concentration is between 1300Hz and 2100Hz. By using these bandwidths the data transmission systems are placed where delay distortion is lowest.

In special circumstances, delay equalisers are included in the telephone circuit to obtain the required figures for delay distortion.

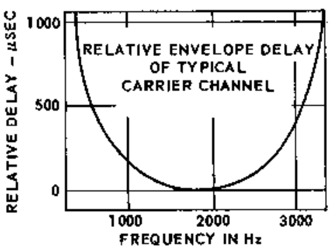


FIG. 4. RELATIVE ENVELOPE DELAY OF TYPICAL TELEPHONE CHANNEL.

3.5 Crosstalk. Wherever telephone circuits follow adjacent paths, they are susceptible to crosstalk interference. Crosstalk may be produced by inductive and/or capacitive coupling in parallel lines. Unwanted signals are produced in the disturbed circuit. Generally, three types of crosstalk are considered to exist:-

(i) Intelligible crosstalk, which is in the same frequency range, but lower in amplitude than the original or desired signal.

(ii) Unintelligible crosstalk, which is translated in frequency, or appears in the disturbed circuit in an inverted order.

(iii) Babble, which is crosstalk from a number of sources, either intelligible or unintelligible. With babble, the resulting sound has an apparent syllabic rate, but because of the number of interferring signals, does not appear as intelligible crosstalk. Babble is normally evident during the busy-hour periods and is similar to noise.

Crosstalk performance could be readily calculated if it were only necessary to measure coupling between two circuits. However, the magnitude of crosstalk in the disturbed circuit will depend on the relative power levels in the disturbing circuit and the disturbed circuit.

3.6 Noise. Types of noise interference which may affect voice communication include:-

(i) Thermal Noise. Sometimes called white noise or random noise; it is inherent in any circuit and is produced by the random movement of electrons in conductors, electron tubes and semi-conductor devices. Thermal noise is spread uniformly throughout the frequency spectrum.

(ii) Impulse Noise. Unlike thermal noise, impulse noise occurs in bursts and is not spread uniformly through the frequency spectrum. Some types of impulse distortions are produced by natural causes such as lightning or other electrical disturbances. A great proportion of impulse noise is man-made, resulting from induction from traction systems, power lines, power switching systems, ignition systems, etc. In telephone communication systems, impulse noise is also caused by dialling and switching impulses.

The disturbing effect of these types of noise is generally less than that of crosstalk because in most instances no recognizable syllabic pattern is discernable. However, the disturbing effect on any one circuit will depend upon the type of noise and its frequency distribution. Many types of noise are man made and can be eliminated, or at least reduced in magnitude. Since noise cannot be entirely eliminated, limits for noise amplitude and frequency distribution have been established.

3.7 Frequency Stability. The use of oscillators in carrier telephone systems introduces the problem of frequency stability. This problem is commonly associated with the changes in frequency stability of an oscillator over a period of time. But in telephone circuits the frequency stability that is of concern is the overall change in frequency that occurs between the transmitting and receiving ends of the circuit. The amount of frequency change tolerable is directly related to the amount of change discernable to the ear or the amount of change sufficient to impair operation of signalling, telegraph or data equipment.

For voice circuits, a frequency stability (end-to-end) of about ±2Hz provides a very good circuit. In actual operation, frequency shifts approaching ±15Hz may occur occasionally without seriously impairing the quality of the voice circuit. However, the use of signalling equipment and data transmission has necessitated much greater frequency control.

3.8 Effect of Echoes. The factors, described in para. 3.1 to 3.7, affect the quality of the received voice signals. The problem of echoes is one which affects the speakers. Telephone echo gives a completely unnatural effect and must be avoided.

Telephone echo is created primarily at the far end of four-wire transmission circuits where conversion to two-wire working takes place. This is illustrated in Fig. 5. Because of unavoidable impedance mismatch at the four-wire - two-wire point, the transfer of energy to the subscribers telephone circuit is not complete and some of the sound is reflected back to the talker. In the telephone receiver, the speaker hears his own voice delayed by the delay time of the circuit. The circuit delay time is, in general terms, a function of velocity of propagation and distance. An echo delay of about 45 milliseconds is considered a minimum before the echo effect is objectional to the speaker. For echo delays in excess of this figure, echo suppressors should be used.

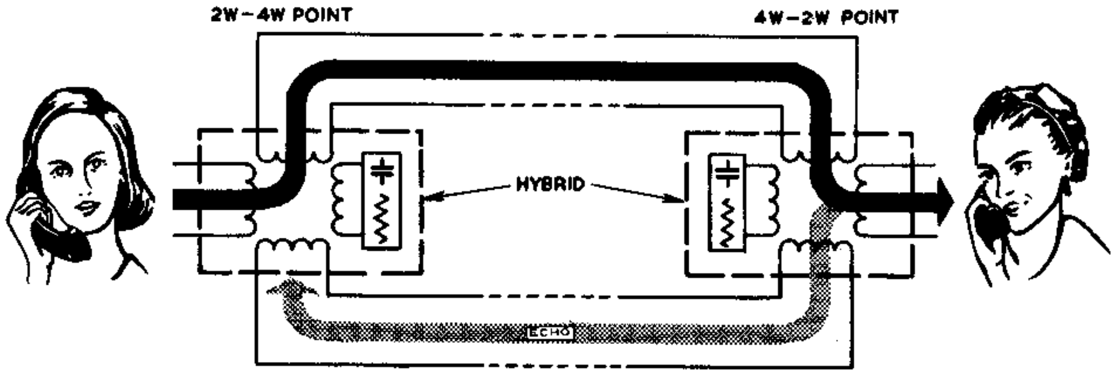


FIG. 5. ECHO EFFECT AT FOUR-WIRE - TWO-WIRE POINT.

3.9 Fig. 5 shows that the loss across the hybrid at the receive end is critical as regards the amount of sound energy returned. When the hybrid is perfectly balanced the loss across the hybrid is, in theory, infinite. With a severe unbalance , for example, a normal line termination but an open circuited or short circuited network, the loss across the hybrid is equal to about 6dB.

The loss across the hybrid can be subdivided into normal hybrid loss and "return loss". The normal hybrid loss is equal to 6dB and the return loss is dependant on the degree of impedance mismatch. For example, with a severe mismatch the return loss is equal to about 0dB and the total loss across the hybrid is about 6dB. If an impedance ratio of 2:1 exists between the line and balance network then the measured loss would equal 16dB. The return loss for 2:1 impedance ratio is 10dB. The subject of return loss is covered in the paper "Transmission Measurements - Basic Principles".

The return loss of the impedance ratio of the line and balance network is the only variable in the loss across a hybrid. Because of this, the normal hybrid loss is ignored and "return loss" only is considered for expressions of standards for echo effect.

Loss across the four-wire - two-wire circuit is expressed in two ways. These are:-

- Stability Balance Return Loss.

- Echo Balance Return Loss.

3.10 Stability Balance Return Loss gives an indication of the amount of speech energy returned to the talker. It is measured between the send and receive paths of the four-wire circuit with the two-wire end of the circuit terminated in its nominal impedance. The loss is measured in dB over the frequency range 300Hz to 3.4kHz.

Fig. 6 shows a simple circuit to measure stability balance return loss. Relative levels of -13dBr (V.F. EQUIP. OUT) and +4dBr (V.F. EQUIP. IN) are assumed. If a level of +4dBm is applied to V.F. EQUIP. IN and -33dBm is measured at V.F. EQUIP. OUT then the stability balance return loss is equal to 20dB, that is, 37dB - (11dB pad loss +6dB hybrid loss) = 20dB.

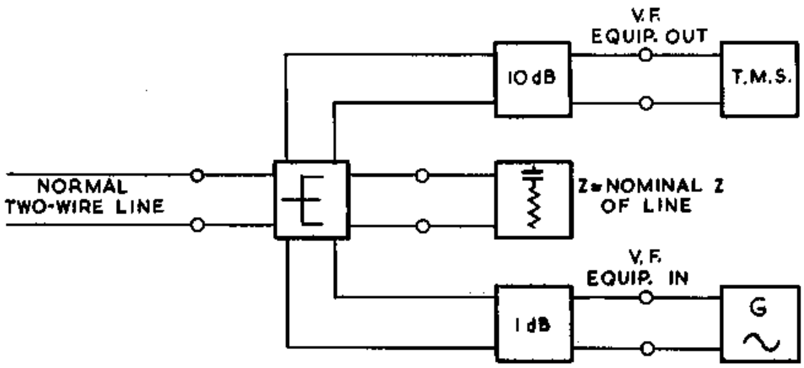


FIG. 6. MEASUREMENT OF STABILITY BALANCE RETURN LOSS.

3.11 Echo Balance Return Loss is the weighted return loss of the balance impedance of the hybrid against the impedance of the two-wire line when terminated in its nominal impedance. Measurement is made in a similar manner to stability balance return loss. A speech weighting noise generator is used for the signal source and a psophometer for the measuring set. A typical measuring set-up for echo balance return loss is shown in Fig. 7.

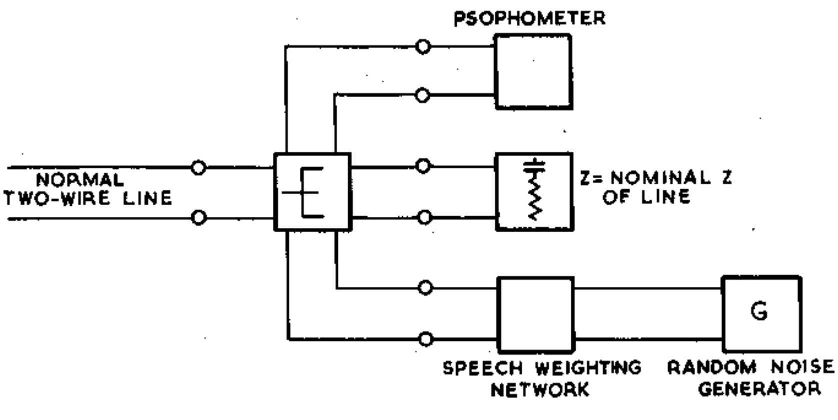


FIG. 7. MEASUREMENT OF ECHO BALANCE RETURN LOSS.

3.12 General Service Requirements. The following features of a telephone system affect the subscribers satisfaction with the service provided:-

(i) Transmission quality. This determines the ease of conversation and is discussed broadly in paras. 3.1 to 3.7.

(ii) Availability of equipment and lines to provide the desired service. Ideally, sufficient telephone lines and equipment should be available to ensure that all call attempts mature. This is not regarded as feasible from an economic point of view.

In practice sufficient switching and line plant is provided to ensure that during the busiest hour of traffic, the percentage of call attempts which cannot mature does not exceed a prescribed figure. For S.T.D. traffic, the probability of a call failing because of insufficient plant or lines should not be worse than 1 chance in 50.

(iii) Accuracy of setting up the connection. It is important to subscribers that a required call be established at the first attempt. The extension of subscriber dialling to the trunk network has highlighted the need for accuracy of setting up the connection within this network. Apart from errors that can occur due to faulty dialling on the part of the subscriber, other errors can occur in switching equipment and trunk line equipment.

(iv) Reliability of Service. Once having established a call it is important that it should continue without interruptions and without interference. Additional information is given in Section 4.

3.13 The Department is developing a system of quality controlled maintenance for its telephone network. The overall service performance of the network and an estimate of the subscribers satisfaction with the service is obtained by two measurements which are:-

(i) Statistics of subscriber trouble reports. The Department uses this method to gauge the network performance. It can be misleading at times because a low reporting rate can mean that, although the subscribers are dissatisfied with the service, they have become accustomed to it.

At the time of writing a maintenance programme is being established to allow an analysis of service performance to be made by computer programming.

(ii) Test calls set up by the Department. The results obtained from this measurement enable an assessment of the network to be made under "live traffic" conditions. The calls can be made on a sampling basis and a check can be made on accuracy of setting up, freedom from interruptions and transmission quality. In ARM installation this test will be made by means of a "Test Call Answering Relay Set". (T CARS).

3.14 The overall performance of the telephone network, that is, the combination of transmission quality and equipment reliability, is governed by the performance of the various component sections, which are broadly as follows:-

(i) Telephone instruments.

(ii) Subscribers' lines to the exchange.

(iii) Exchange switching equipment.

(iv) The links between the exchanges.

All of these component sections are connected in tandem for the establishment of a call.

Fig. 8 shows the main elements of equipment and lines used to establish a typical trunk telephone call. The division into the four categories mentioned can be seen. The links between exchanges are provided by junction or trunk circuits. The trunk circuits are provided by physical wires in cable or on poles and by circuits of carrier systems; in some cases the physical pairs are equipped with voice frequency amplifiers or two-band systems. The use of carrier systems has developed to a point where they are the normal method of provision of trunk circuits greater than about 20 miles in length. Some of the carrier systems in use have been installed for a relatively long period, and do not conform with the present standards. These will ultimately be replaced with modern systems.

The nominal maximum losses shown for the various sections of the connection are discussed more fully in para. 5.1. The figures shown are based on a nominal maximum overall loss of up to about 30dB.

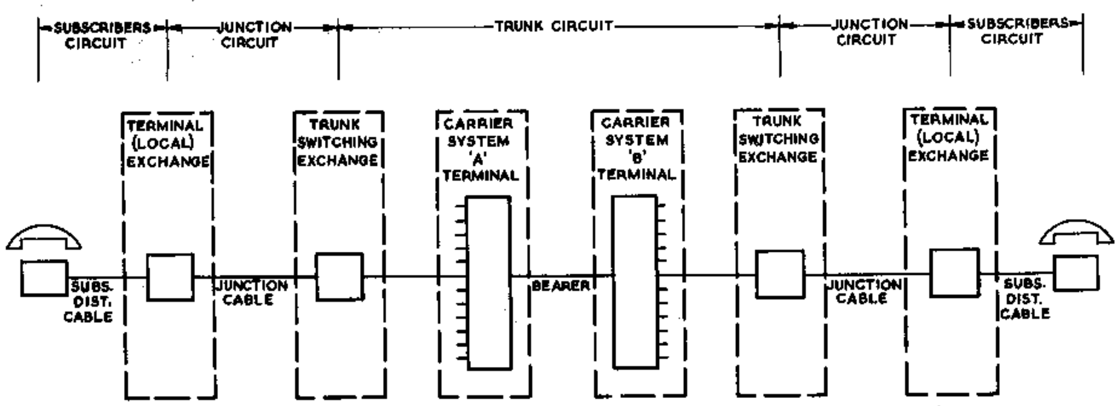


FIG. 8. EQUIPMENT AND LINES USED FOR TYPICAL TRUNK CALL.

3.15 This paper indicates suitable service standards for the trunk circuits which are used as links between exchanges. The service standards for other component sections of the network are given in relevant E.Is. and other papers in the course.

4. INTERRUPTION TO TRAFFIC.

4.1 An interruption to traffic is defined as a loss of traffic time either reported or detected. The maximum duration and the maximum number of interruptions are specified as service standards.

The specification for duration of interruptions is expressed as % reliability. A nominal figure of 99% reliability is required for all trunk circuits for each calendar month. The information for this standard is recorded between the hours of 8 a.m. and 10 p.m. daily.

Any interruption of a duration greater than 300 milliseconds is regarded as an interruption to service. The specification for the number of interruptions is nominally 1.5 outages per circuit per month.

Both these specifications are a guide and are varied slightly to suit local requirements.

4.2 From an equipment aspect, components and construction methods are chosen for maximum reliability. Facilities are built-in to equipment to monitor automatically certain vital components, and in some cases changeover to stand-by equipment is provided.

Test access to the transmission and signalling paths is provided to facilitate testing. Break and/or bridging access is provided at points in the circuit where monitoring of transmission levels is required. In this way the necessity to interrupt circuits for testing purposes is reduced. Test access to the high frequency transmission paths is provided at certain points for fault finding and other maintenance purposes. Where 12 or more channels are included in a high frequency path the test access points should be such that the possibility of interference to the transmission path is reduced to a minimum. In modern equipment the test access point is isolated from the transmission path by a hybrid and masking pad.

Short interruptions of less than 300 milliseconds in length are not serious for telephone operation, however, even an interruption of this short duration will cause errors in telegraph and data transmission. These short interruptions have a number of causes, among them being changeover of carrier supplies, changeover of amplifier equipment, and power supply disturbances. Indiscriminate changeover of equipment should be avoided in order to keep the number of short interruptions to a minimum.

As a large proportion of traffic interruptions are apparently man-made, it is desirable to avoid, as much as possible, any interference with equipment which is functioning satisfactorily.

4.3 On a number of routes, equipment is added to record the outage time of some carrier systems. Fig. 9 shows a typical recording for a broadband system. To make the record really effective, any recorded outage is noted with the possible cause and any other relevant information.

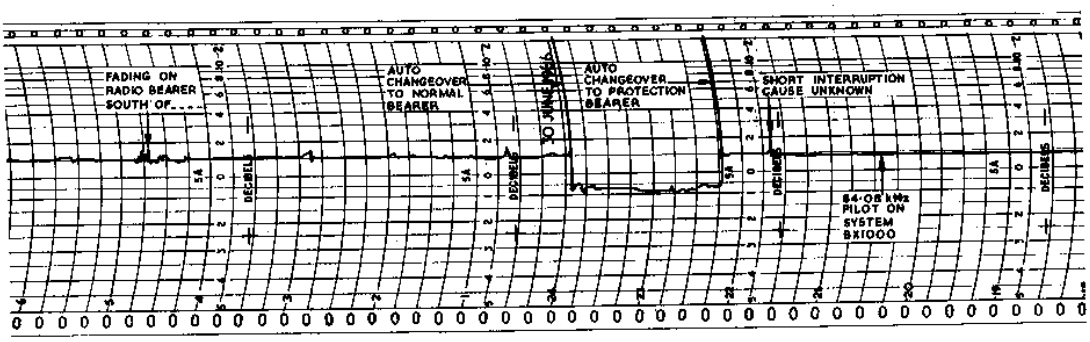


FIG. 9. TYPICAL RECORDING OF CIRCUIT OUTAGE.

5. LOSS.

5.1 The transmission performance, which governs the ease with which subscribers can converse is an important aspect of telephone service. A nominal overall loss of up to about 30dB is allowable from subscriber to subscriber on any call within the Australian network. From a transmission point of view there are two main divisions of the network. The first division, the local plant, comprises the telephone instruments and line to the local exchange, together with the transmission bridges. The second division is the trunk and junction network and a nominal maximum loss of 15dB is permissible in this section. The remainder of the overall allowable loss occurs in the local plants. The loss of each trunk circuit is expressed in dB at a test frequency of 800Hz. The nominal maximum losses for the various divisions of the telephone network are shown in Fig. 8.

It is possible for up to nine separate trunk circuits to be involved in a connection within Australia. These trunk circuits comprise links between exchanges. A link between exchanges can comprise one or a number of circuits which can be provided in different ways; for example, 2-wire physical, 2-wire amplified type, 4-wire type carrier derived, etc.. Links can be provided by one or more routes.

Links in the network fall into three classifications:-

(i) Direct Links.

(ii) Terminal Links.

(iii) Transit Links.

Direct Links. These links interconnect terminal exchanges directly and are switched to subscribers' line circuits at both ends.

Terminal Links. These links connect terminal exchanges (originating or terminating) with higher order switching centres.

Transit Links. These links interconnect transit switching centres.

As a general rule the loss of the trunk circuits that constitute these links is kept to a minimum. It is desirable to operate as many circuits as possible at a "zero" loss. However, because reductions of loss tend to cause instability and tend to degrade echo conditions, it is arranged to operate some circuits at a finite loss.

The design loss for direct and terminal links range from 0dB to 8dB. Where no special precautions are taken to ensure that a proper balance is applied at all times, a loss of not less than 3dB is required.

The design loss for transit links is 0dB for circuit lengths up to 350 miles, 0.5dB for circuit lengths between 350 and 750 miles and 1dB for circuit lengths greater than 750 miles. Links meeting these requirements are referred to as having "0dB basic loss".

5.2 Variation of Circuit Loss. It is desirable to keep line variations which may occur over a short period of time to a minimum. The standard deviation from the normal circuit loss should not exceed 1dB.

5.3 With the introduction of ARM exchanges it is expected that automatic transmission equivalent test sets will be installed to test circuit loss from switching point to switching point. That is between the exchange reference points. The test access point will be as close as possible to the exchange reference point. On some trunk circuits automatic level recordings are made.

6. FREQUENCY DISTORTION.

6.1 The nominal bandwidth of standard trunk circuits is from 300 - 3,400Hz. In general, this bandwidth can be obtained on physical trunk circuits, although the use of V.F. repeaters or two band systems, to reduce the circuit loss, also reduces the highest frequency transmitted to about 2,600Hz.

The circuits obtained by 12 circuit and broadband carrier systems conform with the 300 - 3,400Hz requirement. Modern three circuit systems have an upper frequency limit of 3,000Hz and older systems of this type have an upper limit of 2,700Hz. The frequency range for older single circuit systems is even more restricted.

To check the frequency distortion of a trunk circuit, a frequency response measurement is made. The permissible variation of the loss versus frequency characteristic of any channel is measured with respect to the loss at 800Hz. Typically, a variation of 1dB is allowed on the level received at 800Hz, over most of the frequency range of the channel. Theoretically the measurement should be made from exchange reference point to exchange reference point, although at the time of writing this is not always practicable. Special record forms are used to record the frequency response of channels of various carrier systems.

The record forms T.R.M. 55, T.R.M. 56 and T.R.M. 57 are used to plot the frequency responses of channels of single circuit, three circuit and 12 circuit systems respectively.

6.2 Preliminary frequency response requirements for trunk circuits connected to ARM exchanges are established, and ultimately it is expected that all trunk circuits will meet these requirements. The requirements are based on the specified frequency response for modern channelling equipment. Fig. 10 shows the average of the combined frequencies responses of the transmit and receive equipment of the twelve channel modems in one group. Measurements of channel loss are made at intervals over the frequency spectrum and the results, relative to the loss at 800Hz, should remain within the limits shown on the graph.

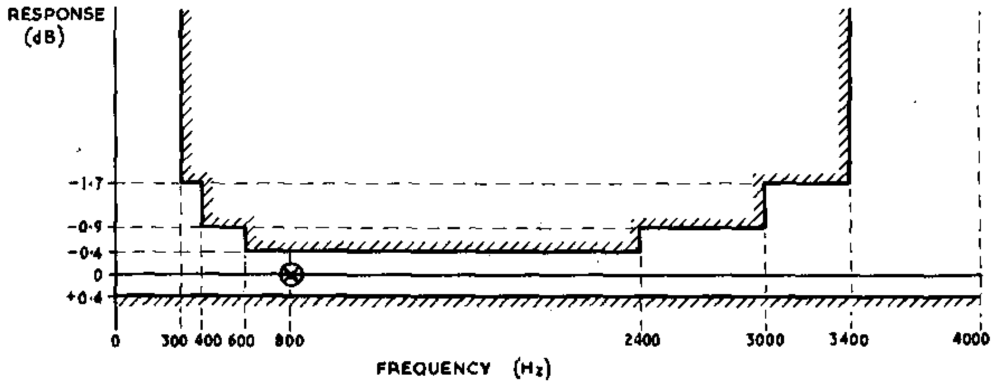


FIG. 10. AVERAGE OF COMBINED FREQUENCY RESPONSES OF 12 CHANNEL MODEMS IN ONE GROUP.

6.3 The use of tandem connections, and the introduction of additional equipment in trunk lines causes a degrading of the frequency response. Acceptable installation limits for transit and terminal links are shown in Figs. 11, 12 and 13. The transit links are subdivided into four-wire and four-wire - two-wire types. There are only minor variations in the three responses.

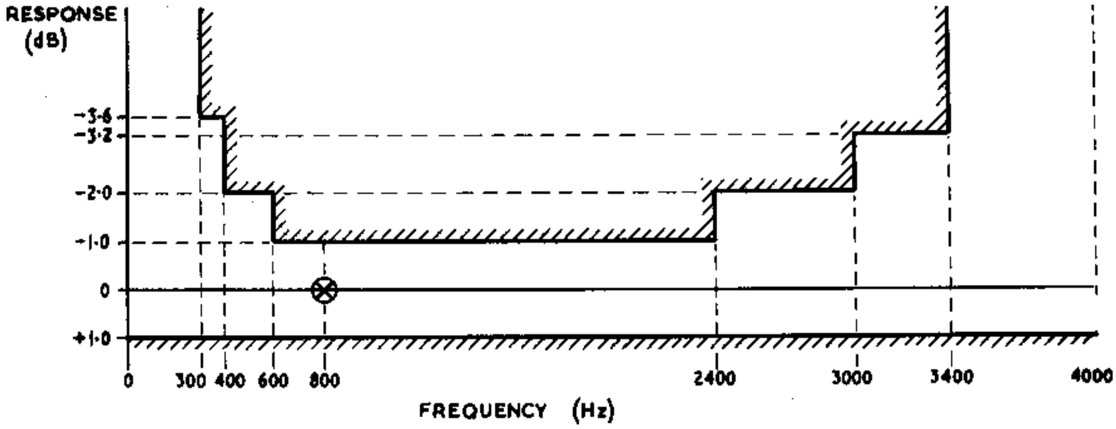


FIG. 11. FREQUENCY RESPONSE. 4W - 4W FOR TRANSIT LINK.

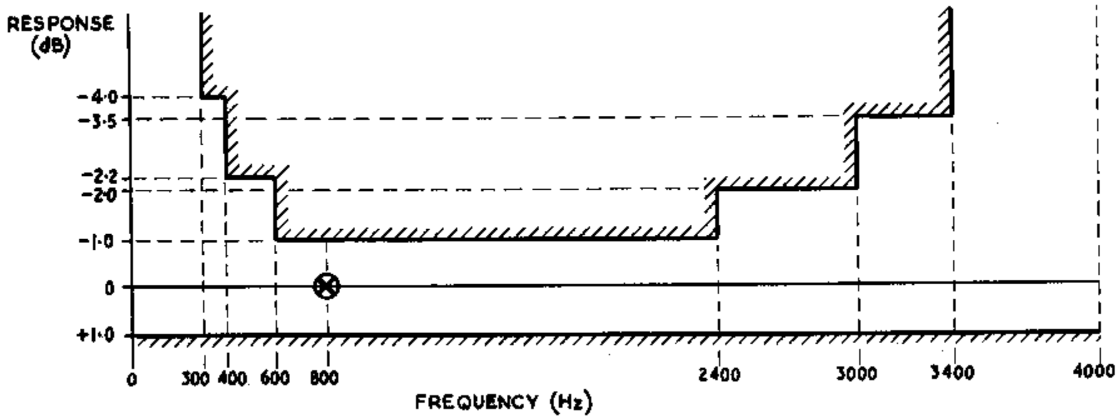


FIG. 12. FREQUENCY RESPONSE. 4W - 2W FOR TRANSIT LINK.

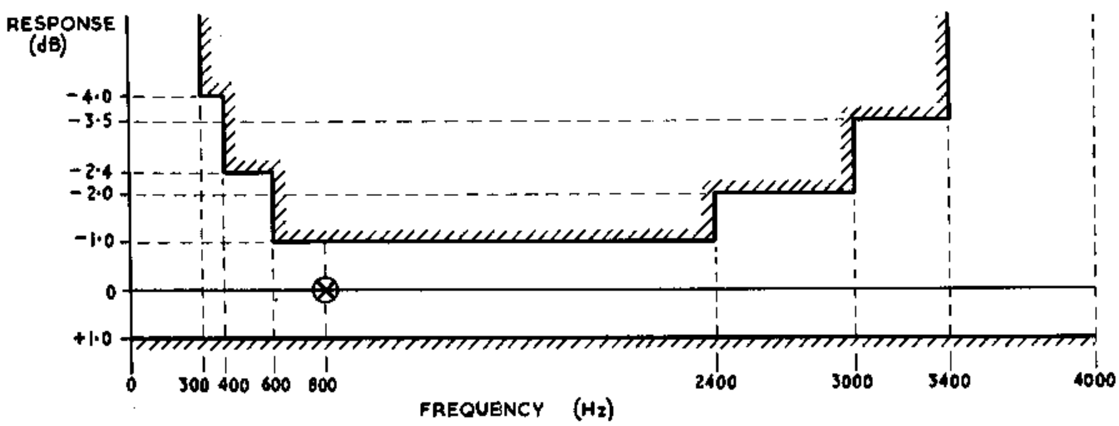


FIG. 13. FREQUENCY RESPONSE. 4W - 2W FOR TERMINAL LINK.

7. VOLUME RANGE.

7.1 A trunk circuit must have a volume range sufficient to satisfactorily transmit voice frequencies for average subscribers. To do this the trunk circuit must be linear over a wide volume range. The limiting factors to the maximum level that can be transmitted are, firstly, the possibility of crosstalk into adjacent circuits and secondly, the possibility of overload of circuit components, for example, amplifiers. Non-linear distortion results from circuit component overload. Some trunk circuits, for example, circuits of rural carrier systems, would not normally have a satisfactory volume range and in these cases compandors are added to obtain the required range.

7.2 A measurement of circuit linearity makes a partial check on the volume range of the circuit. The linearity of the circuit is tested over the required volume range but a measurement of noise is required to completely check the volume range. The linearity test is not normally required for maintenance purposes.

The limiting test which is associated with the linearity test should only be performed as a special test if the circuit performance points to a fault in the limiting equipment. Limiting equipment is added in the V.F. circuit preceeding the modulator. Its main purpose is to prevent the possibility of peaks of voice input overloading transmission equipment. Limiting equipment is particularly essential in multi-channel systems where the possibility of a number of channels transmitting peaks of voice simultaneously exists. The limiting test checks the volume level at which limiting commences.

7.3 The standard for linearity is such that the overall gain of any channel from transmitting direction input to receiving direction output, with an 800Hz test tone, over a range from - 40dBm0 to +7dBm0, does not differ from the gain at 0dBm0 by more than 0.5dB.

7.4 The standard for limiting, which applies in the transmitting direction only, is such that limiting commences when the peak channel power at the input is equivalent to between +7 and +8dBm. For each 10dB increase in input power, thereafter, the output power increases by not more than 2.5dB.

7.5 The relationship between the minimum and maximum levels that can be satisfactorily transmitted is expressed in chart form in Fig. 14. All levels are expressed in dBm and a nominal line-up level of 0dBm is assumed. It should be noted that any decrease in noise level gives an effective increase in volume range. A margin of about 10dB is required between the lowest signal level and noise, therefore a lower noise level allows a lower signal transmission level.

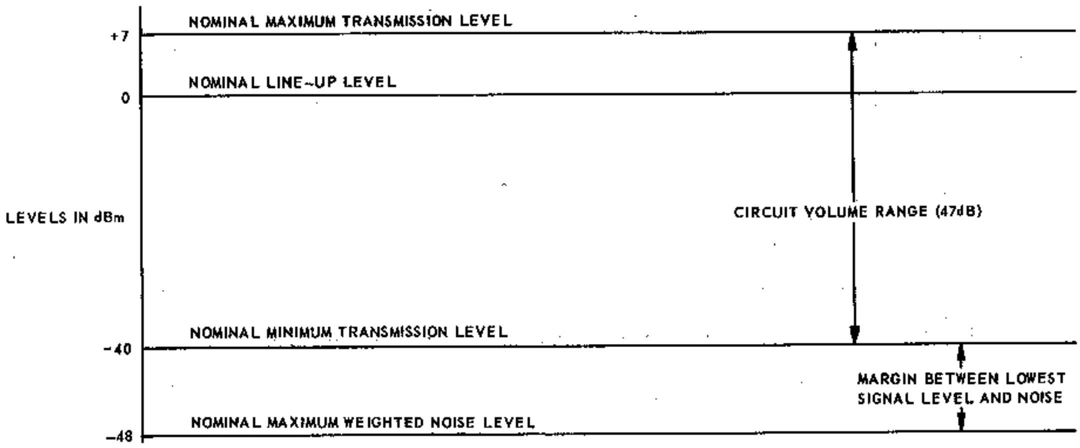


FIG. 14. VOLUME RANGE - TRUNK CIRCUIT.

8. NON-LINEAR DISTORTION.

8.1 Under normal maintenance conditions it is not necessary to make measurements to check the degree of non-linear distortion, but suitable standards for new equipment are given for both harmonic distortion and intermodulation distortion. These standards are met by most circuits, although circuits derived on rural carrier systems using compandors may not conform..

The intermodulation standard is stipulated primarily to ensure that trunk circuits are suitable for M.F.C. signalling or carrier telegraph system operation. New frequencies, produced by intermodulation, could have an interferring effect in both M.F.C. and V.F.T. systems.

8.2 Harmonic Distortion. With a 400Hz tone applied at +5dBm0 at any transmitting direction input (for example HYB. LINE OR MOD IN), the total harmonic distortion measured at the corresponding receiving direction output (for example, HYB. LINE or DEM. OUT) does not exceed 26dB below the level of the fundamental. That is, it does not exceed 5% distortion.

8.3 Intermodulation Distortion. The equipment is loaded with two tones of equal relative power levels in the range - 38dBm0 to - 5dBm0 (representing approximate extreme levels encountered in operation). The two tones are in the frequency range 330 - 3300Hz. Under these conditions third order products of intermodulation falling in the frequency range 330 - 3300Hz are not less than 40dB below the level of the test frequencies. Second order products under the same conditions are not less than 30dB below the level of the test frequencies.

Assuming two fundamental frequencies, f1 and f2, the second order products of modulation are $f1 \pm f2$. The third order products of modulation are $2f1 \pm f2$ and $2f2 \pm f1$.

9. NOISE.

9.1 In a crowded room a person may have trouble being understood even when speaking in a loud voice. When the room is empty the same voice may seem to be too loud. In both cases the same amount of speech power was present but in the former case interference prevented it from being identified by the listener. In communications, interference is called "noise" even though it may be electrical rather than auditory in nature. For the purpose of this paper "crosstalk" and noise are regarded as being synonomous

The interferring effect of noise is different to the measured noise power amplitude. This is because the human ear is more susceptible to some frequencies than others within the V.F. range. Noise frequencies at about 600-1000Hz have a severe interferring effect, but frequencies at either end of the range have only a slight interfering effect. Fig. 15 shows in graph form the approximate interfering effect of noise frequencies in the V.F. range. When a network having the reverse characteristic to that shown in Fig. 15 is used in conjunction with the noise meter, the meter gives an indication of the actual interference produced by the noise frequencies. This is called a "weighted" noise measurement. A direct measurement of noise is called a "flat" noise measurement.

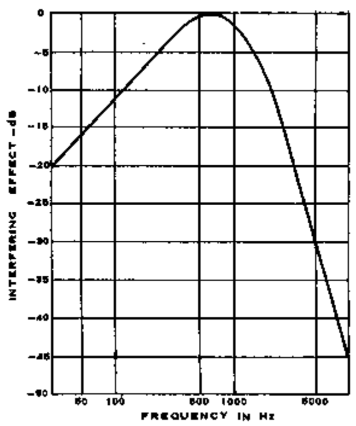


FIG. 15. INTERFERING EFFECT OF NOISE ON SPEECH.

9.2 In the trunk network, overall noise requirements are based on an objective of noise performance of not worse than -48dBm0p (-48dBm0 weighted), on a system operating over at least 1,000 miles of route. To meet this objective, the crosstalk and noise standards for various parts of a circuit must be carefully considered.

Among the factors to be considered to obtain the required noise figure are, intra-office wiring, system repeater spacing, number of circuits per system, crosstalk reduction methods used at line, etc. Details for these are included in appropriate E.Is.

The overall circuit requirements with standards quoted for the busy hour are as follows:-

- Circuit length 2000 miles: -45dBm0p
- Circuit length 1000 miles: -48dBm0p
- Circuit length 500 miles: -51dBm0p
- Circuit length 250 miles: -54dBm0p
- 125 miles or less : -57dBm0p

10. FREQUENCY SHIFT.

10.1 As stated in Section 2, the human ear does not readily discern small changes in frequency, and for this reason, a voice circuit could operate with a frequency error up to 15-20Hz. A maximum frequency error of 2Hz is allowed for trunk circuits.

10.2 When data transmission equipment is associated with a trunk channel, the design objective is a zero frequency error. When the frequency error is excessive, frequency correcting equipment is associated with the data transmission equipment. Frequency correcting equipment is also normally associated with F.M. V.F. Telegraph systems.

10.3 At the time of writing, methods of synchronising trunk circuit are under review. It is assumed that methods of adjustment for frequency shift (out-of-syncronism) will be different for carrier systems using a single modulation stage to those using more than one modulation stage.

11. SIGNALLING PERFORMANCE.

11.1 Various methods of signalling are associated with trunk circuits. Although generator signalling and D.C. dialling can be used with some trunk circuits, it is more common for some form of voice frequency signalling or out-of-band signalling to be used.

The majority of modern carrier telephone channels are provided with inbuilt out-of-band signalling facilities. A signalling carrier frequency of 3.825kHz is the nominal standard and is used by most twelve channel modem equipment. Some modern three channel systems use a signalling carrier of 3.425kHz.

Standards for voice frequency signalling equipment are not given in this paper. Any trunk circuit conforming to the standards quoted in the previous sections is suitable for voice frequency signalling.

11.2 The objectives for signalling distortion for out-of-band signalling systems are:-

(i) For a speed of 10 i.p.s. and a ratio of 33-1/3 to 66-2/3%, the bias should not exceed 1mS and the standard deviation should not be greater than 1mS.

(ii) For a speed of 8-12 i.p.s. and a ratio of 20/80% to 50/50%, the bias should not exceed 2mS and the standard deviation should not be greater than 2mS.

12. ECHO STABILITY.

12.1 The problem of echo is applicable to four-wire - two-wire circuits only and the following figures are a suitable guide.

Circuits for transit links should have an average stability balance return loss of 20dB with a limit of 15dB and an average echo balance return loss of 25dB with a limit of 20dB.

END OF PAPER.