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The Long Line Telephone: Telephone 804

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Among the telephones used by the Australian Telecommunications Commission is a special high performance model (Telephone 804) intended for use on high-loss subscribers' lines. The principal features of the telephone are a semiconductor transmitter amplifier with volume limiting and a precision plug-in balance network for sidetone control.

This paper gives some of the background of the development of the telephone and discusses the principles of some of the circuit techniques used. Some aspects of the performance of the telephone are described and some of the restrictions which must be placed on its use are mentioned.

INTRODUCTION

In telephone networks a large amount of capital is invested in cables, and there is always interest in ways of reducing this investment without degrading the performance of the network. From time to time, devices or systems which might be used to reduce this expenditure (e.g., by allowing cheaper cables to be used) are proposed but most are rejected because problems related to technology or integration into the telephone network increase their overall cost.

In the middle 1960's the Australian Post Office conducted a computer aided cost analysis of several possible methods of providing longer than average lines at lower cost. This study indicated that of the methods considered, the use of a more sensitive telephone in addition to the standard telephone would be the most effective. Around the same time transistor technology was becoming "mature", i.e., reliable, cheap, high performance devices were becoming available and knowledge of transistor technology was becoming established at all levels of the electronics industry. The time was ripe for the development of an effective amplified telephone.

Subsequently, a project to develop a sensitive (or "long line" because longer lines of a given gauge would be possible) telephone was commenced. The telephone would be used principally with loaded cables and achieve its cost saving by allowing the use of lighter gauge cables and avoiding the use of open-wire lines. The largest savings would occur in rural areas. Total savings in excess

of \$2M per annum were estimated with a requirement of around 2,500 long line telephones per annum.

Some time after the development project had commenced a description of a broadly similar Japanese telephone was published (Ref. 1), indicating that at least one other administration was aware of the cost saving potential of this type of telephone.

THE LONG LINE TELEPHONE PROJECT

The basic purpose of the new telephone was to extend existing subscriber line loss limits while retaining the existing order of local system sensitivity. A nominal target set for the performance of the telephone was that limit transmission performance should occur on a line having a loss of about 6dB greater than that of a limit line using standard telephone. To explore means of coping with the sidetone problem resulting from such an increase in telephone sensitivity, the project commenced with the development of two fundamentally different prototype versions of the long line telephone. One version used a compromise sidetone balance network, an amplified transmitter and an attenuator in the receiving path, the attenuation of which was controlled by the transmitter signal level. The other version incorporated an amplified transmitter and several balance networks, any one of which could be selected via a switch in the base of the prototype telephone. After a series of objective and subjective tests, the second version was selected as being more satisfactory. The

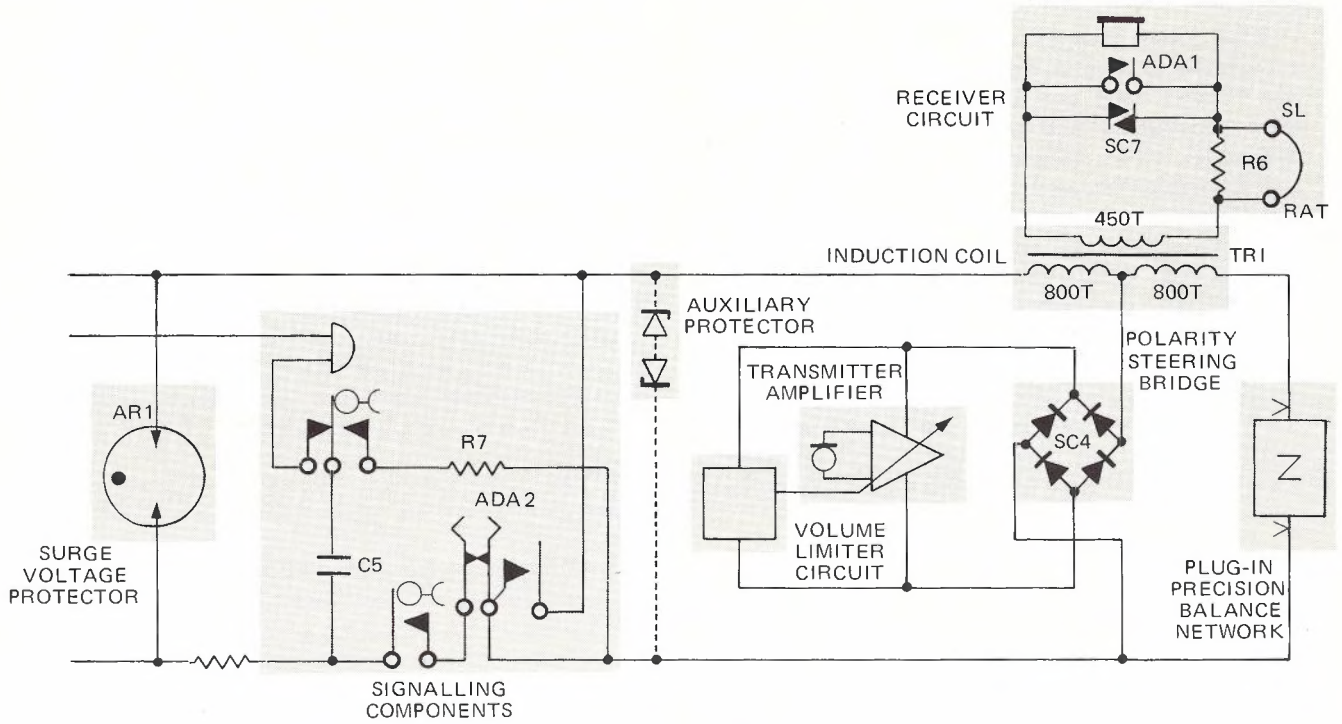


Fig. 1 — Telephone 804 Block Schematic

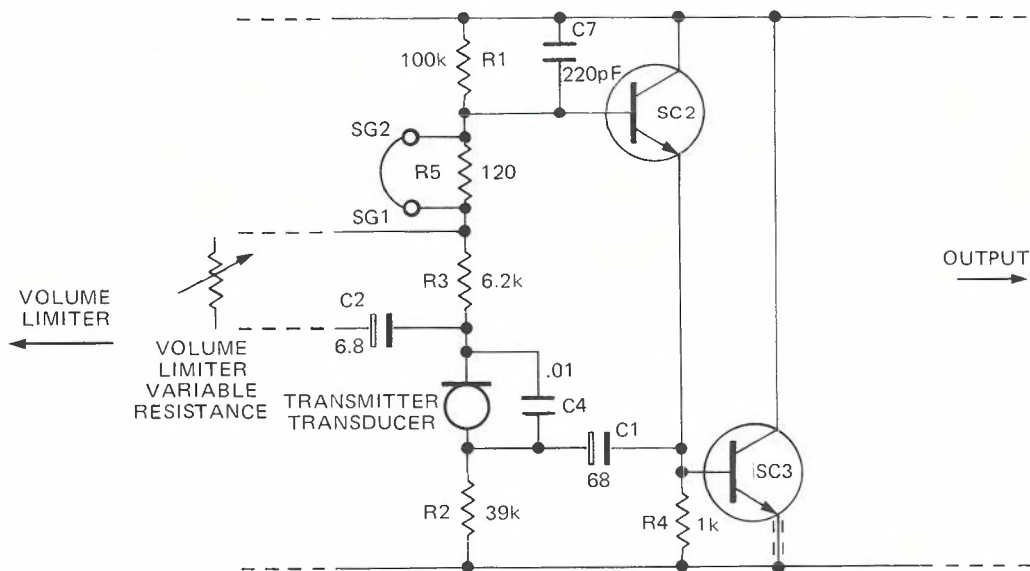


Fig. 2 — Transmitter Amplifier

principles used in this telephone were then embodied in a design for field use.

After some changes were made, such as from a switched to plug-in balance network, the design was "frozen" and one hundred of the telephones were constructed and used in a field trial. The telephones were installed in two areas (Mildura and Armidale/Tamworth) which were selected for such factors as the availability of suitable staff to conduct the field trial and a high lightning-induced damage risk. During the field trial further effort was put into the design of the balance networks and minor improvements to the circuit. Information fed back from the field trial was valuable in this process. By the time the field trial had concluded, the design of the telephone had advanced to the stage where it was considered suitable for manufacture as the long line telephone, "Telephone 804".

TELEPHONE 804

General Description

Telephone 804 is a conventional two-wire handset telephone, indistinguishable in external appearance from the Telephone 802 general purpose telephone (Ref. 2). (It utilises the same case, handset, receiver transducer, connecting cord and plug, dial and calling unit). To simplify maintenance and reconditioning procedures, etc., it is largely an adaptation of readily available components and therefore an acceptable rather than an optimum design has been achieved.

Telephone 804 (Fig. 2) features a transmit circuit employing a discrete-component solid-state amplifier powered from the line current and a passive receive circuit. Satisfactory control of sidetone, level to line, received level, echo, and crosstalk are achieved through a combination of measures. These include the use of plug-in precision sidetone balance networks, provision for send and receive sensitivity adjustment by means of removable links and a transmit volume limiting circuit. There are also restrictions on the types of lines which may be used, their installation practices and their minimum loss. In addition, the types of telephone service which can be provided are restricted.

For the longer lines where the line loop resistance may exceed the exchange signalling limit, a dc signalling extender (installed in the telephone exchange) is used in conjunction with the telephone.

Receiving

Most telephones have a speech circuit consisting of a transmitter, a receiver and a passive circuit which is designed to couple the transmitter and receiver to the line but not to each other. Some

form of balancing network is an essential part of these circuits. Subject to the usual restrictions of linearity etc., fundamental physical laws dictate that such a (passive) telephone circuit must have losses with power being dissipated in the balancing network. Furthermore if the circuit parameters are adjusted to reduce the losses for sending, then the losses for receiving must increase and vice-versa. A commonly used measure of the degree to which the sending efficiency is favoured is the Y-ratio (Ref. 3). The Y-ratio of Telephone 804 is less than that of the Telephone 802 and although the same type of receiver is used it is selected from normal production for high sensitivity. With these two measures sufficient receiving sensitivity is achieved without recourse to an amplifier.

Sending

The high sending sensitivity required of the telephone dictated that if an available transducer was to be used then amplification was essential. This fact reduced the cost penalty of using a stable, low-distortion transducer (implying low sensitivity, hence requiring an amplifier) instead of the (high sensitivity) carbon type. A rocking armature transducer identical to that used as the receiver was chosen to avoid the difficulties involved in supply and maintenance if a new type of transducer were introduced.

The transmitter amplifier (see Fig. 2) circuit consists of a simple shunt feedback amplifier with an added volume limiter circuit (Fig. 3). The original volume limiter used a half-wave voltage doubler rectifier but this suffered from a deficiency where certain utterances would cause the limiter to overshoot and produce undesirable clicks in the output of the amplifier. A change to the transformer coupled full wave rectifier greatly reduced the problem whilst still allowing the required voltage step-up needed to operate the field effect transistor variable resistance circuit.

The volume limiter is used both to control cable crosstalk with loud talkers by restricting the amplifier output voltage and to ensure that the output does not clip with such signals. The limiter characteristics are shown in Fig. 4. The threshold of gain compression is such that the volume limiter has negligible effect on the transmitting sensitivity with normal talking levels. As indicated by the distortion curve associated with Fig. 4, a 15 dB increase in input level above this threshold is possible before overloading of the transmitter becomes significant.

Because of the feedback used in the amplifier, the sending sensitivity of the telephone is virtually independent of line current. Maximum sensitivity occurs at about 75mA feeding current, dropping by about 0.3 dB at 40 and 110mA, and by about

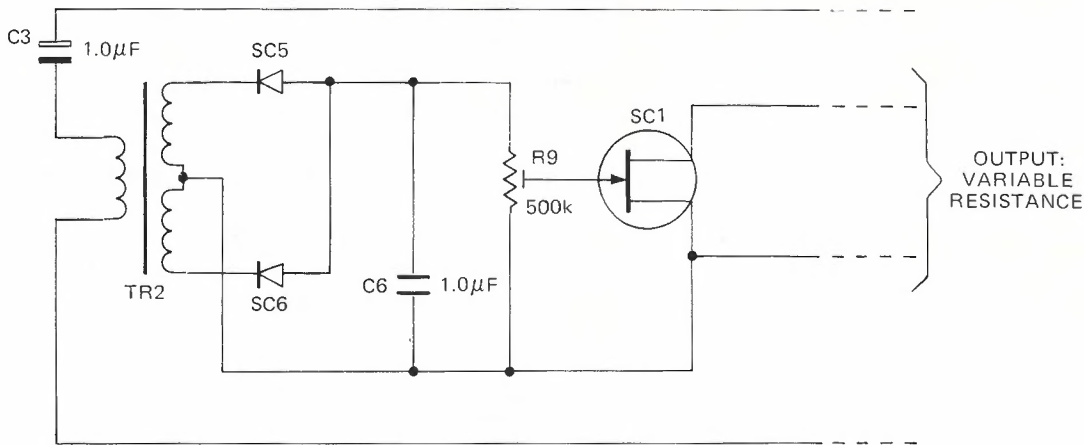


Fig. 3 — Volume Limiter

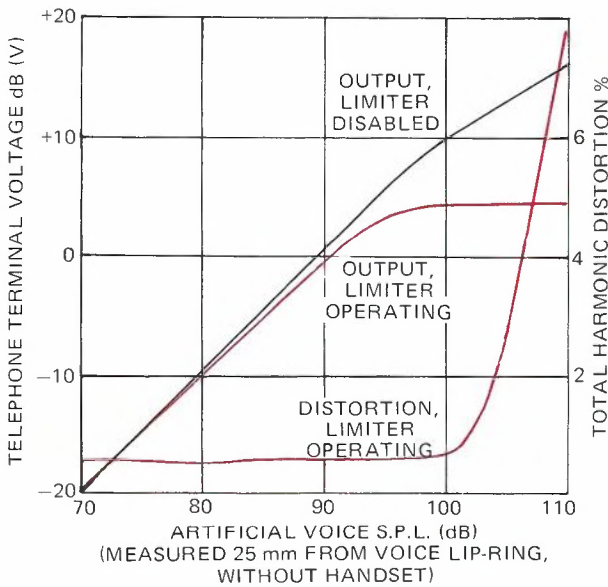


Fig. 4 — Volume Limiter Characteristic (1kHz, typical line conditions)

0.9 dB at 20mA. An increase in the output impedance of the amplifier can be regarded as the primary cause for the slight drop in sensitivity at low currents.

In common with most other (overseas) telephone transmitter amplifiers, the dc voltage drop of the amplifier in Telephone 804 is largely independent of line current. This characteristic is better than one where the drop is proportional to line current because it ensures that the amplifier has sufficient

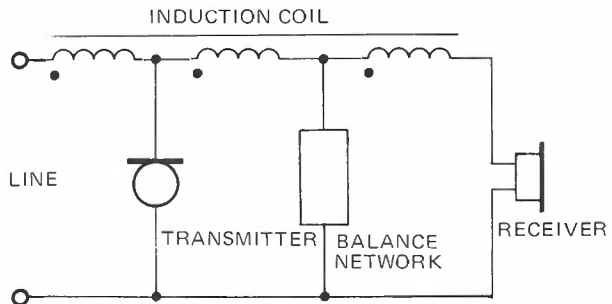


Fig. 5 — Another Type of Induction Coil

output swing capability at low line currents whilst not imposing the penalty of very high power dissipation at larger line currents. The dc characteristic of the whole telephone is somewhat similar to that of a constant voltage drop device of 5.6 V in series with a 55 ohm resistor.

Sidetone

The induction coil used in Telephone 804 is a "bridge" type and is somewhat unusual for a modern central battery telephone. The type illustrated in Fig. 5 is more common because it allows the telephone designer more freedom in the choice of Y-ratio and transducer impedances. A similar freedom is available with the bridge type only if an extra matching transformer is used. This means that a telephone using the type of induction coil shown in Fig. 5 will usually be cheaper (particularly if a low resistance carbon transmitter is used). However, it was found in the early stages of the development of the long line telephone that with

this type of induction coil it is inherently more difficult to achieve a sidetone balance of the required precision (a similar observation is made in Ref. 1). Hence the bridge type of coil is used, and the 800 turn windings (Fig. 1) are bifilar wound thus ensuring that the contribution of the induction coil to any sidetone circuit imbalance is negligible.

A combination of further measures is used to ensure adequate sidetone control. Operation on short, low-loss lines is not permitted, so that regardless of the terminating impedance offered at the local exchange, the telephone tends to see an approximation to the characteristic impedance of the line. The lowest loss line on which this telephone may be used has a loss only slightly lower than the maximum loss line permitted for the standard (801/802) telephone.

Also, a plug-in balance network is used which is selected to suit the subscriber's line. Each balance network was designed as a compromise to give a high degree of sidetone suppression over a range of the longer lengths of the particular line for which it was intended, with the line terminated at the exchange end by either a 600 Ω or 1200 Ω resistive impedance. (These impedances were chosen to represent a junction link provided by either a carrier system or a loaded cable, respectively, and ensured that reasonable sidetone suppression was obtained over a range of possible exchange impedances). In addition, the balance networks were designed to minimize peaks in the sidetone frequency response and give about equal weight to low and high frequencies, so that the sidetone would sound natural to telephone users.

A tester containing nine different balance networks (all for unloaded cables), a noise source and an ac millivoltmeter was developed and used in the field trial of the long line telephone. It was used to select the balance network which gave the best sidetone at each installation. Although the tester generally worked satisfactorily it was later decided to restrict the number of different balance networks which are required, by specifying strict rules for the techniques (mixed gauges, lead-in cables, cable tees, etc.) which can be used in the provision of the subscribers' line. If these rules are complied with, the correct balance network is easily predicted and a tester is no longer necessary.

For loaded cable, relatively accurate building-out of the line capacitance of the last (subscriber end) loading section must be used. The capacitance is built-out to a full section (1830 metres) from the last loading coil, thus it is never necessary to include a loading coil in the building-out network. The balance network used for loaded cable (Fig. 6) necessarily incorporates an inductor in addition to the usual resistors and capacitors. The balance net-

works for unloaded cables are similar but with L1 and C4 replaced by a resistor.

By removing two internal straps (see Fig. 1 and 2) the sending and receiving sensitivities can each be reduced by about 3dB, thus reducing the sidetone level by about 6 dB on lower-loss subscriber lines.

In early experimental versions of the telephone the polarity steering bridge was placed nearer the line terminals, ahead of the induction coil. This had the advantage of allowing electrolytic capacitors to be used in the balance network if large capacitors were needed (e.g., to block dc through the network). It was found however that the non-linear diode impedances degraded the sidetone balance, becoming worse at higher sending levels. Hence the bridge was shifted to its present position.

Sending and Receiving Frequency Responses

The sending and receiving sensitivity versus frequency characteristics are governed by the transducers used. Because the main use of the telephone is with loaded cable, no special measures were taken to compensate for the cable frequency response.

Typical send and receive frequency responses on a long loaded cable are shown in Fig. 7. Although the receive frequency response is quite good, the sending response is only just acceptable. The poor low frequency response is a consequence of using as a transmitter a rocking armature transducer which was designed to be used as a receiver, although the interaction between the transducer impedance and the shunt feedback amplified input does improve the response slightly. This improvement is illustrated (fig. 7) by the poorer low fre-

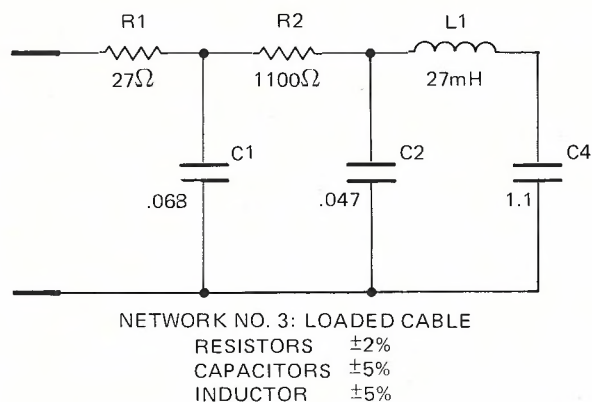


Fig. 6 — Balance Network Example

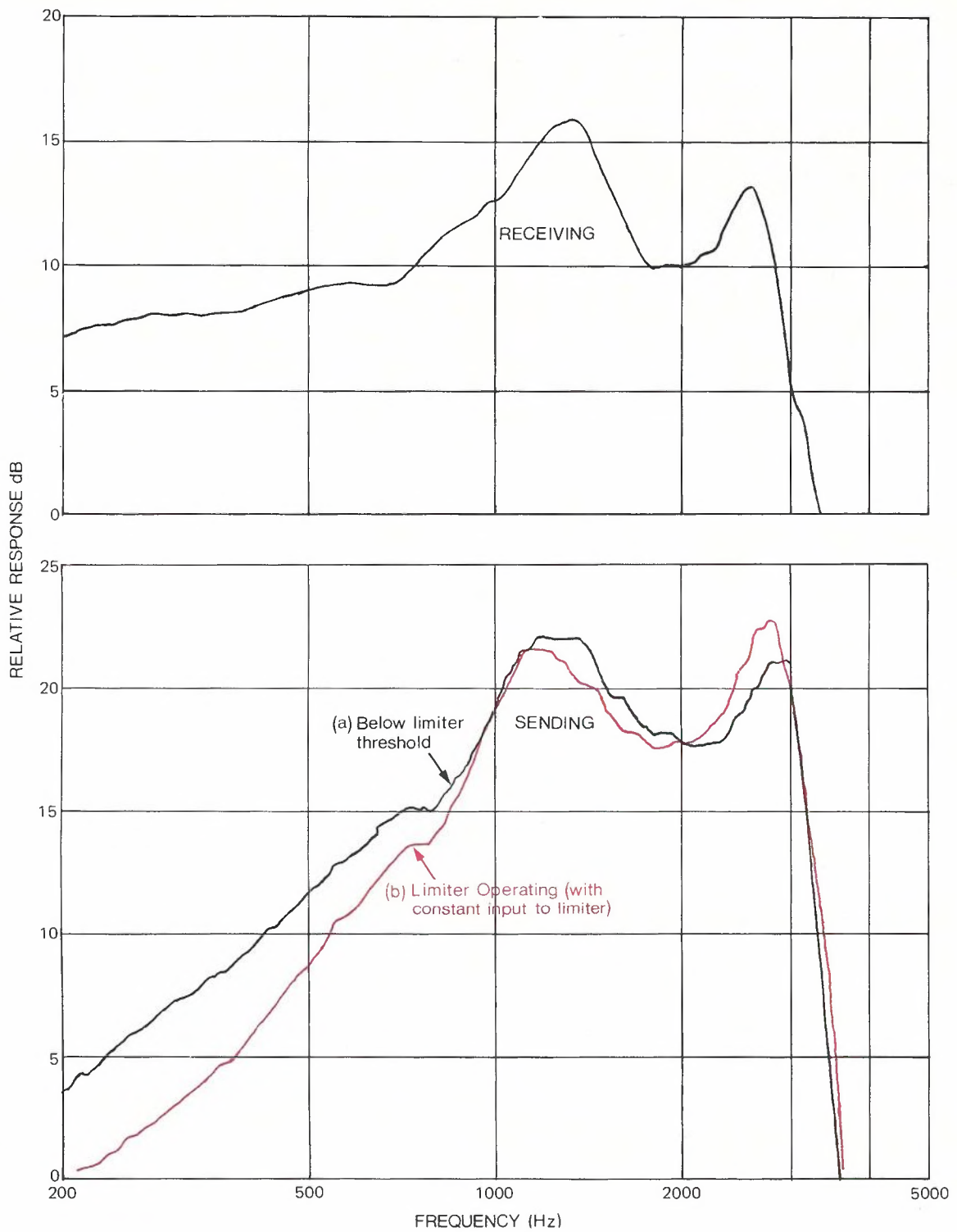


Fig. 7 — Sending and Receiving Frequency Responses (including 39 km. of 0.90 mm Loaded Cable)

quency response which occurs when the limiter operates and swamps the transducer impedance with extra resistance between the transducer and amplifier. The amplifier has insufficient gain to allow the response to be significantly improved by equalization.

Line terminal impedance

With its use restricted to high-loss lines, the line terminal impedance of the telephone is not an important factor determining the return loss at the exchange. This meant that considerations of the line terminal impedance of the telephone had no direct influence on its design. Sending, receiving and sidetone performance were the independent factors and the manner in which satisfactory performance in these was achieved determined the line terminal impedance. It turns out that with a 600 ohm balance network installed in the telephone its impedance essentially rises with frequency and is approximately 500 ohms (angle 20°) at 1 kHz and 600 ohms (resistive) at 3 kHz.

Feed-current sensitivity

As mentioned above, the sending performance of the telephone varies little with line current, for currents between 20 and 110 mA. The line terminal impedance also varies little with line current. The receiving performance is even less affected.

It is common practice to make use of the relationship between line loss and current (via resistance) to make the performance of a telephone plus line virtually independent of line length. To do this the sending and receiving sensitivities of the telephone are made to decrease as the line current increases. This feature is called "automatic regulation" (telephone 802 has this feature). Unfortunately, the relationship between line loss and current depends upon the gauge of cable used and since a variety of cable gauges are normally used a compromise must be accepted. The problem is worst with high loss lines. Automatic regulation is not used in Telephone 804 because this telephone is used only on high loss lines and therefore only a very restricted benefit could be derived, at the cost of increased complexity, price and development time.

Crosstalk

Crosstalk is potentially a serious problem with Telephone 804 because of its high sending and receiving sensitivities. Satisfactory crosstalk is virtually ensured however, by two factors. Firstly, because the telephone is used on lines of higher loss than permitted in the past, it is almost certain that at least the portion of cable nearest the subscriber will be recently installed and therefore have the high crosstalk attenuation of modern cables.

These cables have high crosstalk attenuation because the specification for crosstalk attenuation of the plastic cables likely to be used with Telephone 804 was enhanced concurrently with its development. The other contributing factor is that the transmitter volume limiter is set to limit the sending level of unusually loud talkers.

Reference Equivalents

Reference Equivalents are one performance criteria which can be used as the basis for planning the transmission performance of a telephone network. A good discussion of reference equivalents appears in Reference 3.

Basically, a Reference Equivalent is a subjective measure of an aspect of the communication performance of a telephone. Thus there are Sending Reference Equivalents, Receiving Reference Equivalents, etc. Telecom Australia uses the CCITT recommended NOSFER system as one basis for measuring the performance of telephones. With this system a comparison based on loudness is made between an aspect of the performance of a telephone and a corresponding part of a defined reference apparatus. An attenuator in the reference apparatus is varied until loudnesses are judged to be equal. The setting of this attenuator is then called the Reference Equivalent (Sending, Receiving or Sidetone) of the telephone. Thus the greater the Reference Equivalent, the less "loud" is that aspect of the telephone performance.

When the term "Reference Equivalent" is used without a qualifying adjective (apart from "Sending", "Receiving" or "Sidetone") it normally refers to a measurement based upon loudness, rather than other measures such as sound articulation scores.

Telephone 804 is designed to have the following limit Reference Equivalents: Sending +16 dB maximum; Receiving +3 dB maximum; Sidetone +12 dB (minimum) when connected to maximum loss lines falling to +8 dB (minimum) on minimum loss lines. These figures apply for a telephone having transducers with the minimum permitted sensitivity.

Signalling

The signalling circuit and components of Telephone 804 (Fig. 1) are virtually identical to those of the Telephone 802.

The long (hence high resistance) lines on which the telephone can be used are beyond the limits for looping and dialling of some types of exchange. It is therefore necessary to use some form of signalling extender at the exchange in such cases.

When very long lines are used, e.g. 60 km (of 1.27 mm loaded cable), some problems may be experienced in ringing poorly adjusted bells in the

telephone if 50 Hz ringing current is used. No problems should occur with 16 2/3 Hz ringing current.

As mentioned above, capacitance building-out is a necessary feature of using Telephone 804 with loaded cable. The building-out capacitor is placed in a small box underneath the telephone socket and there is therefore very little resistance between the line terminals of the telephone and this capacitor. Resistor R8 (Fig. 1) is included to limit the discharge current from this capacitor thus preventing the serious spark erosion of the dialling contacts which would otherwise occur.

Reliability

Reliability may be a problem with Telephone 804 because of two factors; firstly it contains semi-conductors (sometimes derided as fast acting fuses), and secondly it is used on long lines and hence induced high voltages (e.g., from lightning) can be expected to be a greater problem than with other telephones. Some form of protection is therefore necessary.

Following the field trial and a series of laboratory tests it was concluded that a single gaseous arrester (Fig. 1) was likely to provide the best compromise between cost and reliability. A place has been provided on the circuit board for extra (secondary) protection (the Zener diodes shown in Fig. 1) to be provided if experience indicates that it is necessary. The diodes would work in conjunction with R8.

Interference

In common with most electronic equipment, the telephone is sensitive to interference from electromagnetic fields from radio transmitters, etc. This sensitivity has been reduced to a level which is regarded as acceptable by the inclusion of capacitor C4 (Fig. 2). Doubtless, some situation will exist where this is insufficient and further, ad-hoc measures will be necessary.

Restrictions

Besides the rather basic restrictions mentioned above of maximum and minimum line lengths (to ensure adequate sending, receiving and sidetone performance) there are other restrictions which must be placed on the use of the telephone which restrict the types of service which are provided.

Whilst parallel operation of two of the telephones is possible, if the telephones are used simultaneously then the resulting impedance shunting of each telephone by the other will cause both to have unacceptably high levels of sidetone and weak sending and receiving performance (with respect to the distant subscriber but not to each other, of course).

Thus although parallel connection is allowed, subscribers must be advised that simultaneous operation should be avoided.

The relatively high voltage drop required by the transmitter amplifier leads to other problems. For example in one common type of switchboard the operator's circuit, which uses a carbon transmitter, derives its power by being placed across the subscriber's line when the telephonist wishes to talk with the subscriber. In this case Telephone 804 will not draw enough current to ensure its proper operation.

Use of the telephone to solve the problem of a high loss line between a PBX and parent exchange is discouraged. Without treatment of the PBX equipment, inadequate sidetone performance on extension-to-extension calls would be a problem and there would be a large difference between the loudness of internal calls, and those to the rest of the telephone network.

CONCLUSION

A telephone has been developed which will meet transmission performance objectives when used with high loss lines. Where new cables are to be installed it can be used to allow the use of smaller gauge (hence cheaper) cables than would otherwise be used. Alternatively, it can be used with a given cable gauge to provide services which would otherwise not meet performance objectives due to the length of the line. It also allows cable to be used in situations where (relatively expensive) open wire would otherwise be necessary.

Telephone 804 probably has a performance close to the limit which is possible with present cables and an essentially linear, two-wire telephone (excluding techniques such as switching, carrier, etc.). An attempt to design a similar type of telephone to operate on longer lines would soon encounter the problems of higher crosstalk and greater difficulty in achieving adequate sidetone performance. To extend the line attenuation limits by one dB whilst maintaining the same performance requires two dB extra crosstalk attenuation and two dB extra sidetone rejection. The difficulties soon become formidable, with better (more uniform, etc.) cables and more complex installation practices becoming required as well as higher performance in the telephone.

Around the time that the first production run of Telephone 804 was being arranged, a change in policy concerning rural telephone services took place such that demand for the telephone was reduced. Nevertheless the telephone is finding significant application in rural areas.