THE

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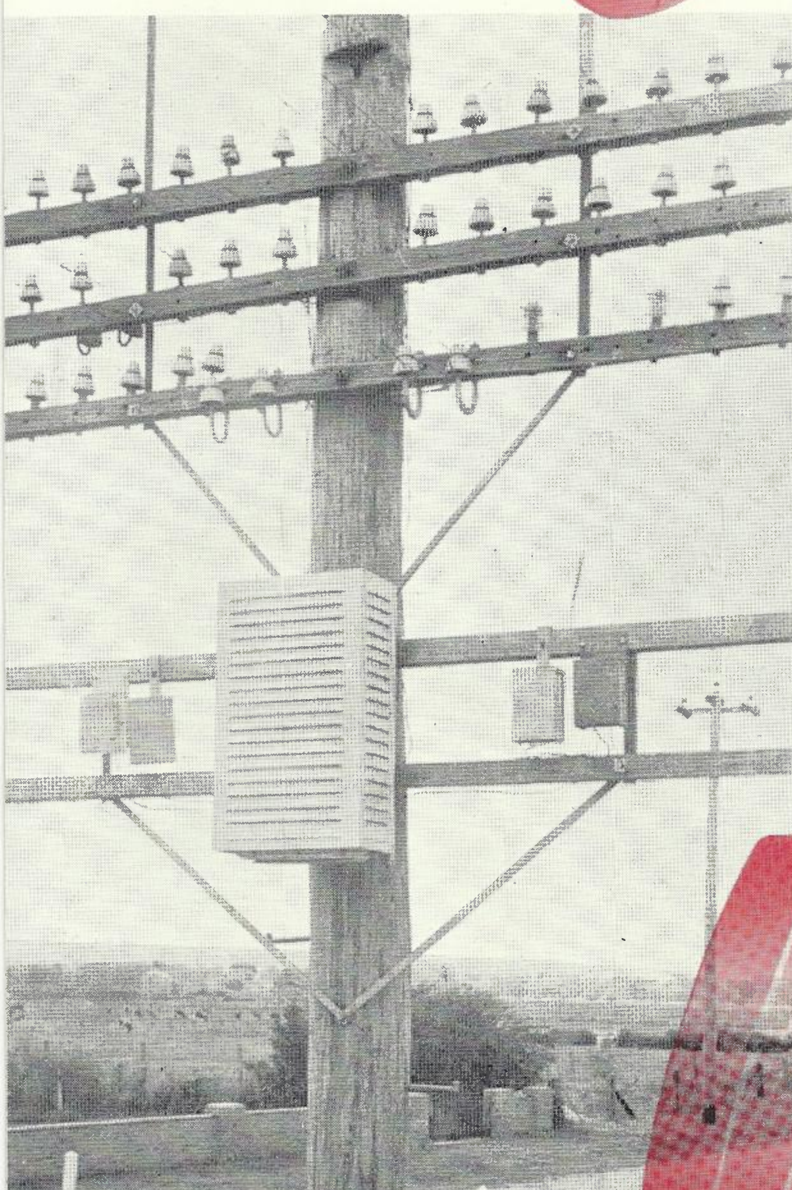

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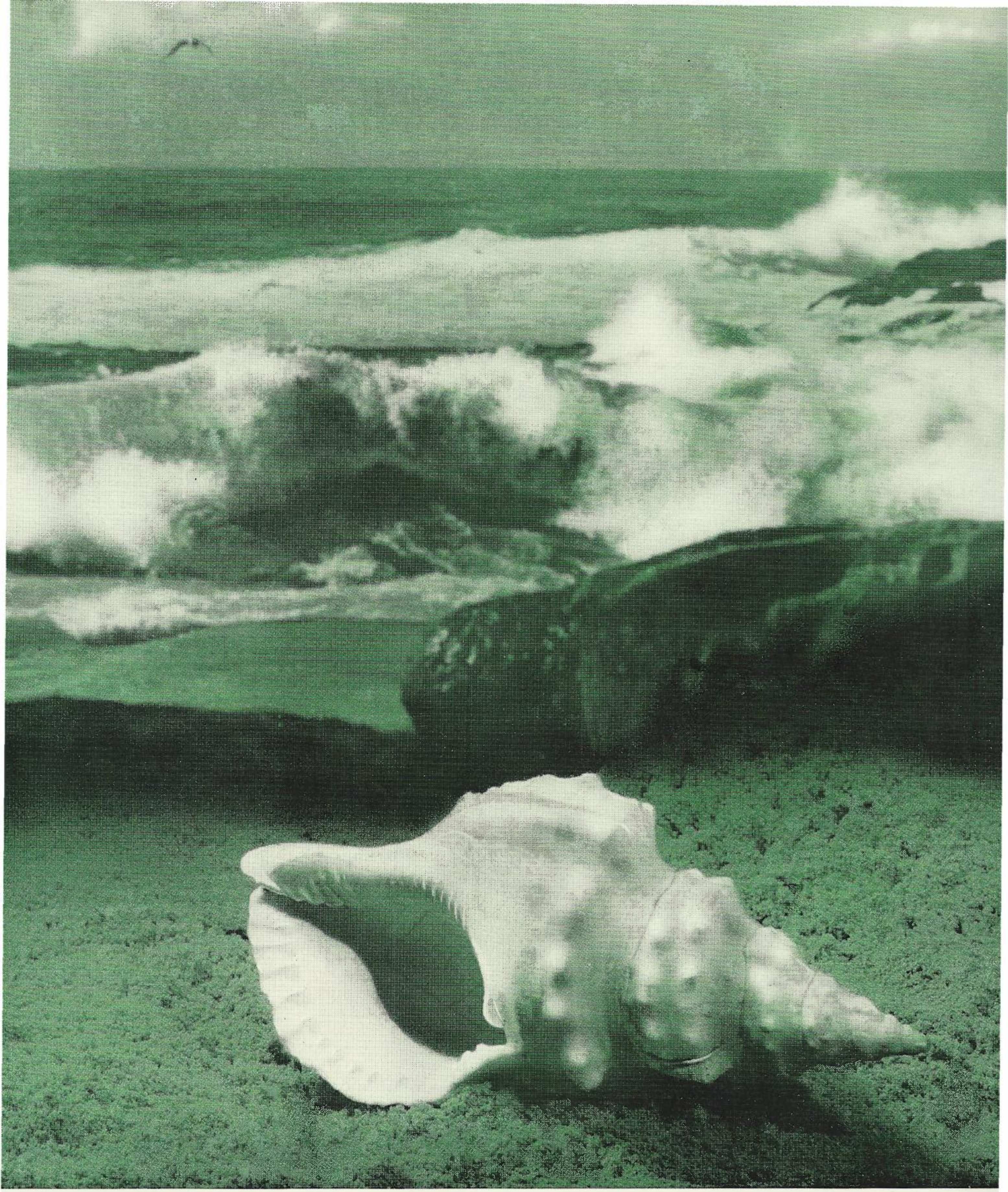
VOL. 12, No. 5 Registered at the General Post Office. Melbourne, for transmission by post as a periodical. OCTOBER, 1960



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* For addresses see page 379

INTRODUCTION TO JUNCTION TRANSISTORS

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PART I—BASIC TRANSISTOR ACTION AND THE COMMON-BASE AMPLIFIER

*R. N. HURST**

INTRODUCTION

As transistorized equipment comes into use, the broadcast engineer will find that a new dimension must be added to his field of knowledge. Transistors—resembling tubes in some ways, differing from them in others—will put new demands on the skill and ability of the men who install, maintain, and repair broadcast equipment. To help broadcast engineers acquire this new skill, we present here the first of a series of articles to explain the fundamental behaviour of junction transistors in familiar terms. In these articles, the physicists' point of view of a transistor is intentionally avoided in order to permit the reader to approach this new subject through the concepts of well-known electronic circuits.

This year marks the tenth anniversary of the invention of the transistor, which during this time has developed from an unpredictable device with sharply limited applications to a stable and reproducible element, which can be employed in a wide variety of circuits. During these years of development, RCA broadcast engineers have kept a watchful eye on this promising device. Circuits using transistors were regularly evaluated, and those meeting broadcast standards of quality were incorporated into products. Until recently, however, these products were limited to audio devices because no commercially available transistors were capable of acceptable high-frequency operation. Recently, there has been an accelerated development of new devices and techniques which promise to put the transistor into all types of broadcast equipment. Even as this is written, the forerunners of many kinds of broadcast equipment using transistors are taking shape.

Hence it is important for the broadcast engineer to know something of the characteristics of transistors: how they operate; what their limitations are; what their advantages are; and, ultimately, to become as familiar with transistor circuitry as he is with vacuum tube circuitry.

BASIC TRANSISTOR ACTION

A transistor may be considered as an extension of an ordinary junction diode, which consists of two pieces of semiconductor material of slightly different composition, joined together with wire leads provided for connection to each piece. Although the difference in the chemical compositions of the two pieces is slight, the difference in their electrical characteristics is very great. To identify these different materials, one is called *P-type material,* and the other, *N-type material.* The physics of these differences is not discussed here, it is sufficient to say that a junction diode will conduct heavily if a voltage is placed across it with the P-type material positive and the

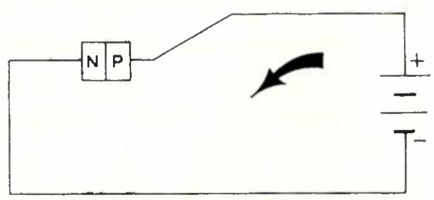


Fig. 1.

N-type negative, but will conduct only slightly if the polarity is reversed:

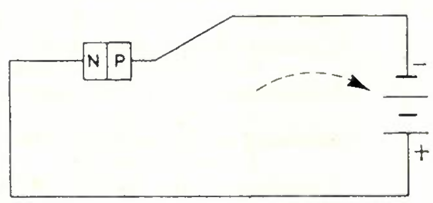


Fig. 2

When the diode is conducting heavily, it is said to be *forward biased;* when it is conducting slightly, it is *reversed biased.*

If this diode structure is extended to include another junction, leaving the original junction reverse-biased as above, and providing a *forward* bias for the new junction diode which was formed by adding the left-most P-region, the circuit will appear as follows:

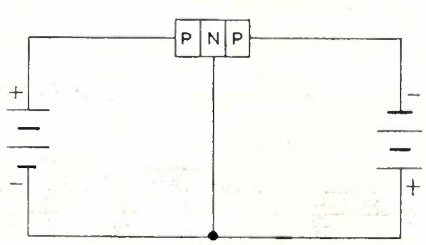


Fig. 3

One might expect *(wrongly)* that a heavy current would flow in the forward-biased diode, a small current would flow in the reverse-biased diode, and there would be no interaction between the two diodes:

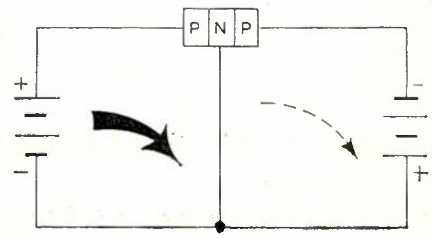


Fig. 4

This is not the case, however, For the circuit shown, the forward-bias current of the left-hand diode would flow completely through both junctions, except for a small current which would flow as shown in this sketch:

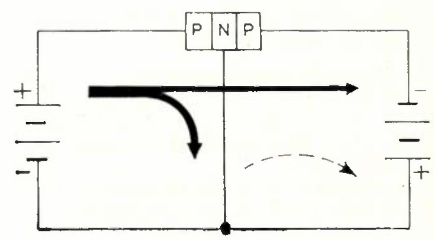


Fig. 5

This unexpected behaviour, which is observed only if the centre region is thin, is the basis for transistor action.

Since the left-hand P-region emits current into the transistor, it is called the *emitter.* The middle region (the N-region here) through which the emitter current passes is called the *base.* The right-hand P-region, which collects the current emitted by the emitter, is called the *collector.*

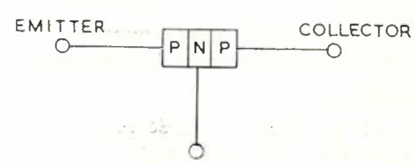


Fig. 6

A transistor constructed in this manner (as a "sandwich" of N-type "meat" and P-type bread) is called a *PNP Transistor.* By reversing the "meat" and the "bread" another arrangement is possible:

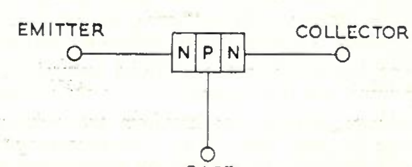


Fig. 7

*Editorial Note: This is the first of a series of three articles which appeared in "Broadcast News" published by the Radio Corporation of America. It is reprinted by the kind permission of the author and the Editor of "Broadcast News". Many readers of the Telecommunication Journal of Australia have requested that a simple introduction to transistors should be published and this series is the most suitable we have seen. The series is abstracted from a group of transistor lectures given jointly by the author and Mr. A. C. Luther. The author wishes to acknowledge the fact that many of Mr. Luther's valuable contributions to the lectures have been retained in these articles.

This arrangement is called an *NPN Transistor*. The major difference between the two is that the various voltages applied to a PNP transistor must be reversed for an NPN transistor.

In schematic diagrams, a PNP transistor is symbolised in this way:

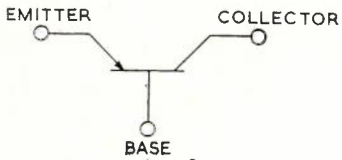


Fig. 8.

and an NPN transistor this way:

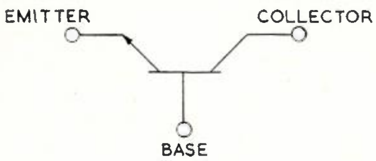


Fig. 9.

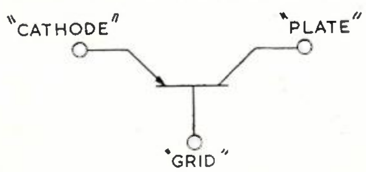
You will notice that both NPN and PNP transistors exhibit left-to-right symmetry; that is, the emitter and collector of a given transistor are both made of the same material, and apparently connected to the base in the same way. It is reasonable to ask whether it makes any difference which of the outer regions is the emitter and which the collector. In some transistors, called *symmetrical* transistors, it makes no difference. In most transistors, however, the emitter and collector regions are manufactured differently. It is this difference which determines the proper naming of these regions. Regardless of this difference, a typical small transistor may usually be made to operate in a very limited manner with emitter and collector leads interchanged.

TRANSISTOR VERSUS VACUUM TUBE

The transistor, being an amplifying device, bears a resemblance to a vacuum tube in that the three "elements" of a transistor correspond (approximately) to the three elements of a triode tube:

Transistor	*Vacuum Tube*	
Emitter	Cathode	
Base	Grid	(10)
Collector	Plate	

This correspondence between transistor and vacuum tube can be used to produce the following equivalent symbols:



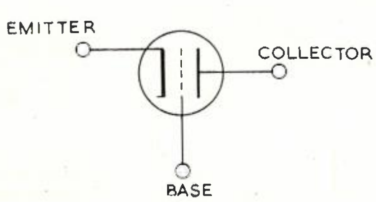


Fig. 11

One should not infer, however, that these equivalences are anything but approximate. For example, consider the difference between a grid and a base. A grid, in normal negative-biased operation, draws no current. The total cathode current flows in the plate circuit:

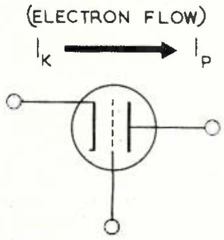


Fig. 12

It was stated above, however, that the emitter current in a transistor divide between the collector and the base, so that the base has an appreciable current flowing in it:

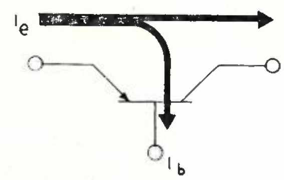


Fig. 13.

Since the current that flows (for a given voltage) is an indication of the impedance of a circuit, the fact that the base draws current while a grid does not leads to the conclusion that the impedance seen looking into a base would be very much smaller than the impedance seen looking into a grid. The conclusion is correct; a typical vacuum tube, it is well known, has a grid impedance of several megohms, while a typical transistor may have a base impedance less than 2000 ohms:

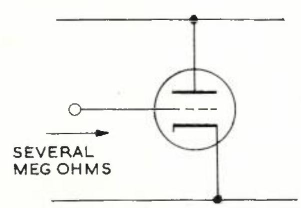


Fig. 14.

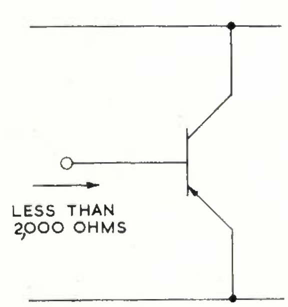


Fig. 15.

DEFINITION OF ALPHA AND BETA

Although sufficient current flows in the base circuit to make the base appear as a low impedance, this base current represents only a small portion of the emitter current—approximately two per cent in a typical transistor. Remaining 98 per cent appears in the collector circuit. This current division is used to define an important transistor parameter called *alpha*. If 98 per cent of the emitter current of a certain transistor flows in its collector, the transistor has an alpha of 0.98. Mathematically, it is stated:

$$\alpha_{DC} = \frac{I_c}{I_e} \qquad (16)$$

Since I_c (dc collector current) and I_e (dc emitter current) are bias currents, their ratio is called *dc alpha,* hence the dc subscript. The more frequent use of the word alpha refers to a ratio of signal currents (where i_c and i_e are signal currents in the collector and emitter, respectively.:

$$\alpha_{AC} = \frac{i_c}{i_e} \qquad (17)$$

The word alpha as used herein always refers to the ratio of signal current, unless there is a statement to the contrary. It is interesting to note, in passing, that both definitions give almost the same value for alpha.

Since the collector current is always a little less than the emitter current, alpha will always be a little less than one. Therefore, a transistor will offer loss instead of gain for a *current* signal impressed on the emitter and observed at the collector:

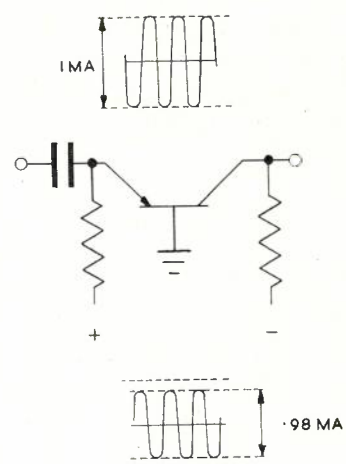


Fig. 18.

Nonetheless, useful arrangements can be made using this circuit, even though it does not give us a *current* gain. Some of the ways of using this configuration, which is called the *grounded-base configuration,* are discussed later in this article.

How, then, is current gain obtained? It is obtained by controlling the base current (two per cent in the foregoing example) by applying a signal to the base. The base current, when controlled by a small fluctuating (signal) current, causes a corresponding fluctuation in the much larger emitter current, thereby causing the same fluctuation in the collector current:

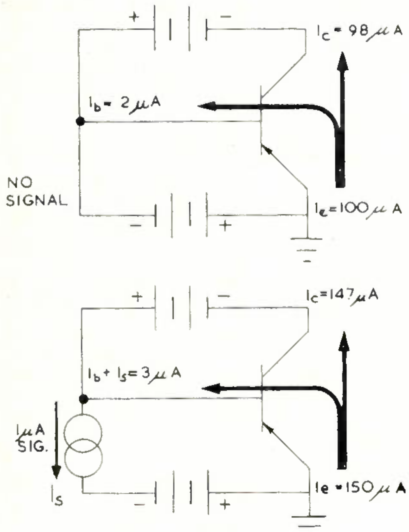


Fig. 19.

Since the small signal-current introduced in the base circuit causes a larger signal-current to appear in the collector circuit, we say that a *current gain* has taken place.

The current gain obtained here is clearly the ratio between the collector current and the base current. This current ratio is another important transistor parameter, and is called *beta*. Mathematically, it is stated:

$$\beta_{DC} = \frac{I_C}{I_B} \quad (20)$$

This ratio is called *dc beta*, for reasons similar to those given for dc alpha. More frequently, the word beta refers to a ratio of *signal* currents:

$$\beta_{AC} = \frac{i_C}{i_B} \quad (21)$$

This definition of beta is the one which is used in this article unless there is a statement to the contrary.

In sketch 19, a signal current of $1\,\mu A$ in the base caused a change of 49 μA (147 μA −98μA) in the collector current. The beta of this transistor would be:

$$\beta = \frac{49}{1} = 49 \quad (22)$$

This is a fairly typical value.

Note that in the configuration employed to give current gain, the ground point was moved from the base to the emitter. This circuit is therefore called the *grounded-emitter configuration*, or *common-emitter*[2] *configuration*. It is roughly equivalent to the grounded-cathode configuration of a vacuum tube, but the analogy should be employed with caution. For example, it has already been pointed out that the impedance, looking into the base, is typically 2000 ohms, instead of the high impedance usual for a vacuum-tube grid.

Note also that signals and biases in transistors are described as currents, not as voltages, as is common in vacuum tubes. The gain (beta) which roughly corresponds to mu in a vacuum tube, is a *current* ratio, whereas mu is a *voltage* ratio. It is usually much more convenient, for transistor work, to describe the circuits in terms of currents, rather than in terms of voltages.

CHARACTERISTIC CURVES OF TRANSISTORS

In the introduction to this subject, the transistor was presented as an extension of an ordinary junction diode. This same approach can be used to derive the characteristic curves of a typical transistor, which show very clearly the behaviour that can be expected.

If we set up a laboratory experiment in which we apply several different reverse-biasing voltages to a junction diode, and measure the resulting currents,

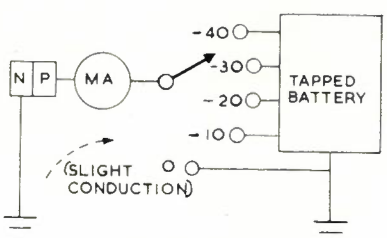


Fig. 23.

we can plot from the resulting data a curve showing the reverse-bias characteristic of a junction diode:

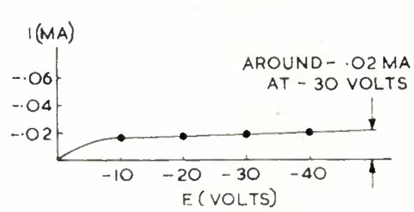


Fig. 24.

Simply extending this reverse-biased diode (to make it into a transistor) will not change the curve,

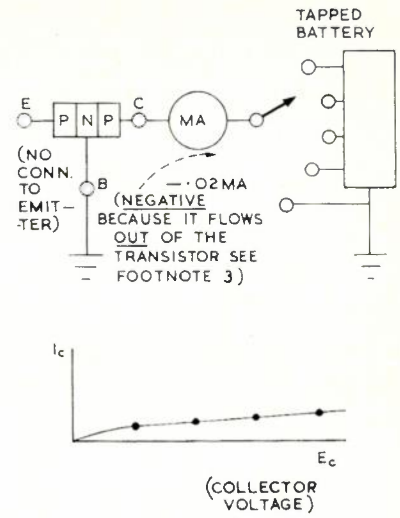


Fig. 25.

but forward-biasing the *new* junction (which is the way we establish transistor action) will cause a definite change in the curve, since the forward-bias current will flow through both junctions and appear in the circuit containing the milliammeter:

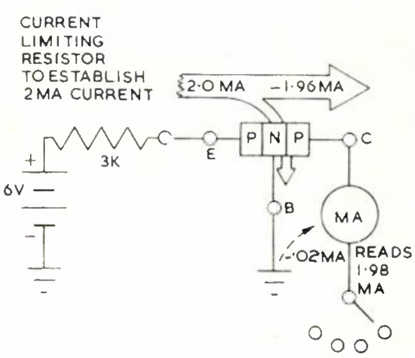


Fig. 26.

This additional current will displace the entire curve upward:

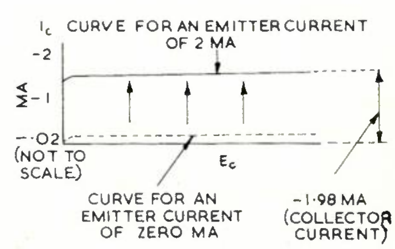


Fig. 27.

If we choose a different value of emitter current—say 3.0 ma instead of 2.0 ma—the curve will be displaced upward even farther:

[2] In these articles, the prefix "common-" will be used in preference to "grounded-," since it is more general. For example, it is not unusual to have a common-emitter amplifier in which the emitter is not connected to ground.

[3] Conventional network theory states, arbitrarily, that current flowing *into* a network is positive; current flowing *out*, negative. This convention is followed in these articles. It is also used in transistor data sheets.

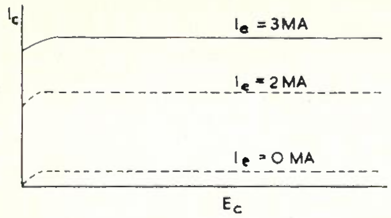


Fig. 28.

By selecting several different values of emitter current and showing a curve for each one, we can generate an entire family of curves:

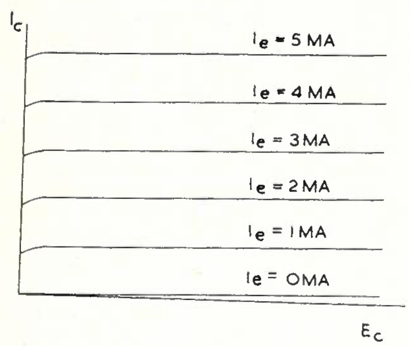


Fig. 29.

This family is typical of the curves found in data sheets.

You will note that these curves are drawn for a transistor operating with its base grounded:

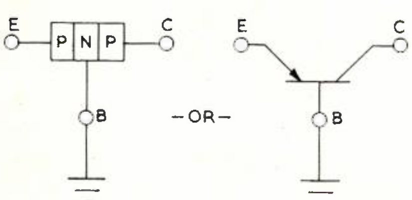


Fig. 30.

Therefore, these curves are called *common-base curves,* and an amplifier built using a transistor connected in this manner is called a *common-base amplifier*. These curves can be used to show the behaviour of a common-base amplifier.

TRANSISTOR AMPLIFIER

Let us suppose that a piece of broadcast equipment contains this common-base transistor amplifier (using a PNP transistor):

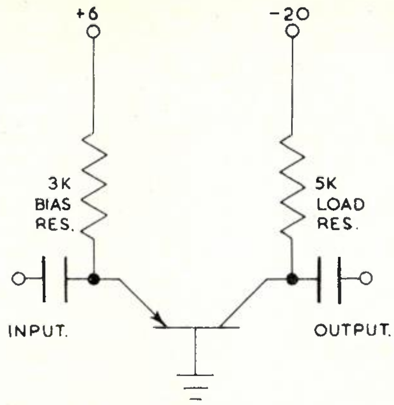


Fig. 31.

We wish to know how this amplifier is operating—what the bias is, how much collector current flows, how much power is dissipated in the collector, and how much gain it will offer. All these facts may be ascertained by a simple construction on the common-base characteristics.

Start by drawing a load line on the characteristics. This construction is exactly the same as the corresponding construction on vacuum-tube characteristics. You will remember that a typical pentode in this circuit:

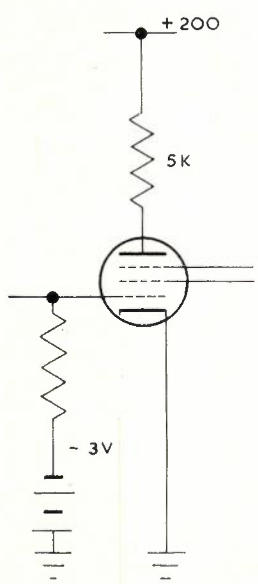


Fig. 32.

will have a load line connecting the 200-volt point and the 40-ma point. (the 40-ma point is obtained by dividing 200 volts by 5,000 ohms):

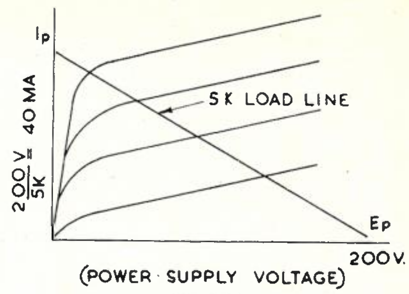


Fig. 33.

In an exactly similar manner, the load line for the common-base amplifier will be a straight line connecting the—20-volt point and the -4-ma point:

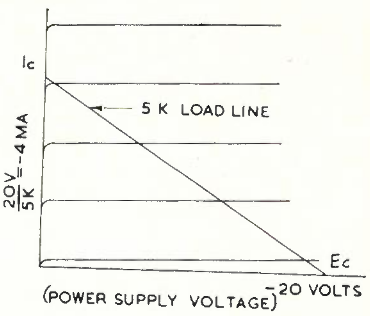
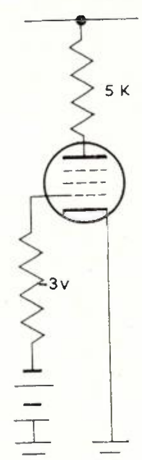


Fig. 34.

Just as for vacuum tubes, the operating point of the transistor amplifier must lie somewhere on its load line. For the pentode, the operating point lies at the intersection of the load line and the curve representing the particular bias chosen by the design engineer:



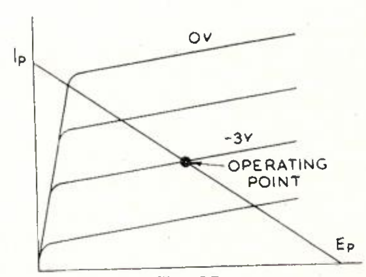


Fig. 35.

The bias for this transistor amplifier, however, is a *current,* not a voltage. The bias current is that current which the 6-volt supply can cause to flow in the series combination of the 3K resistor and the forward biased emitter[4] junction:

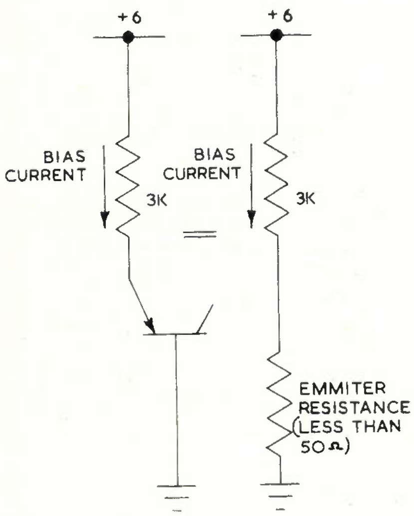


Fig. 36.

Since the emitter resistance is usually very small (less than 50 ohms), its resistance may be neglected in computing the bias current. The current is therefore:

$$I_e = \frac{6 \text{ volts}}{3{,}000 \text{ ohms}} = 2 \text{ ma} \quad (37)$$

which will put the operating point at the intersection of the load line and the 2-ma curve:

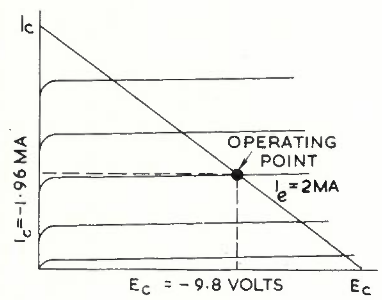


Fig. 38.

This transistor amplifier therefore operates with a bias current of 2 ma, a collector current of –1.96 ma, and a voltage at the collector of –9.8 volts:

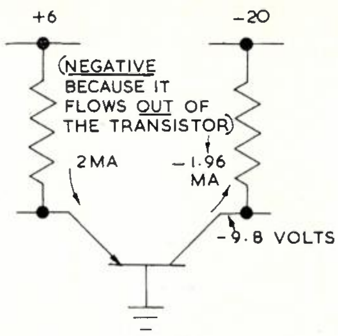


Fig. 39.

The power dissipated at the collector is given by the formula:

$P = IE = (–1.96 \text{ ma}) (–9.8 \text{ volts})$
$= 19.2$ milliwatts

The gain of this amplifier depends upon whether it is being used to obtain voltage gain or current gain. Its voltage gain can be large; its current gain is always less than unity, that is, this amplifier produces current loss instead of gain. Its actual current gain is equal to alpha, about 0.98 for a typical transistor:

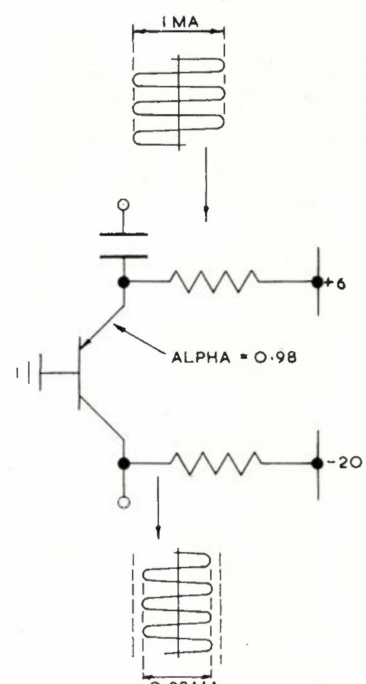


Fig. 40.

The *voltage* gain (the ratio of output to input voltages) can be calculated from the output and input impedances. The output impedance, in this case, is known to be a 5000-ohm resistor, but the input impedance was stated vaguely to be "less than 50 ohms". Fortunately, there is a simple way to calculate the input impedance (emitter resistance). It is given by the formula[5]:

$$R_e = \frac{25.6}{I_e} \quad (41)$$

in this formula R_e is the emitter resistance in ohms, and I_e is the emitter current in milliamperes. For the transistor amplifier in this example, the emitter is biased with 2 ma, so the emitter resistance is:

$$R_e = \frac{25.6}{2 \text{ ma}} = 12.8 \text{ ohms} \quad (42)$$

Now, knowing both input and output impedances, we can calculate the voltage gains. If a 1-ma signal flows into this amplifier, it will produce a 12.8 millivolt swing across the 12.8-ohm emitter resistance:

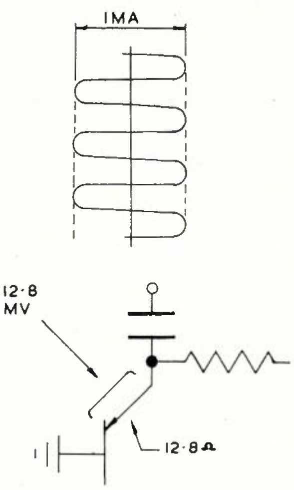


Fig. 43.

Almost all of the 1-ma signal current (98 per cent of it) flows in the 5,000 ohm load resistor, producing a 5-volt drop across it:

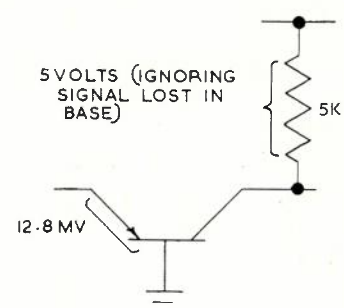


Fig. 44.

The voltage gain in this case is:

$$G_v = \frac{5 \text{ v}}{12.8 \text{ mv}} = \frac{5}{0.0128} = 391 \quad (45)$$

The same answer can be obtained by taking the ratio of the output and input resistance:

$$G_v = \frac{5{,}000 \text{ ohms}}{12.8 \text{ ohms}} = 391 \quad (46)$$

The same common-base amplifier, then, can provide a *voltage* gain of 391, but can give a *current* gain of less than

---

[4] The comparison of *grid* bias and *emitter* bias could confuse the reader into thinking the *grid* and *emitter* are equivalent. They are not; the comparison is used merely because the graphical constructions are similar. The *grid* corresponds to the *base*.

[5] This expression is derived from basic semiconductor physics. It can be shown that Re = (kT/e)/Ie, where k is Boltzman's constant. T is the absolute temperature, and e is the charge on an electron. Inserting proper values gives a value of 25.6 for kT/e, at 24 degrees C. This is a theoretical value subject to appreciable variation in practical transistors.

1. It is clearly to our advantage to use this type of amplifier as a voltage-gain device. But what makes the difference between a voltage amplifier and a current amplifier?

VOLTAGE VERSUS CURRENT AMPLIFIER

The distinction between a voltage amplifier and a current amplifier is mainly one of convenience. A voltage amplifier is one whose input signal comes from a *constant-voltage source* (note, this term is defined below). When an amplifier is driven from a constant-voltage source, its input voltage is known or easily determined. If the output voltage is also known or easily determined (as it usually is) it is easy to take the output-to-input ratio, which gives the voltage gain. Under these circumstances, it is *convenient* to consider the amplifier as a *voltage* amplifier.

Similarly, if an amplifier's signal source is a *constant-current source* it is *convenient* to consider it as a *current* amplifier for the ratio of input-to-output currents may be easily determined. This ratio gives its current gain.

CONSTANT-VOLTAGE VERSUS CONSTANT-CURRENT SOURCES

Practical approximations to constant voltage sources are familiar to almost everyone. A battery is a good example of a dc constant-voltage source. Consider this circuit:

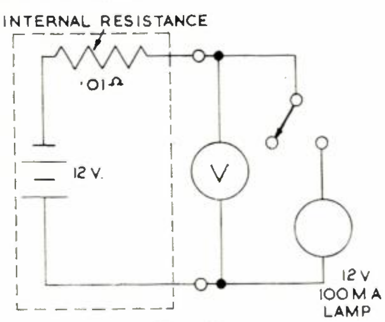


Fig. 47.

Note that a 12-volt storage battery lights a lamp when the switch is thrown. When the switch is open, the voltmeter reads 12 volts. When switch is closed and the lamp is connected, the voltmeter shows no perceptible change in voltage. Therefore, the storage battery is a constant-voltage source, for its output voltage does not change when the load is connected.

Constant-current sources are less common, but one can be synthesised for the purpose of explanation. Consider the following circuit:

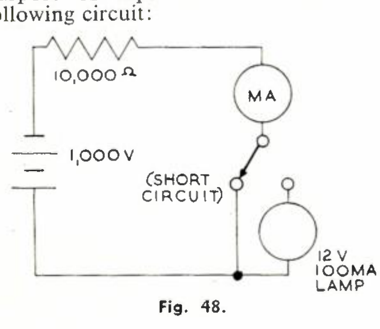


Fig. 48.

Note that a 1000-volt battery supplies current to a lamp when the switch is thrown.

When the switch is in the short-circuit position, the milliammeter indicates that 100 ma flows in the circuit. When the lamp is lit, the milliammeter shows no perceptible change in the 100-ma current. We therefore say that the battery-plus-resistor combination is a constant-current source, for its output current does not change when the short circuit is replaced by the load.

One can easily see that these "constant" sources are only *approximately* constant. How nearly constant they remain depends upon the relationship between their internal impedances and their respective load impedances. In practical cases, a source is called a *constant-voltage source* when its internal impedance is much less than the impedance of the load it feeds. Likewise a *constant-current source* is a source whose internal impedance is much *greater* than the impedance of the load it feeds. Inspect the two dc examples above, to verify these statements. (The 12-volt lamp has an impedance of 120 ohms.)

VOLTAGE VERSUS CURRENT AMPLIFIERS

Through vacuum-tube experience, it has become the custom to think of *all* amplifiers as voltage amplifiers, since the grid of a vacuum tube makes almost any source look like a low-impedance (constant-voltage) source, by comparison:

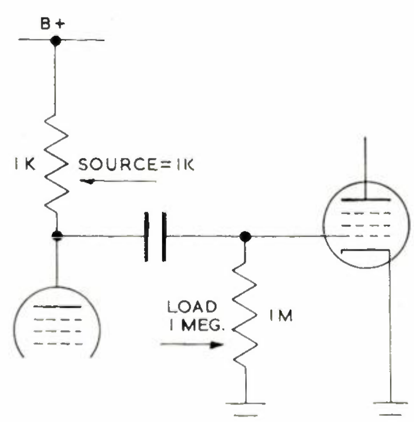


Fig. 49.

With transistors it is not always thus. If a common base (CB) amplifier has an input impedance of 12.8 ohms:

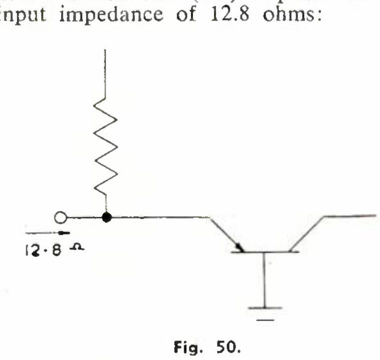


Fig. 50.

it must be fed from a source of even *lower* impedance in order to be conveniently classed as a voltage amplifier:

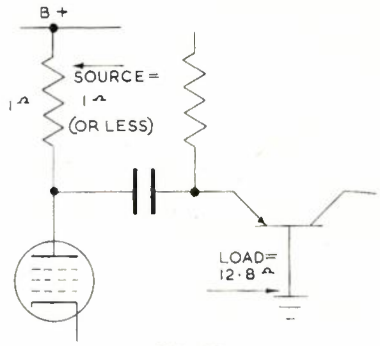


Fig. 51.

This is not always practical. Transformers may be used to obtain such low impedances in narrow-band or tuned amplifiers, but wide-band amplifiers usually cannot make practical use of such an arrangement.

On the other hand, transistors are particularly well-suited for operation as current amplifiers. A transistor—especially in the common-base configuration—has such a low-impedance input that many sources are higher-impedance in comparison, and therefore are treated as current sources. Consider, as an example, the dc current source used as an example above, but with an ac signal in place of the battery:

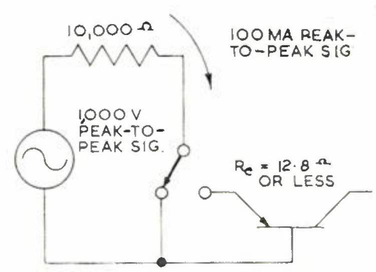


Fig. 52.

The impedance of the source—10,000 ohms—is certainly much greater than the impedance of the emitter.[6] A constant signal-current of 100 ma, peak-to-peak, will flow, without regard for the position of the switch. Driven thus from a constant-current source, the transistor may most easily be regarded as a current amplifier.

Unfortunately, this particular configuration does not give a useful current gain. With a 100-ma signal flowing into the emitter, only a 98-ma signal will flow from the collector (if alpha = 0.98). The common-base amplifier actually gives a current *loss* instead of a current gain.

We may summarise the behaviour of a common-base amplifier thus: If a very low-impedance source is available, it will operate as a voltage amplifier, giv-

6 The emitter resistance of 12.8 ohms was calculated for a bias current of 2 ma. To operate linearly with a signal swing of 100 ma, bias current would have to be at least 50 ma, which would give, by (40), Rc = 0.51 ohms.

ing large voltage gains. Such sources are rather uncommon, however, particularly for wide-band amplifiers. If a moderately-high-impedance source is available, it will operate as a current amplifier, but will give a current gain of less than one, and hence is not useful.

In spite of such stringent restrictions, the common-base configuration is frequently used in a large variety of circuits. It will be seen acting as an impedance transformer, as a capacity isolator, or as a means of obtaining non-inverted gain from a tube. Examples of these three applications are given below.

TRANSISTOR APPLICATION AS IMPEDANCE TRANSFORMER

The CB configuration can be put to practical use in improving the gain obtainable from a delay-line driver. This application is an example of its use as an impedance transforming device. Consider the following circuit:

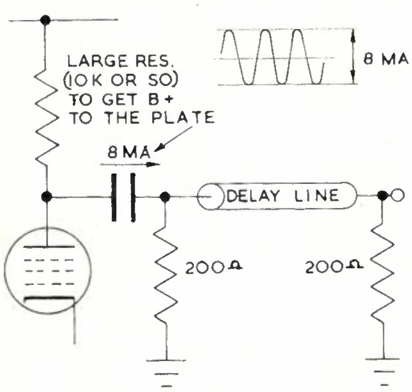


Fig. 53.

In this circuit a pentode drives an 8-ma peak-to-peak signal into a delay line which *must* be terminated in its chacacteristic impedance of 200 ohms. The 8 ma will divide equally between the input termination and the output termination:

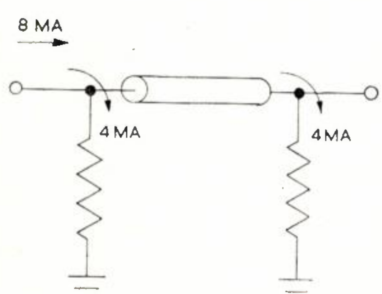


Fig. 54.

The 4 ma that flows at the output will result in an output signal of:

$$e_o = iR = (4\ \text{ma})\ (200\ \text{ohms}) = 0.8\ \text{volts} \quad (55)$$

A considerable improvement in the output level can be made by inserting a transistor in this manner:

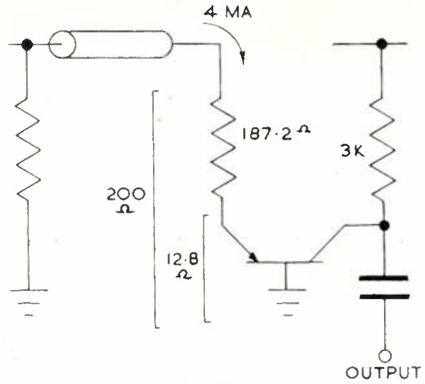


Fig. 56.

(Means of biasing are ignored to keep the picture uncluttered). In this case, the 4-ma signal flows through the transistor and appears (except for the two per cent lost in the base, which we ignore here) in the collector circuit. The voltage output from this circuit is:

$$e_o = iR = (4\ \text{ma}) = (3{,}000\ \text{ohms}) = 12\ \text{volts} \quad (57)$$

This is an *effective* gain of 15 over the first circuit.

TRANSISTOR APPLICATION AS CAPACITY ISOLATOR

A common-base amplifier as a capacity isolator, can also give an effective gain. Consider the following circuit:

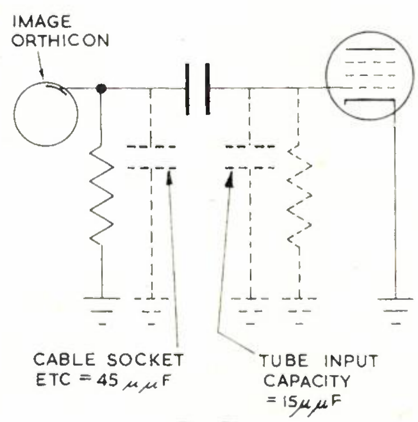


Fig. 58.

In this circuit a total of 60 μμf of stray capacity shunts R_L, the 20K load resistor. If the stray capacitance were less, a larger load resistor could be used. The signal voltage available at the grid of the tube would then be greater, in direct proportion to the size of the load resistor. As the circuit now stands, however, 20K is about the largest practical value of load resistor.

Now, modify the circuit in this manner:

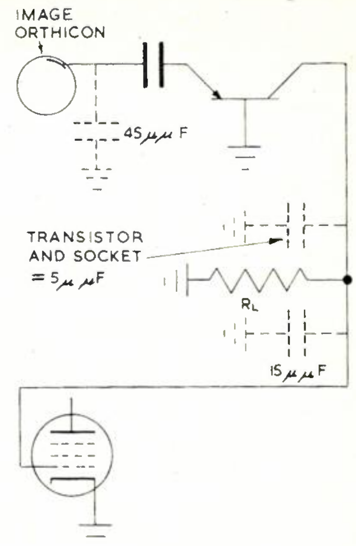


Fig. 59.

Note that only 15 + 5 = 20 μμf appears across the load resistor. Since this is only ⅓ of the 60 μμf of the first circuit, R_L can be 3 times as big, or 60K. The result is an *effective* gain of three.

TRANSISTOR APPLICATION FOR PRESERVING SIGNAL POLARITY

A common-base amplifier can also be used to preserve the polarity of a signal, whenever necessary. If a tube giving a gain of ten is required to amplify a pulse, the following circuit might be empoyed if an output signal of inverted polarity could be used:

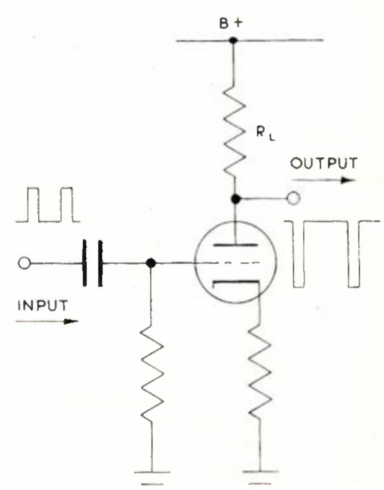


Fig. 60.

However, if a noninverted pulse is required, the above circuit cannot be used. (A noninverted pulse can be obtained at the cathode, but not at the required level.) To obtain a non-inverted pulse of the required amplitude, a common-base transistor amplifier could be added in this manner:

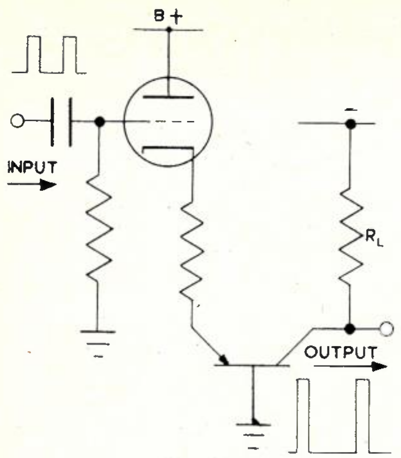


Fig. 61.

This circuit gives almost the same gain as the first circuit, and does not invert the signal.

POWER GAIN

A common-base transistor resembles a transformer in its ability to give voltage gain, but with an important difference. The difference lies in the transistor's ability to give a *power* gain as well. For example, consider a 10-to-1 step-up transformer in which the primary signal voltage and signal current are 0.2 volt and 10 ma, respectively:

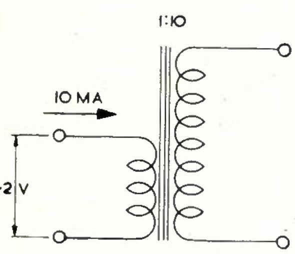


Fig. 62.

Then, the secondary voltage will be 10 times as great (2 volts) and the secondary current 1/-0th as great (1ma):

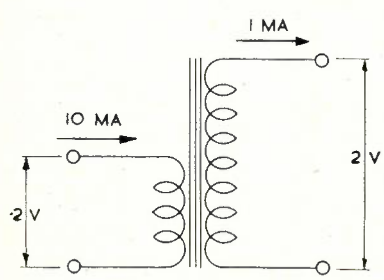


Fig. 63.

The power at the output, (neglecting losses) is the same as the power at the input:

$$P_{in} = E_{in} I_{in} = (0.2 \text{ volts}) (10\text{ma})$$
$$= 2 \text{ milliwatts}$$
$$P_{out} = E_{out} I_{out} = 2 \text{ volts}) (1 \text{ ma})$$
$$= 2 \text{ milliwatts} \quad (64)$$

Now, compare a transistor with similar input conditions as the 10-to-1 step-up transformer:

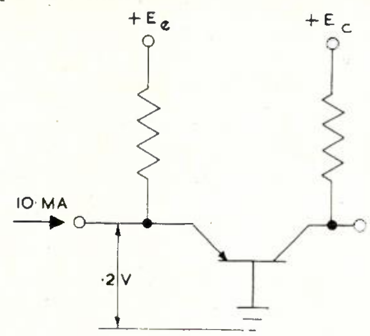


Fig. 65.

The transistor can be given a collector load which will give the same signal voltage gain as the 10-to-1 step-up transformer:

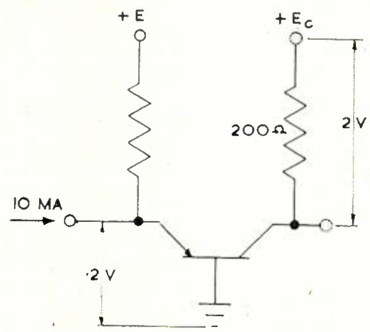


Fig. 66.

The signal current, however, at the output is not reduced proportionately, but instead is virtually the same as the input current.

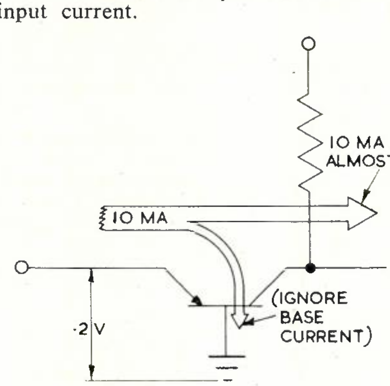


Fig. 67.

Therefore, the signal power at the output is ten times greater than at the input:

$$P_{in} = e_{in} i_{in} = (0.2 \text{ volts}) (10 \text{ ma})$$
$$= 2 \text{ milliwatts}$$
$$P_{out} = e_{out} i_{out} = (2 \text{ volts}) (10 \text{ ma})$$
$$= 20 \text{ milliwatts} \quad (68)$$

This power gain is a better indication of a transistor's gain capabilities than is *voltage* gain or *current* gain. Voltage or currant gain can be obtained from an ordinary transformer; power gain cannot.

MAXIMUM VOLTAGES AND CURRENTS

The maximum collector voltage that can be applied to a transistor is limited by a phenomenon called *breakdown*. Consider this example in which the collector voltage is increased beyond a certain limit:

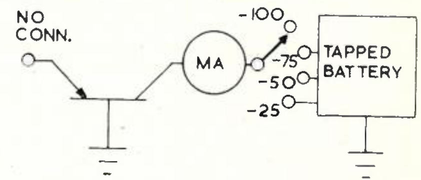


Fig. 69.

Then the collector junction will begin to pass abnormally large current:

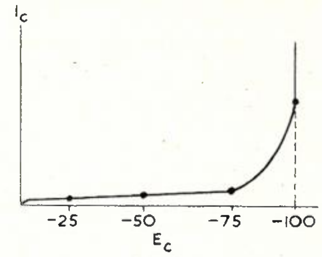


Fig. 70.

The voltage at which the curve breaks sharply upward is called the *breakdown voltage*. In this region, a transistor does not behave normally. To insure proper transistor action, the operating point must be well removed from the breakdown region.

A transistor will not *necessarily* be destroyed by breakdown. If a transistor rated at 200 milliwatts breaks down from over voltage and, while in the breakdown region, dissipates 500 milliwatts, it will very likely be destroyed or at least damaged. On the other hand, a transistor may go into breakdown without being damaged at all if the circuit includes a series resistance to limit the maximum power to a safe value.

Breakdown defines the maximum allowable voltage. However, the maximum current, which bears no relation to the breakdown voltage, is not so well defined. At higher and higher currents, progressively smaller portions of the emitter current appear in the collector, with the result that alpha, which is around 0.98 at small currents, may become 0.6 or 0.5 or even less. The practical limit on high currents is reached when alpha falls below some arbitrary limit, set by the designer to fit the particular requirements of the circuit at hand.

Thus far the transistor has been introduced and its characteristics and uses as a common-base amplifier have been described. It has been pointed out that there are many restrictions on the common-base configuration which limit its usefulness. The next part in this series will describe a configuration which is not so limited—the common-emitter configuration. It will be shown how a common-emitter amplifier can provide both voltage gain *and* current gain, simultaneously, but at the expense of an inherently narrower bandwidth.

POLE-MOUNTED REPEATERS FOR CARRIER SYSTEMS

J. C. WILSON*

INTRODUCTION

The spacing of carrier system repeaters depends on many factors, e.g., signal to line noise ratio, signal to repeater noise ratio, power handling capability of amplifiers, filter discrimination, intermodulation (particularly in filters and amplifiers), and economics. In some cases these factors interact. Sometimes one or more becomes insignificant. Throughout the history of carrier systems different factors have predominated at different times mainly because of the state of component development at any time.

SIGNIFICANCE OF NOISE

The one thing that always remains important is the overall channel signal to noise ratio. This, more than anything else, determines the usefulness of the channel. In practical cases the effect of varying the signal to noise ratio by a few db's does not have a marked effect on intelligibility of a conversation but it will be obvious that some reasonable criteria must be chosen so that several systems can be linked together with a predictably good result. This is very important for subscriber trunk dialling in a big country like Australia or in international working and for this reason the subject has been studied intensively in the C.C.I.T.T. whose recommendations are followed by most administrations including the Australian Post Office. (1)

POWER REQUIREMENTS AND REPEATER SPACING

An interesting feature is the large reduction in power handled as the number of repeaters is increased on a given length of line. Table 1 is a striking illustration for an assumed line section with a loss of 100 db. For purposes of illustration line noise level at —70 dbm will be assumed on any practical segment of the line and the required received signal to noise ratio is taken as 50 db. It is also assumed that the signal to noise ratio of the input signal is better than 50 db and the noise figure and intermodulation noise of all repeaters is insignificant.

Table 1 shows:—

(a) That it is impossible to cope with very high attenuations by increasing the gain at the sending end. Apart from the amplifier problems and the fact that our lines are not designed to handle these powers it would be extremely difficult to design filters with sufficient discrimination and freedom from intermodulation distortion.

(b) If amplifying devices have equal efficiency and cost, proportional to power handled, it would be best to use as many repeaters as possible (up to the stage where accumulated noise caused the power handling capacity to increase). In practice this would lead to efforts to find much cheaper line construction.

(c) If the cost of an installation does not decrease beyond a certain signal power handling capacity then, other factors permitting, it is best to use repeaters for that amount of power.

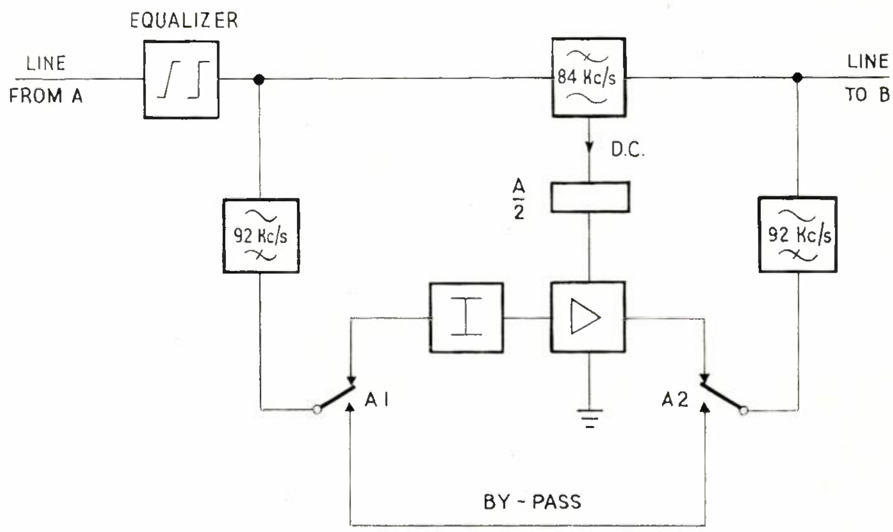


Fig. 1.—Schematic Diagram of Minor Repeater.

The last point has most practical significance and it so happens that valves with output power in the range of milliwatts to a few watts and the feasibility of power supplies, filters, buildings, etc., for this power range make an agreeable combination. It is this stage that we have reached with valve-type carrier systems. As a point of interest the upper limit in practice is in submarine cable working where output powers of 100 watts or so are used at land-based repeaters (2).

THE IMPACT OF TRANSISTORS

The advent of transistors threatens to alter the present picture. Their power efficiency is much better than valves and tends to remain good as they are used below their maximum rated capacity. Table 2 gives a comparison of power consumptions for multistage valve and transistor amplifiers capable of delivering prescribed output powers.

Table 2

Output Power		Valve Amplifier	Transistor Amplifier
Milliwatts	Rel Level		
1000	+30 dbm	12.5 W	2.0 W
10	+10 dbm	6.5 W	0.025 W
0.1	—10 dbm	4.1 W	0.0015 W
0.001	—30 dbm	4.1 W	0.0015 W

Table 1

No. of Repeaters	Accumulated Noise at Receiving Term	Required Rec. Signal	Repeater Gain	Repeater Output Power		Total Power Trans. to Line
				Db Rel 1 Mw	Watts	
1	—70 dbm	—20 dbm	100 db	+80	100,000	100 Kw
2	—67 ,,	—17 ,,	50 ,,	+33	2	4 W
4	—64 ,,	—14 ,,	25 ,,	+11	0.0126	50 Mw
8	—61 ,,	—11 ,,	12.5 ,,	+1.5	0.0014	11.2 Mw
16	—58 ,,	— 8 ,,	6.25 ,,	—1.75	0.0007	10.7 Mw

Transistors, therefore, urge a more critical examination of some of the other factors. A typical one is filter requirements. Roughly speaking, as less power is handled construction of filters is easier and as the required discrimination is reduced so will other requirements be easier to meet. Table 3 shows the filter discriminations required for an assumed system stability margin of 40 db for the

* See page 377

case illustrated in Table 1. Herein the filter discrimination (or stop-band loss) is numerically equal to half the sum of the repeater loop gain and the stability margin. (There are two filter sets in the loop.) The repeater stability margin must exceed the system stability margin by $20\log_{10}N$ (N is number of repeaters) except in some cases where advantage can be taken of certain statistical conditions.

Table 3

No. of Repeaters	Discrimination in each Directional Filter Set
1	120 db
2	73 db
4	51 db
8	41.5 db
16	38.25 db

Considering that at least basic, terminating, and high transition loss sections or their equivalent are needed in all cases this shows that there is no great direct advantage to be gained in the construction of filters for much shorter repeater sections than valve amplifiers permit. The same applies to other networks such as equalisers, transformers and inter-stage coupling networks. In order to reduce the proportions and cost of repeaters for very short sections, therefore, advantage must be taken of component design.

Table 2 shows that the problem of providing power for repeaters is considerably eased by using transistors. For instance, power can be fed over a line for a transistor repeater operating in the power output range of a valve repeater, but more important, a transistor repeater operating at low levels, e.g., —40 db on 1 watt could quite well be powered by 3 or 4 solar cells.

It is worth mentioning here that system design using methods other than the conventional carrier suppressed single sideband frequency division with amplitude modulation are being given serious consideration to take advantage of the prospect of closer-spaced repeaters offered by transistors but denied by the cost of conventional filters and networks.

PRESENT POSSIBILITIES

The stage has now been reached where it is possible to reduce power requirements of repeaters enormously by using transistors; also by skilful employment of the most suitable network components it is possible to construct a carrier-system repeater small enough to mount on a pole or in a manhole (3). This is a particularly attractive prospect for remote locations where the cost of power supplies, lead-ins, buildings and associated amenities can be saved. Of course, the repeater would be no less complicated than a conventional repeater, so to avoid maintenance work outdoors, it must incorporate facilities for quick identification and convenient replacement of a faulty sub-assembly to the extent that inbuilt reliability cannot be guaranteed.

Designs for short-distance repeaters for several purposes have been considered in the Research Laboratories at Headquarters. Because of actual plant needs the design of a specialised 12-channel open-wire system repeater has been carried forward first. The aim is to avoid the necessity of building extra repeater stations and installation of power supplies on 3-channel routes in outback areas where it is desired now to install 12-channel systems. Other applications which appear interesting are to make up for extra loss in repeater sections where line diversion has been carried out, or to compensate for losses in excessively long cable entrances.

A 12-CHANNEL OPEN-WIRE MINOR REPEATER

The first attempt is a repeater for use only in the high-frequency direction of a 12-channel open-wire system where the loss is about 0.1 db per mile greater than in the low-frequency direction on the normal bearer, namely, 200 lb. H.D.C. On outback routes with few pairs and no entrance cables it would be feasible to extend the low-frequency direction of our 12-channel systems to about 130 miles. In order to achieve similar performance in the high-frequency direction it is necessary to add about 14 db net gain. In practice many 3-channel repeater sections exceed 130 miles and there is some doubt about atmospheric noise levels in inland and tropical areas, so it was decided to build a repeater with 23 db net gain which could be reduced as required or which will allow the insertion of a similar repeater with less gain in the low-frequency direction. (Use of more than one minor repeater in either direction would be feasible.)

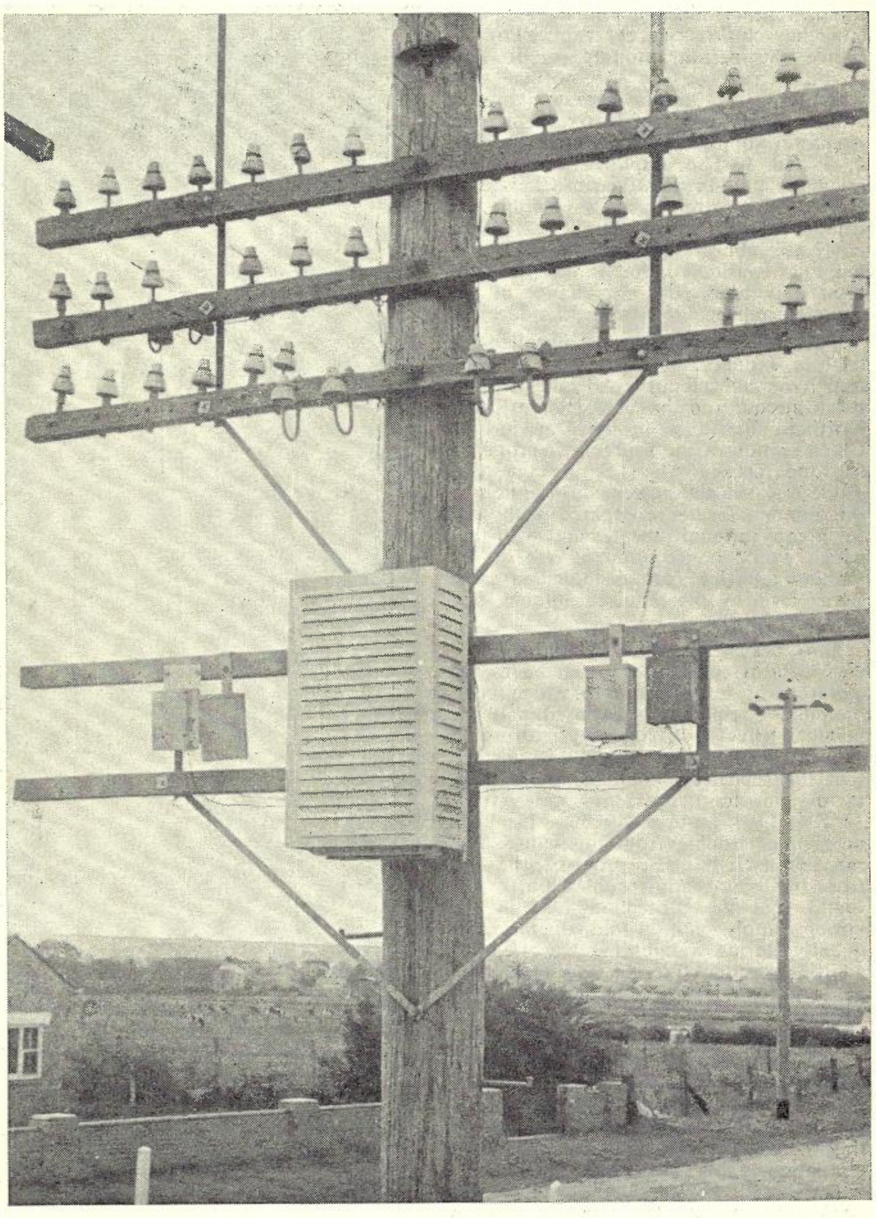


Fig. 2.—Minor Repeater mounted on Pole.

The repeater was wholly designed in the Research Laboratories and is intended to be installed at a point in a repeater section where the high-frequency 12-channel signal falls to the permissible level in relation to noise. A schematic circuit is shown in Fig. 1. The repeater housing contains all equipment except protection which is provided in standard pole-mounted housings. Power is fed on a cailho to the 12-channel bearer from the 130-volt supply at the nearest attended station but a local D.C. supply can be used if desired. In the event of power supply failure the repeater is automatically switched out of circuit and the system will still operate with reduced transmission quality. Regulation is not provided in the minor repeater because there is sufficient range in the normal repeaters of the system. The transmission band attenuations have been designed with extreme care so that insertion of a minor repeater does not affect any system characteristics except gain. For instance, this permits mop-up equalization to be carried out in the normal way whether or not minor repeaters are in circuit. Photographs of this repeater and its power supply unit are shown in Figs. 2, 3 and 4. The amplifier and control relay are plug-in units because it is considered they are more susceptible to trouble than the other assemblies. If these other assemblies are as reliable as expected it is considered that it will be sufficient only to provide for change of the complete repeater if a fault does develop.

Two minor repeaters were installed for trial in January, 1960, one at Bacchus Marsh on a Melbourne-Adelaide section patch circuit, and one at Adelaide River, Northern Territory, in the Darwin-Pine Creek section of the bearer pair proposed for the Darwin-Alice Springs system. Table 4 shows the power consumption of the minor repeater compared with that for a conventional repeater and with that which would be required at one of the existing repeater stations to increase the signal level by the required amount, i.e., 23 db (200 watts).

Two design problems which received very careful consideration related to the extremes of temperature to which pole-mounted equipment is exposed and the possible effects of lightning storms in tropical areas. Laboratory tests indicated that the repeaters should be quite satisfactory in the temperature range from 14°F to 176°F, and so far there has been no sign of trouble from this cause. The repeater itself has also proved to be free from lightning storm troubles, but it was found that the protection fuse in the power supply unit would operate frequently during a lightning storm unless additional surge filtering and fast-acting gas arrestors are used at the office concerned.

Since the design of this repeater was started, more useful transistor types have become available and it would be possible now to build a standard 12-channel repeater for pole mounting. In order to do this, however, a modified form of level regulation using electronic components only should be used and the power needed to operate the repeater from a remote station in all weather conditions

Table 4

	Power Consumed	Remarks
Minor (Pole Mounted) Repeater	1.6 Watts	The amplifier consumes 0.8 watts and control relay 0.8 W. In addition up to 1 watt may be consumed in the line if power is fed from nearest station.
Conventional Repeater	65 Watts	Approx. amount for one amplifier alone. Apart from regulation, if used, much more power would be used in facilities in a building.
200-Watt Repeater	650 Watts	Estimate based on submarine cable techniques.

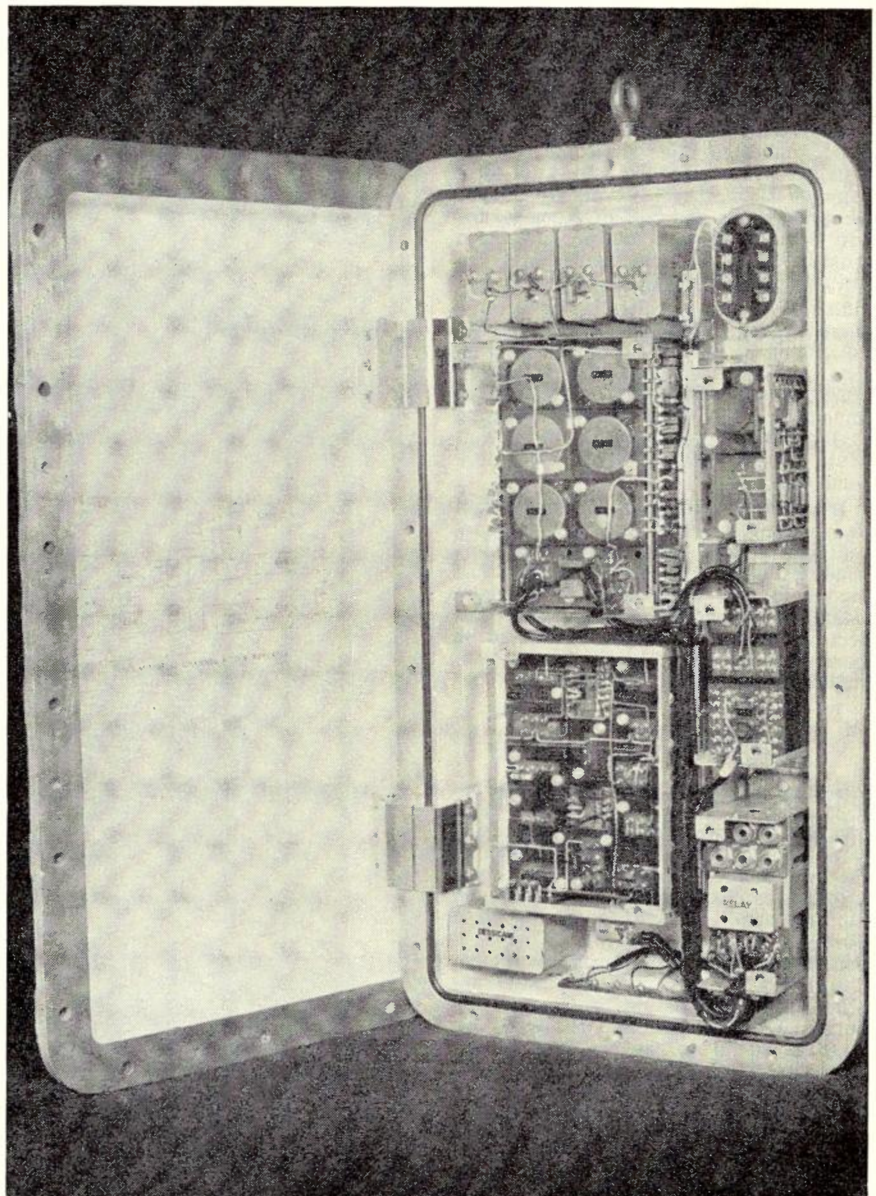


Fig. 3.—Internal View of Minor Repeater.

would require line voltages which approach the allowable limit for safety of linemen.

CONCLUSION

Efficient communications on lightly-loaded outback routes in Australia may depend largely on development of cheap and reliable sources of small amounts of power (milliwatts) and highly accurate, small and cheap components for filters and networks.

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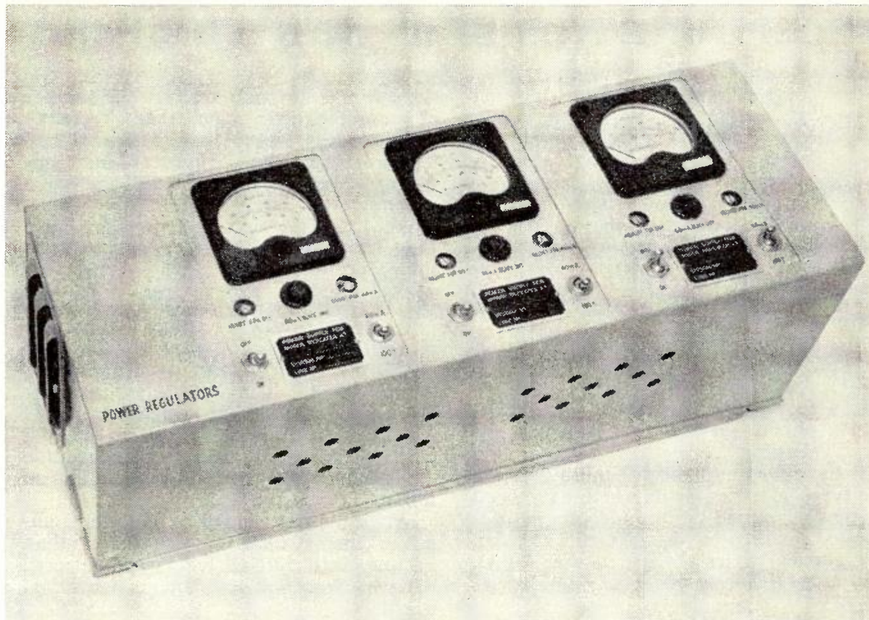

Fig. 4.—Power Supplies for 3 Repeaters.

ACTIVITIES OF THE SOCIETY IN N.S.W.

Formation of Committee: A committee of ten members has been established, the chairman being appointed by the Director.

Composition of the committee is as follows:

Chairman: M. J. Power, Supervising Engineer.

Secretary: W. A. Brooker, Divisional Engineer.

Treasurer: O. Polmear, Clerical, Third Division.

Committee: G. Lewis, Deputy Superintending Engineer.

Members: S. Bundle, Supervising Engineer; G. Black, Telecommunications Division; J. Whybourne, Divisional Engineer; A. Trevor, Fourth Division, Internal Plant; R. Ferris, Fourth Division, Internal Plant; D. Raines, Fourth Division, External Plant.

Six committee meetings have taken place at monthly intervals. Action is in hand to arrange an annual general meeting to receive the committee's report and financial statement and to deal with election of office-bearers, committee and auditor, installation of chairman and transaction of any general business.

Progress: Since formation of the committee the business aspects of the Telecommunication Journal have been given vigorous attention and an increase in circulation from 750 to 1,800 copies has resulted. This activity has stimulated interest in the Journal resulting in an increasing flow of suitable material for inclusion in future issues and in the number of new members.

To facilitate distribution of journals and collection of fees and articles for inclusion in forward issues, Field Representatives have been appointed in the following Sections —

Long Line and Country Installation,
Trunk Service and Telegraphs,
Equipment Installation, Metropolitan,
Equipment Service, Metropolitan,
Radio.

Representatives have also been appointed in the Newcastle area and in several major supply companies, including Standard Telephones and Cables Pty. Ltd., and Telephone and Electrical Industries Pty. Ltd.

Continuing action is in hand to establish representatives in the remaining engineering and non-engineering sections in this State.

The officers selected as representatives, interested Supervising Technicians and Line Foremen generally, have been selected for their ability to move among the members and to deal with any problems which may arise.

Lectures: A successful lecture series, consisting of five lectures, on the "Introduction of Crossbar Switching Equipment" has already been presented in the Sydney and Newcastle areas by members of this Branch. Printed notes prepared for these lectures have been distributed to these areas and to other areas throughout the State.

The average attendance at lectures at each centre was as follows: Sydney — 500; Newcastle — 100.

A further series of five lectures dealing with the introduction of Coaxial Cable is scheduled to commence during October, 1960. It is hoped to stimulate interest among External Plant staff with these lectures.

The present increased activity with the subsequent increase in members has enabled this Branch to considerably strengthen its financial position. The financial position as at 27th July, 1960, was as follows:

Bank Credit	£327/12/6
Outstanding Fees to Central Body	£267/19/6
Balance in Hand	£ 59/13/0

Summarising, the development of the new body and the outstanding work that it is carrying out is stimulating the expansion of, and the vigorous interest now being taken in, the Telecommunication Journal.

TELEPHONE NUMBERS AND THE USER

R. E. BOGNER, M.E. *

INTRODUCTION

The Australian Post Office is introducing an all-numerical presentation of telephone numbers (All-Numeral Dialling—A.N.D. for short). Several advantages over Letter-Numeral Dialling (L.N.D.) have been attributed to A.N.D. These, which have been described fully elsewhere (1, 2) are:—

(1) Improved accuracy.
(2) Faster dialling.
(3) Less chance of phonetic or visual confusion.
(4) All combinations are usable.
(5) Compatibility with other telephone systems for international dialling.

It is the purpose of this article to describe the types of experiments which have been made to examine the user factors in telephone dialling, with special attention being paid to tests done in the A.P.O. Research Laboratories.

BRITISH TESTS

It is believed that the B.P.O. is not seriously considering a change to A.N.D. Many of the larger British centres have director systems which permit the use of the geographically meaningful first three letters of the exchange name in the L.N.D. code used with a 24 letter dial (Fig. 1). It is fairly evident that such a system is a definite aid to memory and its abandonment may meet with very strong public disapproval.

However, the current introduction of subscriber trunk dialling in Britain, with the public dialling long codes (to a total of 13 digits) suggested a need for optimising the codes used and their presentation.

Conrad and Hille (2) of the British Medical Research Council's Applied Psychology Research Unit have conducted some experiments on the memorability of telephone numbers. In their experiments, telephonists were required to write down a number of 8, 9 or 10 digits after they had read it from a card or heard it from a record.

Numerals versus Letters: Because the use of only meaningful letter combinations would seriously restrict the number of combinations available, random arrangements were tested, using 10 letters chosen to minimise sound confusions. Four types of "numbers" were tested:

All letters	e.g. GALI	UOZT
Letters — Numerals	e.g. RTIA	6835
Numerals — letters	e.g. 4295	RAGT
All numerals	e.g. 9014	6208

When heard, the all-numeral form was clearly the best, followed by the two composite forms almost equal, with all-letters worst. The eight digit numbers correctly remembered ranged from 77 per cent. for all numerals to 30 per cent. for all letters. An increase to nine digits caused the score for all letters to fall to 11 per cent.

When the numbers were read, the composite forms were slightly better than all numerals with all letters again worst. All were remembered better than when heard.

The difference between the memorabilities of the two presentations was attributed to the extra time available when reading enabling the subjects to invent "words" out of the letter combinations.

Size of Numeral Vocabulary: It was thought that because simple-looking numbers like 999 are easier to remember than less systematic ones, numbers drawn from a restricted vocabulary may have some advantage. Numbers drawn from 2, 4 and 8 numeral vocabularies were examined.

When the numbers were heard, there was a decrease of correct scores from the 8 digit (32 per cent. correct) to the 2 digit (14 per cent. correct) vocabularies for 9 digit numbers.

Similar numbers when read gave scores of 40 per cent. for the 8 digit, and 70 per cent. for the 2 digit vocabularies.

The change in performance pattern was attributed to the extra time available when reading, allowing a coding into helpful groups.

Grouping: The above experiments suggested that if time was available, and the numbers were suitable, a memory aiding grouping occurred. To see if synthetic grouping could be an advantage, nine-numeral numbers were presented on cards thus:

(a) 123456789
(b) 1234 56789
(c) 123 456 789
(d) 12 34 56 78 9
} Heard and read

They were also heard with the same groupings, and also the last two groupings were heard pronounced:

"One twenty-three, four fifty-six, seven eighty-nine."

"Twelve, thirty-four, fifty-six, seventy-eight, nine."

For both methods of presentation, (b) was the best. This suggested "that although a long string of digits is difficult to memorise, if the string is broken up too much the task can become even more difficult."

Conclusions: Conrad and Hille concluded from their experiments that:

" . . . there is no real advantage in using relatively non-meaningful letter arrangements."

The probability of making an error increases very rapidly as the number of digits changes from 8 to 10. However, the difficulty depends very much on the way numbers are presented.

AMERICAN TESTS

Investigations at the Bell Telephone Laboratories (3) set out to determine: "With A.N.D., would telephone users dial numbers faster, slower, or at the same speed? Are A.N.D. numbers actually harder to remember? And, beyond other considerations, would customers like the A.N.D. system?"

The Bell System uses a 25 letter dial, (Fig. 2) and there is some mnemonic significance in the telephone numbers, as the first 2 digits are the first 2 letters of the exchange name. However, to obtain a reasonable number of suitable exchange names, these bear little relation to geography. The Bell L.N.D. codes are thus qualitatively between the B.P.O. and A.P.O. codes in a scale of meangfulness.

Dialling using Directory: To simulate the dialling aspects of a cutover from L.N.D. to A.N.D. some entries in a Manhattan telephone directory were modified to appear in A.N.D. form. Nine subjects were selected as being representative of telephone users. Each, with a list of names, dialled the corresponding numbers in a special test room. On different days, the normal L.N.D. and the modified A.N.D. directories were used. The calls were observed electrically and answered in a nearby room. "Busies" and "Don't Answers" were introduced at appropriate frequencies.

Special A.N.D. dials (similar to the A.P.O. dial, without the letter card) were used on the A.N.D. days.

It was found that A.N.D. was about 10 per cent. faster (the mean time to dial being about 12 seconds) and slightly more accurate than L.N.D. All subjects preferred the simpler A.N.D. dial, and thought the A.N.D. numbers as easy to memorise.

Fig. 1.—London Dial.

Fig. 2.—New York Dial.

* See page 377.

Allan J 9GrosvenorPdeBalw	BWF 7562
Allan J A 17AlexandraAvCntrbry	WWF 4175
Allan J A 34AdamsSY	MBM 2092
Allan J D 20WardGrPasVaS	YFM 3382
Allan J E 20BloomfieldAvMrbng	XFU 1446
Allan J E 9BruceBoxH	UWX 7961
Allan J E 9RiddleBntlgh	FXU 5996
Allan J H 14DouglasAshwd	WBL 4723
Allan J H 34ChrystobelCrHwthn	LWA 2022
Allan J J BurwoodRdEBurw	JBF 8120
Allan J J 39PrimroseMPds	BFU 5608
Allan J L 7ArmsteadAvCobg	MFL 1030
~~Allan J L Dairy Produce 147BurkeRdGlenI~~	~~YBL 4653~~
Allan J M MelissaStNEss	XFX 1454
Allan J M 1aReserveAvCarn	UUL 6573
Allan Joyce 29AlbertEMelb	FJA 4966
Allan J P 13FellowsMtchm	WWU 1041
Allan J P 15WarrigalRdMent	LXY 1712
ALLAN J R Woolbyr 19King	JMB 3664
Allan J R ShanfordAvBtn	BXM 3765
Allan J R 207MurrumbeenaRdMrmbna ..	MUM 2858
Allan J R 476Collins	YMB 1046
Allan J W Muscn 1WallaceEOak	XUJ 2000
Allan J Warren 61SutherlandRdArm ..	UUY 3569
Allan J Y Chmst 178SydneyRdBwick ..	FFW 1223
Allan J Y Chmst 3AxeltonChelt	WXF 2626
Allan K D R 8 OakPasVa	LFY 9849
Allan Keith 12CoonansRdPasVaS	MFM 3965
Allan K H Commrcl Artist 13Hardware	XMU 3900
Allan K H 3BarkerChelt	YXF 3907

Res 321BeaudesertRdMoorka	048 2287
Barnett W F 219DewarTerCrnda	879 1306
Barnett W P 56ArmadaleStLuc	967 2500
Barnett W V S WynnumRdTnglpa	690 4364
Barney N 355CoronationDveTwong	537 6042
Barney W A 4MillwoodRainwth	036 4970
Barnfield E M BryantStAshg	438 2901
Barnfield F J Plmbr 305LyttonRdHmant ..	190 4683
Barnfield G W 48SeaviewBtn	869 2718
Barns E V CreswickStClay	926 5603
Barns L W 257JunctionRdEagJn	657 3317
Barns N 65WithingtonEB	391 1008
~~**BARNS RAY BREAD MFR**~~	
~~StevensonStRoslie~~	~~36 4405~~
Res 117FernbergRdRoslie	536 4405
Prodctn Mngr (T Kruger Res 36 4093)	
Sales Mngr (V Harvey Res 36 4406)	
Barnsley E L 36LangleyAvWilstn	056 5891
Barnsley N D Electrn BrightonStSgate ..	869 2336
Barnsley T M Mrs 18BallyKelGr	656 1648
Baronoff P 33BrisbaneAnnly	991 1809
BAROSSA CANNERIES 289Queen	362 9015
Barr A S Fruit Mercht TurbotSt	052 5833
Barr E J McCurleyStWyn	496 2628
Barr E P 88McConnellBlmba	195 1117
Barr E S 11McGregorAvWindsr	857 4071
Barr F Nrsg Sister OgdenStStffd	256 2013
Barr F L 34HowsRdTombl	967 1443
Barr G 7DaphneGrnge	656 4742

Fig. 3.—7-Digit Directory Presentation.

Dialling with Memory Incentive: The second experiment was aimed at investigating the rememorising aspects of a changeover from L.N.D. to A.N.D. Nine new subjects were selected, each of whom had already memorised several frequently used numbers. Each day, the subject was asked to place a "certain series" of calls (i.e., apparently the same calls each day, although this is not stated clearly in the original reference), so that there was an approximation to the normal incentive for memorising. Typed "Directory" pages were provided, L.N.D. for three days and then A.N.D. for 16 days. The performances were measured as before, but in addition, whether and how well the numbers were memorised were observed.

A.N.D. was again superior for speed and accuracy. Six of the nine subjects had rememorised in A.N.D. all the numbers they had previously dialled from memory, and two felt that they could do so given more time. One subject expressed a strong dislike of A.N.D.

Memorising: In the first two experiments, it was not possible to isolate memory effects from other difficulties.

To obtain some direct information about ease of memorising, 100 subjects were used, fifty for A.N.D., fifty for L.N.D. Each subject was told a name and a corresponding number (specially made up to avoid familiarity) on successive days, the subject was asked what the number was, and given it again if he had forgotten it. When the first number was memorised, a second pair was given, and when both were memorised, a third was given. Occasionally the subject would be called back without warning up to 15 minutes after a number was given. This procedure was aimed at testing short-term memory as is used in going from a directory to a dial.

The experiment showed that it is just as easy to remember A.N.D. numbers for short periods as it is for L.N.D. numbers. However, it took little longer to memorise A.N.D. numbers for longer periods, e.g., if an L.N.D. number took three days to memorise, an A.N.D. one would take about four days under the above conditions.

Home Test: Seventy-three people used A.N.D. in their homes for 10 weeks. In each home telephone numbers in the ready-reference directory were changed to A.N.D. form and a "card translator" was provided so that other numbers could be dialled using the A.N.D. dial.

The results were assessed in terms of the 73 users' opinions:

Thirty-one preferred A.N.D.

Seventeen found the two systems equally acceptable.

Twenty-four preferred L.N.D., of whom eight felt strongly about retaining it. No one felt that remembering A.N.D. numbers would be a serious handicap.

Field Trial: Following the above experiments, a field trial was conducted in Wichita Falls, Texas. The main conclusions of the laboratory experiments were confirmed.

Conclusions: Based on the results of the experiments and field trial, all-numeral dialling is now being introduced (5).

A.P.O. TESTS

In connection with the National Numbering Plan and the imminent introduction of subscriber trunk dialling, it was appropriate for the A.P.O. to consider the design of its telephone numbers from the user's aspect. The possible advantages of A.N.D. suggested an investigation of this for local conditions which differed from those overseas in that the letters used here were meaningless, and differed in their presentation on the dials.

When the investigation (4) was started, the Bell results were not known, but Conrad and Hille's work gave a good lead on what to expect from the memory aspect. It was decided to proceed with speed and accuracy testing, with other points receiving attention as the need appeared. As things turned out, when the Bell information became available, the Australian results fitted in well to make a fairly clear picture of the expectations of A.N.D.

EXPERIMENTAL PROCEDURES

The testing conditions differed in various ways from the situation experienced by a real subscriber. However, as the main purpose of the investigation was a comparison rather than an absolute evaluation, errors would not be introduced unless serious "interactions" were present. Such an interaction could be caused, for example, by the subjects having had unusual previous experience with one system — i.e., it is equivalent to a bias dependent on the population sample used as subjects. That this was not serious was suggested by agreement between results obtained by experienced and inexperienced operators.

Presentation of Numbers: The immediate problem appeared to be comparison of numbering schemes using seven digits, as these are being intro-

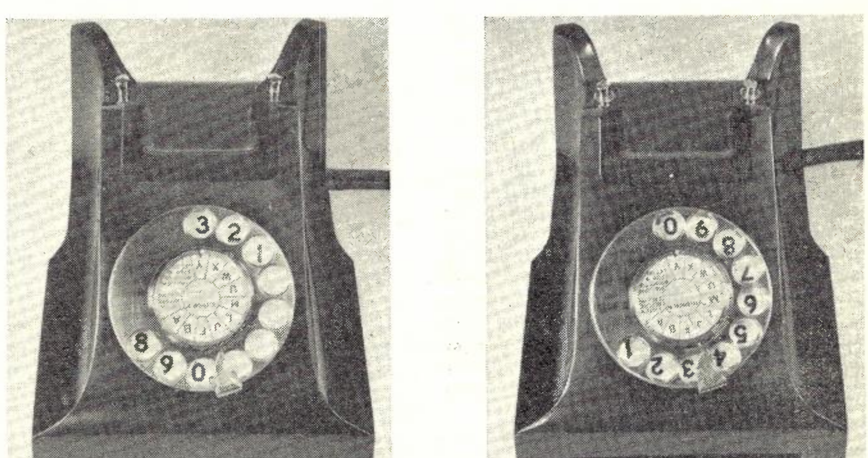

Fig. 4.—A.P.O. Dials.

duced in the larger capital cities. Further, an arrangement of the digits in one group of three followed by one of four seemed reasonable — it was similar to that shown by Conrad and Hille (2) to be optimum, did not conflict with common practice or intuition, and could be tested using existing directories, slightly modified. Accordingly, six pages of each of three copies of the existing directories were modified by the addition of digits to each number using the standard type (Fig. 3).

Operating Conditions: The subject was seated alone with a 300 type telephone (Fig. 4) with the modified directory alongside it. He was asked by the test controller via an inter-communication system to telephone a certain subscriber (selected at random by the controller). He then found the required number in his directory and dialled it.

Observations: A group of seven bimotional switches was used to sort the dialling impulses which were then displayed on a lamp field for checking accuracy. The number which should have been dialled and any errors were recorded. A small difference between the total impulsing times of 0.07 seconds mean in favour of the A.N.D. numbers used was detected (Appendix III) and was allowed for in the final comparisons.

Experimental Results

Only those results which were of particular interest in the development of the investigation or in the drawing of conclusions are described here. A more complete presentation of the data, and explanations of their analysis, may be found in Appendix I.

Three experiments were conducted:

(a) Using four subjects (three men, one woman), a preliminary test was run to examine the orders of magnitude of the effects, and provide data for the design of an experiment using a large population sample. In this test, no dial or ring-tone were provided, and subjects were permitted to leave the handset off the hook. Thirty-three numbers were dialled at a sitting, with 15 minutes' rest between sittings.

An average of about 10 seconds was taken for a 7 digit number, from the first to the last impulse sent to "line". The L.N.D. numbers took 0.57 seconds longer to dial than the A.N.D. numbers.

Wrong numbers occurred only half as often with A.N.D. as with L.N.D.

(b) With three operators (all men) under the same conditions as before, the disadvantage caused by rotation of symbols with the finger plate was examined. For this, dials were modified so that the number plates rotated with the finger plates although the appearance of the dial in its normal condition was unaltered (Fig. 4). It was thought that the small change in the moment of inertia was insignificant. The comparison was made using A.N.D.

It took 0.66 seconds longer to dial with the rotating number dial.

There was no statistical "significance" in the small difference observed in accuracy.

(c) An experiment based on the first, and using 30 inexperienced operators (14 women and 16 men of age 15 to 62 years) was then conducted to compare the numbering schemes. The subjects were non-professional Research Laboratories staff of various occupations. Dial and ring tones were provided in this experiment and subjects were requested to use their telephones as they would normally.

Each subject was used once, for 40 diallings at one sitting. These 40 numbers comprised five groups of four from each system, A.N.D. and L.N.D., alternated. Subjects were started on A.N.D. and L.N.D. alternately to avoid bias due to the effect of learning.

The time from lifting the handset until the first impulse — the "predialling pause" — was measured in this experiment, as well as the interdigital time. These times were about 13 seconds and three seconds respectively.

A.N.D. scored better than L.N.D. for both predialling pause (by 0.29 seconds) and interdigital time (by 0.74 seconds).

However, there was negligible difference in accuracy, A.N.D. giving slightly greater accuracy in this experiment.

Appendix I shows how the results of these experiments were analysed to show that A.N.D. codes are probably easier to memorise for the short period of dialling.

Effects of Changes in Dialling Performance: In the design of such experiments, it is necessary to know just how accurate the answer should be, as otherwise the experiment may well cost more than the saving.

An attempt was made to estimate savings due to changes in the accuracy and time of dialling of telephone numbers based on the cost of the equipment required for the change in traffic. It is apparent that these savings would not be realised in every case, but sometimes would aid other factors to permit larger economies (e.g., by causing a critical difference in traffic carried by a group of switches permitting one less switch to be used).

The calculations showed that a saving of £10,000 p.a. could be expected in the A.P.O.'s telephone network by a reduction in:

(1) the proportion of the wrongly dialled numbers of 0.01,
(2) The predialling pause of 0.7 sec.,
(3) The total interdigital time of 0.23 seconds
(in a step-by-step system).
or (4) The total time to dial of 0.6 sec. (in an equivalent crossbar system).

Appendix II shows how these figures were obtained.

The rather intangible question of the value of customer goodwill should also be kept in mind, but it is difficult to evaluate numerically and this was not attempted.

CONCLUSIONS

L.N.D. numbers have no definite advantage as regards memorability or user preference, even if the letters are incorporated in words. There appears to be a small advantage for A.N.D. numbers for very short-term memory.

A.N.D. is faster by about ten per cent. than L.N.D. us used in Australia, and is at least as accurate.

The change to A.N.D. should save the A.P.O. about £40,000 per year in the present telephone system.

"You have only to take in what you please and leave out what you please; to select your own conditions of time and place; to multiply and divide at discretion; and you can pay the National Dept. in half an hour. Calculation is nothing but cookery." Lord Brougham, 1849.

ACKNOWLEDGMENTS

The author wishes to thank the Engineer-in-Chief for permission to publish this paper. He also wishes to acknowledge the help given by various officers of the Planning Branch, Victoria, the Telephone Equipment Section and the Telecommunications Division.

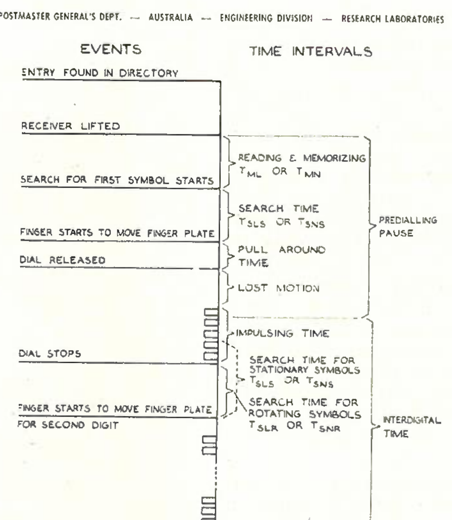

Fig. 5.—Explanation of Terms and Symbols.

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APPENDIX I

Experimental Results

Speed Comparisons: Tests on the original data for interdigital times showed that it was reasonable to treat the values as normal variates. Experiments with four experienced operators showed that A.N.D. was significantly faster, with overall means of 9.35 sec. and 9.92 sec. for A.N.D. and L.N.D. respectively. The difference, 0.57, is highly significant, being about 10 standard deviations of the mean.

When the rotating number dial was compared with the standard dial using A.N.D., the following means were observed:

Rotating number dial .... 10.15 sec.
Standard dial .... 9.49 sec.

This difference of 0.66 seconds is also highly significant.

The results of the test using inexperienced operators are summarised in Table I. The significance of all the differences shown here is greater than 99%.

Table 1 suggests that A.N.D. permits significantly improved performances of both men and women diallers, the main factor being a reduction of 1.03 seconds in the time to dial a number.

This time is composed of:

Interdigital Improvement	+0.81 sec.
Predialling Improvement	+0.29 sec.
Bias in mean impulsing time (Appendix III)	–0.07 sec.
	1.03 sec.

Table 1

		Interdigital Times				Predialling pause			
		L.N.D.	A.N.D.	Diff.	Resid. Variance	L.N.D.	A.N.D.	Diff.	Resid. Variance
Mean times in seconds	Men	13.42	12.79	0.63	11.1 sec²	3.50	3.26	0.24	2.15 sec²
	Women	13.25	12.25	1.00		3.43	3.11	0.32	
	Men & Women	13.34	12.53	0.81		3.47	3.18	0.29	
No. of operators who performed better in system	Men	4	12			3	13		
	Women	4	10			4	10		
	Men & Women	8	22	14		7	23	16	

Men showed somewhat less improvement than women, the interaction being marked in the case of the predialling pause.

Analysis of Speed Results: From the above experiments, a rough analysis may be made of some of the factors influencing dialling speed.

Only male subjects results were available for this, as only males were used to examine the effect of the moving symbols. As it was desirable to use experienced as well as inexperienced subjects results in the same calculation, the experienced subjects' times were weighed by a factor, $\frac{0.63}{0.54}$, which equalizes the L.N.D. v. A.N.D. differences. It is believed that this adjustment is reasonable as it was applied to the same process (i.e., visual searching) in each case, and is only a second order correction.

Table 2 gives the required adjusted values (mean times in seconds, variances of means in seconds²).

Table 2

Time Tested	Subjects	L.N.D.		A.N.D.		Rotating Numbers		Difference	
		Mean	Var.	Mean	Var.	Mean	Var.	Mean	Var.
Interdig.	Inexperienced	13.42	0.035	12.29	0.035			0.63	0.07
	Experienced	11.70	0.0037	11.07	0.0030			0.63	0.0067
	Experienced			11.07	0.0041	11.84	0.0071	0.77	0.0112
Predial	Inexperienced	3.502	0.0067	3.255	0.0067			0.25	0.0134

We may consider the period from the lifting of the handset until the last impulse is sent as being composed of several components, some of which are determined by the subject. These times, which are displayed graphically in Figure 3, are:

(a) The elapsed time between the lifting of the handset and the subject's searching for the first symbol on his dial. Any differences between systems in this time would be attributable to differences in the time required to read and memorise the number from the directory.

(b) The time to search for a symbol on the dial and position the finger. This time is assumed to be the same for all symbols of the same type (e.g., letters, stationary numerals and rotating numerals) in the different systems. In the case of rotating symbols, the search would not normally start until the dial is stationary, although some prepositioning may be possible, especially with numbers because of the simple order. It seems reasonable that the search time for numbers with the standard dial should not be very different whether the finger plate is stationary or not as the numerals are exposed for about ⅔ of the time anyway (Appendix IV), i.e., aboout 0.57 sec. for the average digit dialled.

(c) The "pull around" time to rotate the finger plate until the finger is stopped. It is assumed that this time is independent of the type of symbol used, but it will depend, of course, on the digit dialled. Thus, the mean pull-around time would depend on the digit-sums of numbers dialled. However, as the pull-around time is much less than the impulsing time, the small bias introduced in this way was neglected.

(d) There may be a pause between the two groups of digits while the subject refers to his directory for the second group. It is assumed here that the same behaviour is used when dialling in either system, i.e., that if the subject refers back to the directory in one system he will do it in both. This should be so here as the second group of digits is all numerals in both systems.

Using values from Table 2, we may now calculate certain important differences:

Let Tml be the memorising time for L.N.D. groups.
Let Tmn be the memorising time for A.N.D. groups.
Let Tslr be the search time for rotating letters.
Let Tsls be the search time for stationary letters.
Let Tsnr be the search time for rotating numerals.
Let Tsns be the search time for stationary numerals.

Figure 3 shows the relation of these times to the dialling process. Then:

(a) The difference in predialling times between A.N.D. and L.N.D. can be attributed to a difference in the times taken for memorising plus a difference in the search times for a stationary symbol, i.e., Tml — Tmn + (Tsls — Tsns) = 0.25 sec., with variance 0.0191 sec^2. .. .. (A)

(b) The difference between the interdigital times for A.N.D. and L.N.D. would be due to different search times for the second 2 digits. The first digit performance contributes to (a) above while the last 4 digits are all numerals and so should not exhibit any difference.
This relation is expressed by:
2 Tslr — 2 Tsns = 0.63 — 0.07 = 0.56 sec., with variance .0067 sec^2. (the 0.07 is a correction for the between directory digit sum difference, with negligible variance — see Appendix III).
i.e., Tslr — Tsns = 0.28 sec., with variance 0.0017 sec^2 . . . (B).

(c) The difference between interdigital times for stationary and rotating numeral dials is attributable to the different search times for the 6 digits affected, the search time for the first digit occurring during the predialling pause.
Thus 6 Tsnr — 6 Tsns = 0.77 sec., with variance 0.112 sec^2.
∴Tsnr — Tsns = .13 sec., with variance 0.003 sec^2 . . . (C).
From (B) and (C) Tslr — Tsnr = 0.15 sec. with variance 0.002 sec^2, i.e., the search time for letters is 0.15 sec. per letter longer than that for numbers.

This may be due to —
(a) The smaller type of the letters and their different form.
(b) The separation between the letter symbols and the associated finger holes.
(c) the more obvious order of the numbers.

If we assume that the extra search time required is the same whether the symbols rotate or not, i.e.
Tslr — Tsnr = Tsls — Tsns,
from (A) we find
Tml — Tmn = 0.25 — 0.15 = 0.10
with variance 0.021 sec^2. Thus there is some evidence that it takes longer to memorise the L.N.D. codes, the confidence level in this statement being greater than 75%.

Accuracy Comparison: χ^2 tests of fitted Poisson distributions showed that, under a given set of conditions, it was safe to assume a constant probability of error for all operators. Table 3 summarises the observations. The composition of the crews used for tests (a), (b) and (c) was as given previously.

The result for experienced operators (a) is the only one that shows a significant difference between systems. The size of the experiment with inexperienced operators was designed to provide a 99% confidence level if this difference were real. However, the results of this experiment did not show that same difference and to test the new difference would have required an experiment with about five times as many observations. This was not thought justifiable as the expected saving even if the difference were real would be small and sufficient subjects were not readily available.

The definite accuracy advantage of A.N.D. observed by the Bell Labs. may be attributable to the visual confusion caused by the appearance of the American dial (Fig. 2).

The disagreement between the difference for experienced and inexperienced subjects may be valid, indicating that A.N.D. is definitely superior when people are used to it. On the other hand, the withdrawal of one of the subjects caused some disturbance of the experienced subject experiment, although no effect of this was apparent in the results for speed.

No significant correlation was observed between accuracy and speed of operators, nor between the accuracies of operators in the two different systems. There was no significant difference between operators or systems with regard to the types of errors which occurred. For interest, the analysis of the observed errors into various types was:

- Any digit quite wrong 46%
- One group of digits quite wrong .... 24% (as by dialling ½ of the next higher or lower directory entry)
- Any digit too high or too low by one unit 15%
- A pair of digits reversed, e.g., 3 4 7 2 7 4 1 instead of 3 7 4 2 7 4 1 .... 15%

Table 3

Digit	Number of digits masked during each impulse	Total	Total time dial is off normal, sec.
1	1+2+3+4	10	0.4
2	1+2+3+4+4	14	0.5
3	1+2+3+4+4+4	18	0.6
4	1+2+3+4+4+4+4+	22	0.7
5	....	26	0.8
6	........+4	30	0.9
7	........+4	34	1.0
8	........+4+3	37	1.1
9	........+4+3+2	39	1.2
10	........+4+3+2+1	40	1.3
		270 = (A)	8.5 = (B)

APPENDIX II

Savings due to Dialling Performance Changes

Wrong Numbers: The "wrong numbers" which can be influenced by a choice of dialling system are those due to subscribers dialling incorrectly. Some of these calls will earn revenue slightly faster than successful calls due to the short holding time if the calling subscriber does not claim a refund. However, a sample comparison of subscribers accounts with exchange observations (6) suggested that rather more "wrong numbers" are claimed for than really occur, although this was not investigated fully. Further, the wrong numbers for which refund is made cost rather more for administration. It seems reasonable to ignore any possible profit as a result of wrong number traffic.

Other calls dialled wrongly meet "no progress" conditions if the called number is not allotted. The relative frequency of such calls would depend on the occupancy of the numbering scheme (about 30% in a step-by-step system, 60% in crossbar (7), and their average holding time would be shorter than for those which are answered. A calling subscriber would take, say, two seconds to hang up on encountering a no-progress tone.

Observations of the mean time to answer gave a value of about 11 sec. (6), and it seems reasonable that it would take, say, 10 sec. more to terminate an answered wrong number call. The average 7 digit number takes about 15 sec. to dial and the mean holding time is about 180 sec. (7) so that it is possible to calculate the contribution of wrong numbers to the total traffic.

In a step-by-step system, considering the dialling time as distributed uniformly over the switching stages, the total equivalent holding time may be calculated thus:

Dialling time (ave. for each switch in train	$\frac{15}{2}$ seconds
Answering time — For the 30% of numbers that are allotted	0.3 x 11 seconds
Speaking time — For the 30% of numbers that are allotted	0.3 x 10 seconds
Teminating time for the 70% of numbers not allotted	0.7 x 2 seconds
Total	15 seconds

That is, the equivalent holding time is about 0.08 of the 180 seconds mean for successful calls. Thus, if wrong numbers occur as a small fraction, a, of all calls, they contribute 0.08a of the total traffic.

In the case of a crossbar system, the contribution to the overall cost may be somewhat higher as the expensive common control equipment is involved just as much on wrong number calls as on successful ones. The contribution of wrong numbers to the cost of the remainder of the plant should not be very different from that in the step-by-step system as a large fraction of this would be in the junction system. In the absence of detailed cost information on other systems, the previous value of 0.08a should be a reasonable working figure.

From Ref. 7, the annual cost of providing and maintaining exchange plant and equipment in the A.P.O. network is about £1.6×10^7, including depreciation, and the cost of the wrong numbers would thus be £$1.6 \times 10^7 \times 0.08a$ = £$1.3 \times 10^6 \times a$ per year. In the case of the observed frequency, a, of about 0.04 this is equivalent to about £50,000 per year. When subscriber trunk dialling is widely used, this figure could be doubled roughly (from the approximate equality of the present trunk and local call revenues). It is to be expected that the proportion of trunk calls will increase with the possibility of cheaper, easier calls, but the effect of this on the wrong-number cost would be counteracted by subscribers taking more care on relatively expensive calls.

Speed of Dialling: Eventually, we may be using press-button or other dials in which the signalling rate is much less dependent on subscriber performance than at present. Many particular systems could be considered in detail, but the present one is the most realistic on which to base cost estimates.

The two main subscriber-dependent components of the time taken to dial a number must be considered separately in the step-by-step system.

The predialling pause will only affect the provision of first selectors, line-finders and sometimes junctions. Assuming that one-sixth of the total exchange expenditure is on these we find the cost of the predialling pause as

$\frac{1}{6} \times \frac{1}{180} \times$ £1.6×10^7, or about £15,000 per year for each second saved per call. The interdigital pause time may be roughly considered as being uniformly spread over the switching stages — i.e., half of it is effective for the whole call. On this basis, it can be treated as an increase in total traffic and would cost

$\frac{1}{2} \times \frac{1}{180} \times$ £1.6×10^7, or about £44,000 per year for each second.

In a crossbar system, the same initial control equipment would be held throughout dialling. Later stages would nor normally be affected by the subscriber's sending rate as the "register" provides some buffering. The relevant equipment would have a capital cost of about £3×10^6, equivalent to about £300,000 p.a. (This capital cost is derived by assuming a traffic of .05E for each of 1.8×10^6 subscribers, each taking 15 sec. to dial, and provided with service giving a .01 probability of delay exceeding one sec. from registers each costing £250 in groups of 20 (9,10)* The ratio of capital to annual cost corresponds to the ratio of present plant capital to annual cost (B). Thus, the cost per second of total dialling time is about $\frac{300{,}000}{15}$ = £20,000 p.a. for each second.

APPENDIX III

Digit Sum Distribution in Dial Codes: It was desired to determine the distribution of the sum of the number of digits in the telephone numbers dialled to see how this would affect the size of experiment required. This was done in two ways:

Using Random Numbers: Assuming that every 7 digit number has an equal probability of occurrence, we can find the frequency of occurrence of any particular digit sum as follows:

where $\binom{n}{k}$ is the binominal coefficient = $\frac{n!}{k!\,(n-k)\,!}$

Using this method, frequencies of occurrence were calculated for sums from 0 to 70 and the mean (38.5) and standard deviation (7.9) estimated. A plot of the distribution suggested that it was normal, as is reasonable, considering how the values of the sum are composed.

Using Telephone Numbers: Using the modified telephone directories, 600 numbers dialled from each were tested, giving means and variances as shown:

	Mean Digit Sum	Variance
L.N.D.	37.26	45.58
A.N.D.	36.58	52.55
Difference	0.68	

The difference between the variances is not significant but the difference between the means is, being greater than three standard deviations of the mean. Both means are also significantly different from the random number mean.

The 0.68 impulses correspond to approximately 0.07 seconds' impulsing time.

APPENDIX IV

Time Lost Due to Masking by Finger Plate: When the finger plate is off normal, some of the numbers behind it are covered by the part without holes. The effective time not available for searching may be estimated for any number dialled.

The process is best analysed by considering time intervals equal to that for a hole in the finger plate to pass one symbol, i.e., the time for one impulse If one symbol is hidden for one impulse, the effective loss will be called one "symbol-impulse".

In this manner the symbol-impulses lost for each digit dialled were found by tabulating thus:

Table 4

Operators	Error Frequency			Significance
	A.N.D.	L.N.D.	Rotating Nos.	
Experienced (a)	0.020	0.039		Very high
Experienced (b)	0.018		0.0135	Nil
Inexperienced (c)				
Men	0.028	0.034		Nil
Women	0.036	0.039		Nil
All	0.032	0.037		Nil

Consider the expansion of the expression:

$$F(x) = (x + x^2 + x^3 + \ldots x^r)^n$$

The coefficient of x^p in this is the number of ways of making up p from the numbers 1, 2 . . . r, taken n at a time.

$$\text{Now } F(x) = \left[\frac{x(1-x^r)}{1-x}\right]^n$$

$$= x^n\left[\sum_{k=0}^{n}\binom{n}{k}(-x^r)^k \sum_{k=0}^{n}\binom{-n}{k}(-x)^k\right]$$

Since (A) is the sum of 10 entries, the time for 1 impulse is 0.1 sec. and there are 10 symbols on the dial (A) ÷ 1,000 = 0.27, is the average time in seconds that all numerals are obscured during one return of the finger plate. The expected time for return of the finger plate is found from (B) to be 0.85 sec.

Thus the stationary numerals are obscured for $\frac{0.27}{0.85}$ = 0.32, or roughly ⅓ of the time the dial takes to return to normal.

*Actually provisions of registers will be on a somewhat different basis from that assumed here.

PROTECTION AND DUST PROOFING OF AUTOMATIC EQUIPMENT

G. P. JOLLEY.*

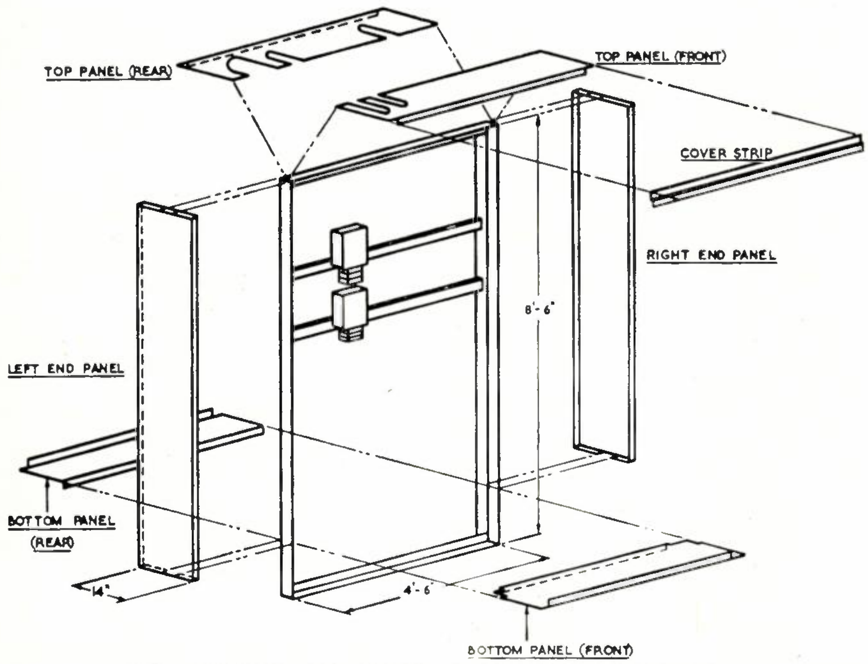

Fig. 1.—Basic Construction of Metal Panels for Enclosed Switch Rack.

INTRODUCTION

The problem of dust deposition on Telephone Switching Equipment is widely recognised. It has been the subject of comprehensive studies by telephone authorities the world over. The practice of providing individual covers for relays, groups of relays, mechanisms and other apparatus is standard, but this method leaves the banks and wipers unprotected. This applies also to cable forms, connection blocks and other miscellaneous equipment, which are exposed to the atmosphere and, therefore, vulnerable to the effects of dust and dirt. It is not within the scope of this article to discuss ways and means of preventing the entry of dust into Telephone Exchanges, as these have already been dealt with by other writers in this Journal.

Ericsson Telephones Ltd., London, recently developed a design for covers to completely enclose 2,000 type equipment. The Telephone Equipment Section at Headquarters became aware of this developmental work and obtained sample covers. A field trial was designed to test the effectiveness of the covers and Civic Exchange, Melbourne, was selected as the most suitable location. This article describes the covers, their installation, and the tests carried out on the completed installation.

DESIGN OBJECTIVES

After careful consideration, the design objectives for the covers were set out as follows:

(1) The enclosure should be capable of being fitted to existing equipment and to apply to all types of racks, also, it must be suitable for new equipment, either at manufacture or installation.

(2) The design to be simple, with smooth external contours, and of sufficient thickness and rigidity to give ease of cleaning. All complicated fixing devices to be avoided so that fitting or removal is easy and fast.

(3) Low Capital Cost. Vacuum forming of plastic panels is ideal as the shapes are produced on wooden moulds.

(4) Panels to be non-inflammable, light to handle, and not subject to corrosion, to be shock resisting — within reason — so that no special care is needed in handling.

(5) Panels to be transparent on the side which mounts the relay sets and mechanisms.

(6) Rear panels to be white to give good light diffusion in the wiring aisles.

(7) Panels to be small for ease of handling. When removed for maintenance there is less possibility of dust entry when a small area of equipment is exposed.

(8) Eliminate the need for separate covers on relay sets, etc.

(9) Thickness of the panels to be such that noise level from switch operation would be low. P.V.C. is superior to metal in this respect.

(10) Surface of panels to be feebly electrostatic, so that dust particles will adhere to external faces for removal by cleaning.

(11) Panels to withstand rises in temperature caused by switch operation.

Fig. 2.—Alternative end panels for installation where movement of racks is not convenient, such as in existing suites.

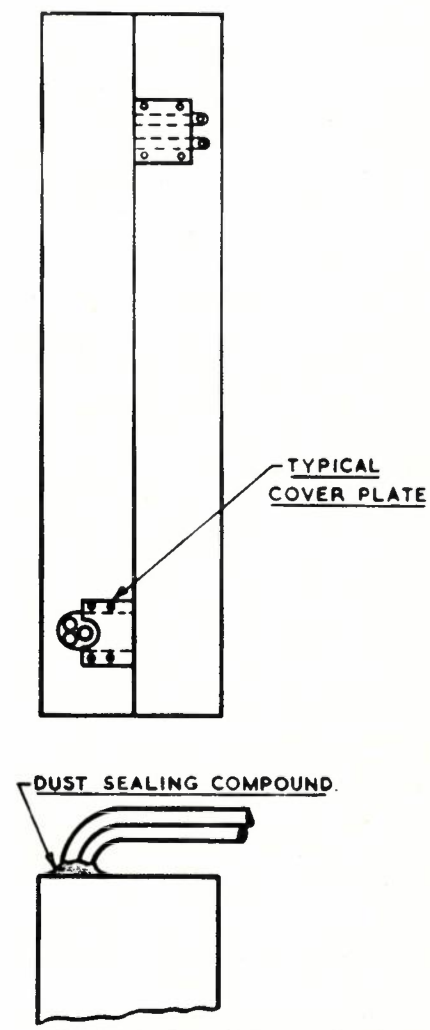

Fig. 3.—Cable entry to covered rack.

* See page 377.

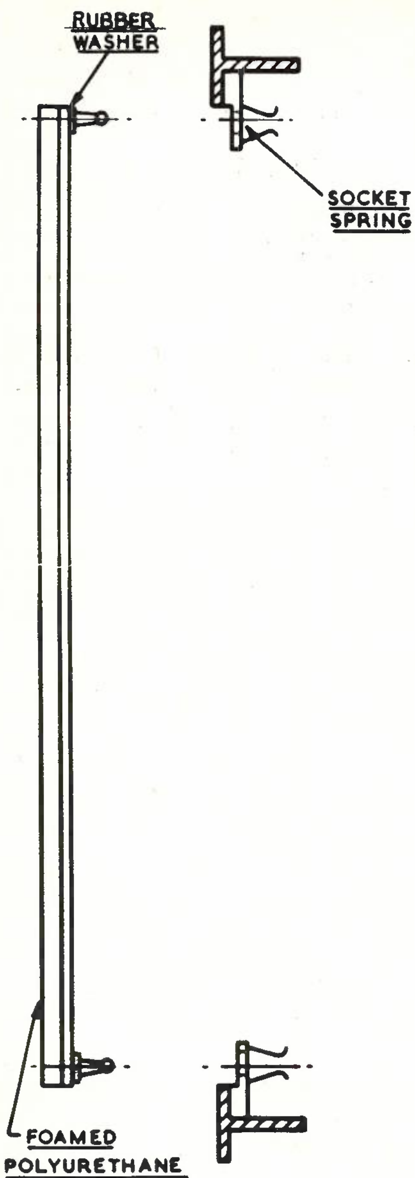

Fig. 4.—Jacked-in centre support for making dust seal with inner edges of removable P.V.C. panels.

DETAILS OF CONSTRUCTION AND FITTING

Figure 1 shows an exploded view of the top, bottom and side panels of an 8′ 6″ rack. The construction is similar to that of a 10′ 6½″ rack except that those described later as delivered to Civic Exchange, Melbourne, had no cutouts in the top panels. The panels are constructed of 0.048″ M.S. stove enamelled white inside and grey outside. The top panels are split longitudinally, which allows ease of fitting and making clearance cutouts for cables, etc. The bottom is made of two flanged panels, with cutouts to clear the rack frame at both ends. The end panels are of identical shape where an isolated rack is to be covered. Cutouts are made at the bottom to clear the frame.

Figure 2 shows alternative end panels for installation where the racks cannot be moved, such as in an existing suite. In the case of intermediate racks the flange is double sided. Existing holes in the rack frame are used to secure the panels.

Clearance cutouts are made for cable entries and bus bars and after assembly any gaps remaining are covered by vulcanized fibre sheet, secured to the panel with self-tapping screws as shown in Figure 3. The final dust seal is made around the cables with caulking compound. This is pressed into any gaps between the cables and covers. Caulking compound always remains soft, which is an advantage if additional cables are to be installed.

The front and rear of the rack are enclosed with removable panels, vacuum formed from 0.040″ rigid P.V.C. sheets. Removal of a panel gives access to five switches, and removal of two panels, and the jacked-in support, which is shown in Figure 4, gives access to a full shelf of switches. Figure 5 shows how the panels are fitted to the enclosure.

The channels for holding the panels are mounted on 1″ T section steel, which is spanned across the enclosure at such vertical measurements as are necessary to suit the equipment. These bars are screwed to the end panels with 4BA nuts and bolts.

Strips of high-density polyurethane (plastic foam) are cemented to the flanges of the end panels, between each pair of T bars. Dust entry is prevented by the fit of the long edges in the channels, and by pressure between the short edges and the foamed strip.

Removal of the P.V.C. panels is very simple, see Figure 8. Both handles are pushed upwards, the panel is then lowered, keeping it fairly flat against the rack just clear of the lower channel.

Replacement of the panels is carried out by using the hand grips and pushing the outer top corner only, fully into the upper channel, flush with the outer edge. Then the panel is pivoted about this corner until the remainder of the edge is engaged in the channel. The outer bottom edge is now guided into the bottom channel, and pressure is placed on the raised portion at the top of the panel to enter the bottom corner into the lower channel. The hands are now moved along the bottom of the panel to engage it fully in the lower channel. Downward pressure is now applied with both hands on the upper raised portion to push the panel fully home.

In August, 1959, material designed to enclose two adjacent group selector racks was delivered to Civic Exchange, Melbourne.

To facilitate evaluation of the performance of the covered racks, it was decided to fit the covers to adjacent racks 1sts A and 1sts B, and to compare these racks with uncovered racks 1sts C and 1sts D, all four racks being adjacent to one another in the same suite.

In this instance the rack covers were fitted by the regular maintenance staff and no great difficulties were encountered. However, large-scale fitting of covers would be best done by a specialised staff using specialised tools.

Labels were fixed on the frames of the switches in 1sts A and B and the switch covers were removed. The last step was fitting the plastic panels and the equipment was ready for test.

Our experience indicates that two men would be able to cover a working rack in a day. New installations would take less time, but working racks have their individual problems.

When the installation was completed it was soon seen that changing fuses was a hazard, as it would be easy to contact

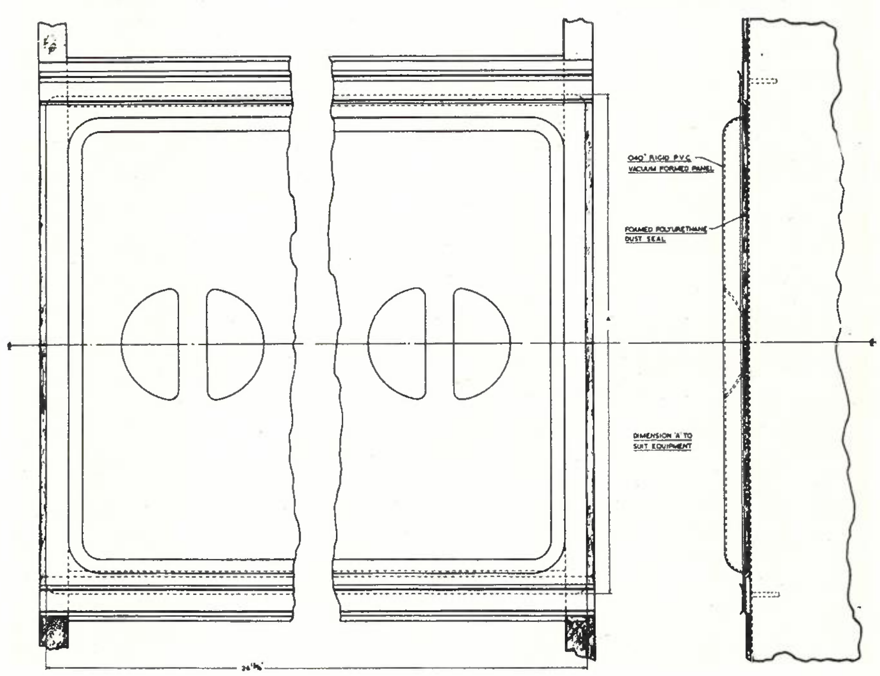

Fig. 5.—Method of fixing panels for dust exclusion on selector rack equipment.

earth when loosening or tightening the screw on the bus bar end. This was overcome by placing "Lassovic" on the web of the flange near the fuse panel. A far better arrangement would be a formed insulating piece to slide beside the fuse panel and returned around the web to prevent contact with the screwdriver blade.

To avoid unnecessary opening of the enclosure the battery jacks were brought out to the bottom of the rack. Release and fuse alarms were also brought out on to keys. These can be seen below the bottom panel in Figure 6. Checking of permanents is done visually and call tracing is no trouble, as the operated relays and wiper position can be seen through the panels. The switches are subjected to functional testing once a week.

Rack	Apr. 1959	May 1959	June 1959	July 1959	Aug. 1959	Sept. 1959	6 mths. Total
1A and 1B	20	15	13	17	14	15	94
1C and 1D	22	8	17	14	15	10	86

SERVICE EFFECTS OF COVERS

The obvious method of establishing the effectiveness of the covers was a study of fault incidence. A table of faults for the six months prior to installation is shown above.

Immediately the racks were covered, racks 1sts A, B, C, D were "blown out" with compressed air and thoroughly cleaned. Also, all wipers were changed on the A shelf of the four racks.

A table of faults since installation of covers on 1A and 1B follows:

Rack	Oct. 1959	Nov. 1959	Dec. 1959	Jan. 1960	Feb. 1960	Mar. 1960	6 mths. Total
1A and 1B	15	7	7	3	2	3	37
1C and 1D	19	14	15	11	9	8	76

The fault incidence for the period April to June, 1960, is similar to that of January to March, 1960. In passing, it will be noticed that the total faults in 1C and 1D have dropped; this is possibly due to the clean down they received.

The banks on 1A and 1B are still clean, whilst those on 1C and 1D are building up dust deposits. The wipers on the A shelves and all racks have been checked. The difference in wear between the racks is scarcely noticeable. A check over a longer period is necessary for these items, but experience in the past has shown that more wear will be experienced on the top wipers as the dust deposits grow.

It was feared that the oil on the switches in the covered racks would dry out due to increased temperature. These fears are unfounded as checks have shown no deterioration of the oil film.

The Research Laboratories were requested to carry out tests on the enclosure along the following lines:

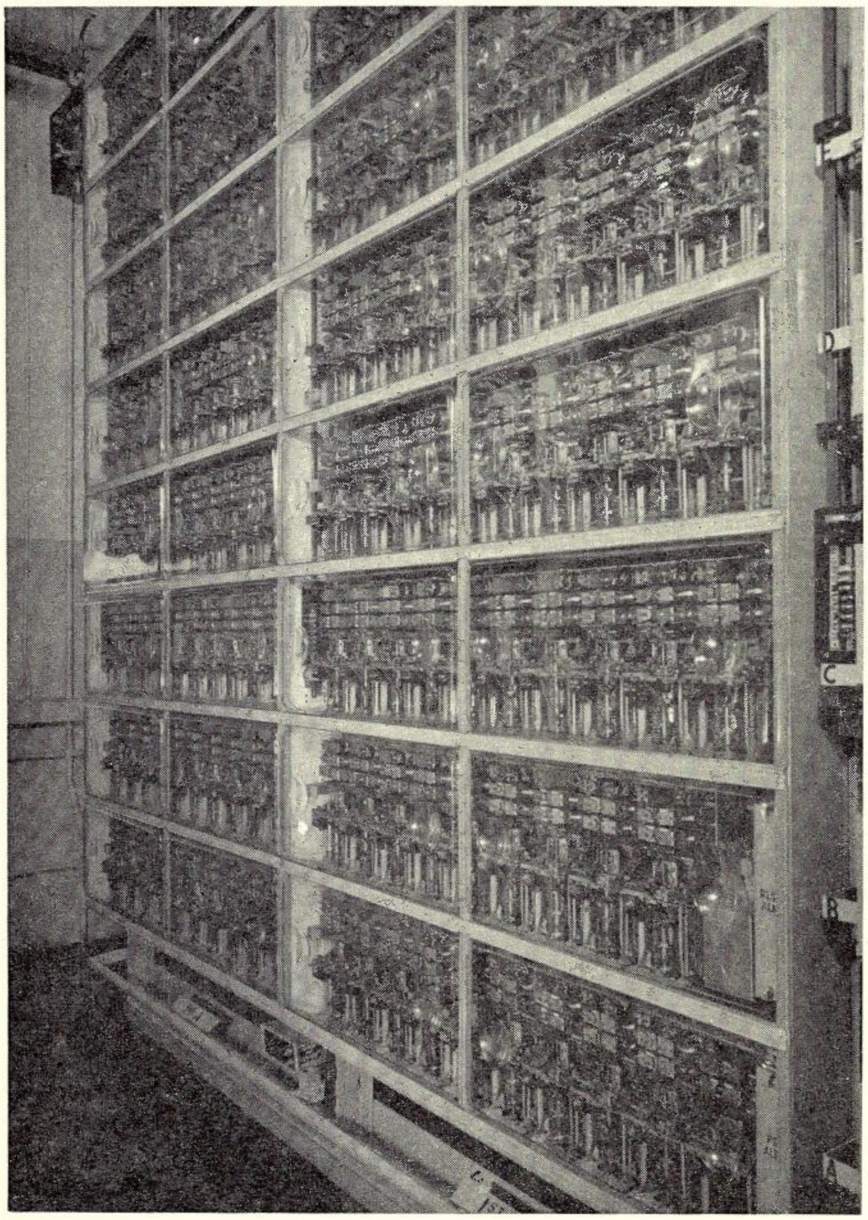

Fig. 6.—Equipment side of rack. Note individual switch covers not necessary and switches visible through clear plastic panels.

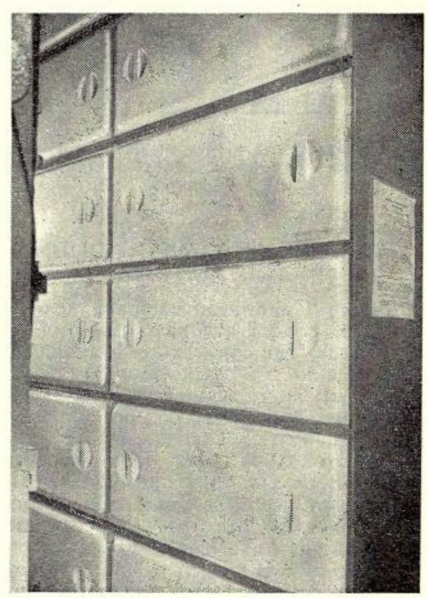

Fig. 7.—Wiring side of rack. Panels are removable as for equipment side and are cream opaque for improvement in aisle lighting conditions.

(1) Dust deposition comparisons between the covered and uncovered racks.
(2) Temperature comparisons between that in the exchange and the covered racks.
(3) Tarnishing.

The rate of dust deposition was determined by greased glass plates, distributed at various heights throughout the covered and uncovered racks. Tests were made over a period of three months. For the first two months the dust concentration was determined by counting the particles under a microscope. Further plates were exposed on the third month and were photographed on removal, the magnification in each case being twenty. Figures 9 and 10 show the deposition on the open racks whilst Figures 11 and 12 show that on slides, in similar positions, inside the covered racks. The striations on the edges of the pictures are due to marks on the grease film caused during application.

These photographs prove conclusively that dust is greatly reduced in the covered racks. Moreover, this difference should become more marked as time goes on, as most of the dust under the covers had settled after a few days, and, if the covers were undisturbed, no further deposition should take place. The deposition on the uncovered racks would be directly proportional to the time of exposure.

Temperature recordings were taken by means of thermistors on hot and mild days and during a holiday period. The readings during the holiday period were taken to ascertain the effect of the switches in the covered rack being idle for lengthy periods.

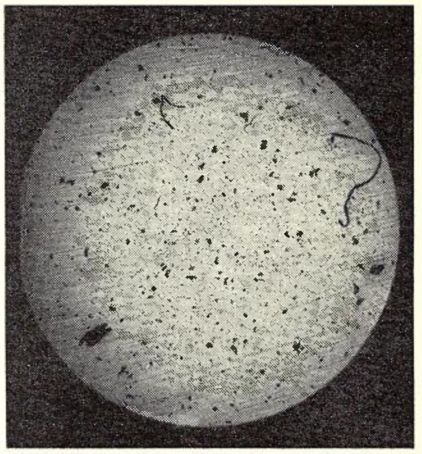

Fig. 9.—Sample of dust deposition on uncovered racks.

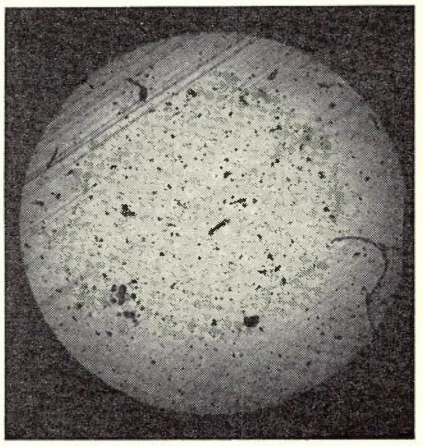

Fig. 10.—Sample of dust deposition on uncovered racks.

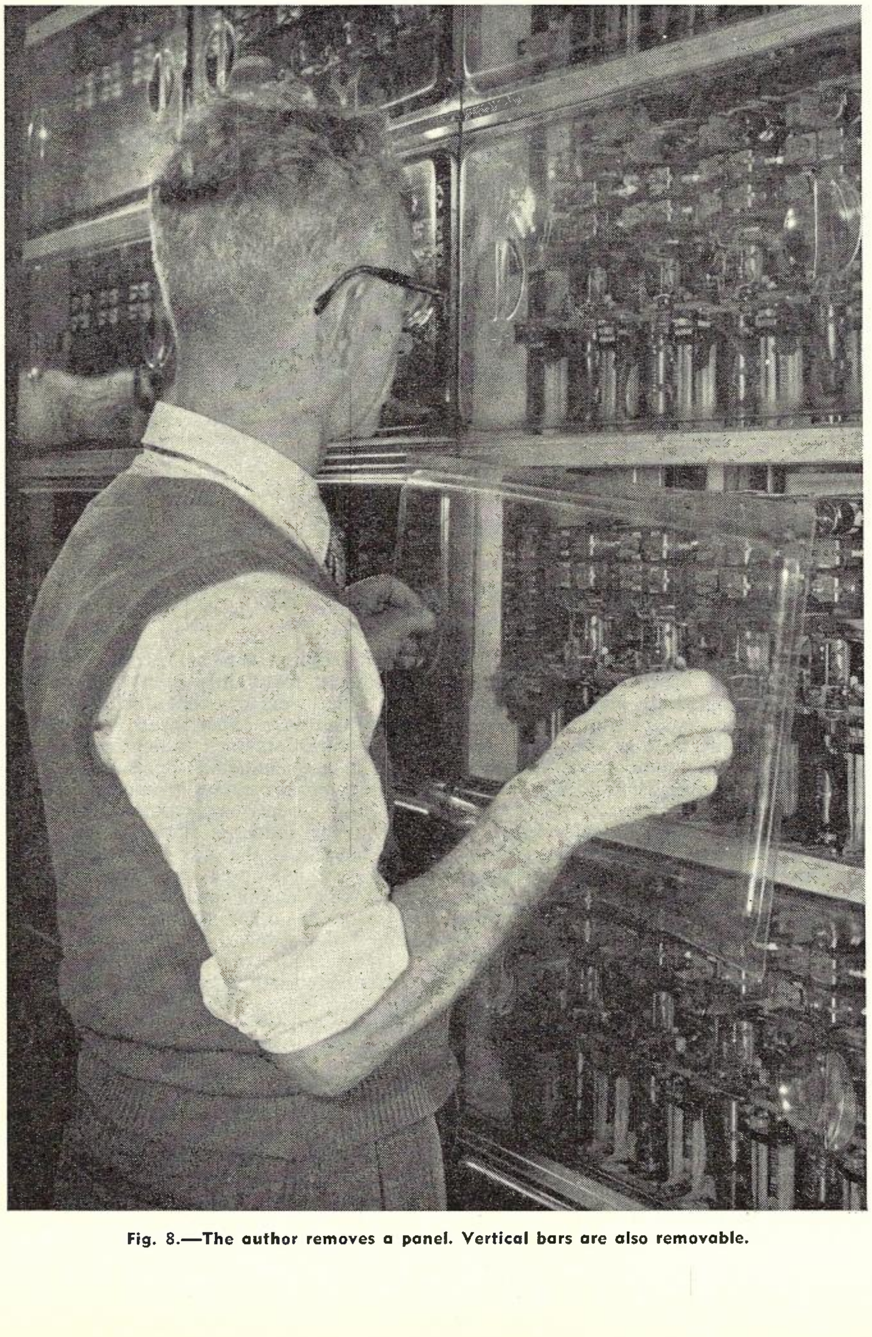

Fig. 8.—The author removes a panel. Vertical bars are also removable.

The results showed that the temperature, inside the covered racks, rose no more than five degrees fahrenheit above exchange ambient temperature. The amount of variation was influenced by the amount of traffic, being very small during the night hours, weekends and holiday period. This slight excess over ambient temperature ensures that little danger of moisture condensation exists and if it did take place it would be on the outside of the covers.

As there is no free circulation of air under the covers, it was thought that a concentration of vapours could build up. If this included free sulphur from the switch cradle rubbers, etc., it could attack the silver relay contacts and cause them to tarnish. To check for this eventuality, pure silver foil was placed in various positions in the covered and uncovered racks. A tarnish test was also made on the panel P.V.C., the foamed plastic, and the caulking compound.

The tarnish test on these materials proved them innocuous, and the silver foil showed tarnish only in the uncovered racks. The absence of tarnish in the enclosed racks, where there is no air circulation, was considered most satisfactory.

Inspections have shown that the banks stay clean and as long as opening of the enclosure is kept to a minimum, should remain clean for a long period. This, in turn, means that wiper wear is retarded. Considering these facts, it should be possible to experiment with bank lubrication without the fear of creating a cutting compound of dust and oil, as was the tendency in previous attempts to bank lubrication using paraffin oil. Research Section is investigating this aspect.

In covered racks switch lubrication will be less of a problem and should last longer, and the oil film will be freed from contamination by dust and dirt. This should mean longer life for the mechanisms.

Most of the noise of switch operation is eliminated. It is uncanny to stand in front of the covered racks and watch the switches operating almost without a sound. This should have a distinct bearing on staff fatigue and is a decided advantage in exchanges where the Test Desk is in the switch room.

As the covers are electrostatic, dust has a tendency to cling to the outside surface. This, combined with the flat surface of the metal work, makes cleaning the racks very easy indeed. The Company supplied a commercial-type anti-static cloth for wiping down the plastic panels, and a rack can be cleaned down in a matter of minutes.

Most human beings are confirmed "fiddlers", and it has been found necessary to discourage the tendency to remove switches from the racks to perform work that could be done equally as well with the switch in situ. There is much less interference with switches on covered racks.

Added to all these factors is the lower fault incidence. It can readily be seen that if an exchange was fully equipped with these covers, less staff effort would be needed to give a comparable or better grade of service. The capital cost of installation could soon be recouped.

The whole concept of covering is lost unless opening of the rack covers is rigidly defined and controlled. Toward this end, the alarms were arranged so that testing could be done without removing the covers. Could we now imagine a system with which all alarms could be tested — perhaps automatically — from a central point in the exchange?

From a Qualitative Maintenance viewpoint, the covers should benefit the Supervisory staff. They could expect that cleaning, oiling, wiper and bank maintenance, at least, would be largely divorced from disturbances partly beyond their control, e.g., inefficient air filtering, cleaning operations generally, doors opening and from staff movements. They would be getting in a very easy fashion the ideal that modern exchange planners are striving for — the equipment isolated.

REFERENCE

Ericsson Publication, "Dustproof Enclosure for A.P.O. Switch Racks—Information for Installing Engineer.

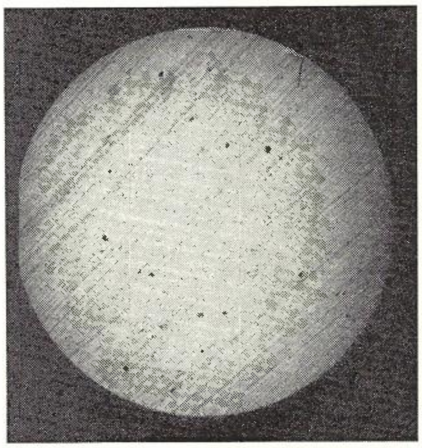

Fig. 11.—Sample of dust deposition on covered racks.

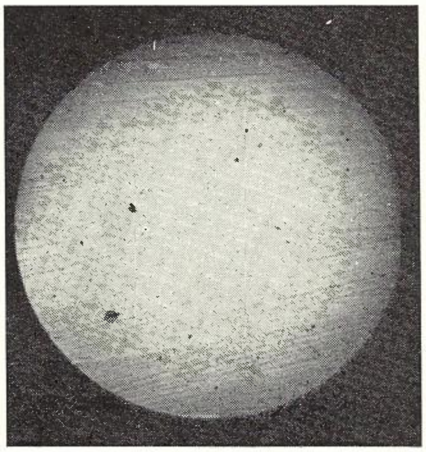

Fig. 12.—Sample of dust deposition on covered racks.

ACTIVITIES OF THE SOCIETY IN VICTORIA

Progress: The Victorian Division of the Society has grown rapidly in recent months with the adoption of the new constitution. The new committee in Victoria, building upon good foundations laid by the earlier Postal Electrical Society, has been able to expand its membership rapidly from about one thousand to approximately two thousand members.

The present committee consists of:

E. D. Curtis, Chairman;
J. S. MacGregor, Secretary;
A. M. Smith, Treasurer;
C. Duncan, Auditor;
E. J. Bulte, Immediate Past President, Postal Electrical Society of Victoria.
A. McPherson, P. A. Warr, A. Wright, W. Kemp, 3rd Divisional Representatives.
C. H. Brown, W. H. Chapman, J. A. Vickers, 4th Divisional Representatives.

To reduce the clerical work associated with this rapid growth of membership and to improve communications generally, members are dealt with almost exclusively in Victoria via Agents, and the number of Agents have been increased from twenty to about one hundred. The pin punch card membership system has also been installed. In addition to many new members within the Department, great interest has been shown in the work of the Society by commercial firms with widely-differing interests and Educational Organisations.

Lectures: The first full-scale venture by the Victorian Division was the series of six lectures on Cross-Bar Telephone Switching Principles held at the City of Kew Town Hall. These lectures, organised by Mr. C. M. Lindsay, were attended by twelve hundred people on the opening night. The series was opened on Thursday, 1st September, by the Victorian Chairman, Mr. E. D. Curtis, Assistant Director, Engineering, Victoria, and the series was introduced by Mr. F. P. O'Grady, Deputy Director-General, Posts and Telegraphs, the Chairman of the Commonwealth Council of Control of the Society. The Lecturers in the series were as follows:

E. Banks, B. Bence, F. Campbell, F. Channon, D. Frame, N. Holah, L. Haig, D. Ibbot, B. Marrows, G. Reed, K. West.

The lectures were held, commencing at 8 p.m., at fortnightly intervals, and lecture notes were distributed. Considerable difficulties were experienced in arranging the lectures on such a new subject for such a large audience. Special sound arrangements, projection arrangements, etc., including special preparation of slides had to be made so that all could see and hear, and the fact that these problems were overcome so satisfactorily reflects great credit on Mr. Lindsay and those many other people who assisted behind the scenes.

Apart from these special lectures the normal bi-monthly lectures of the Society are held in the Radio Theatre of the Melbourne Technical College.

Future: A survey of the penetration of the Society in the State of Victoria indicates that penetration varies between thirty and ninety per cent at different centres, and it is confidently expected that within the next few months as more Agents are established, and as the Society becomes better known, a substantial further increase of membership can confidently be expected.

PULSE ECHO TESTER FOR OPEN-WIRE, CABLE AND COMPOSITE LINES

*S. DOSSING, M.Sc.E.E., M.E.E., M.I.F.**

INTRODUCTION

The techniques of pulse-type radar became known to a considerable number of engineers and technicians during the latter part of the Second World War. Very soon after the war attempts were made to apply the same techniques to the problem of locating faults on power and telecommunication lines. The scope of this paper does not extend to wide-band lines such as wide-band coaxial cables, where the bandwidth is so large that the application of pulse echo testing techniques is reasonably simple. In most cases, other than the wide-band coaxial cables, the limited bandwidths of the lines present difficulties, and the advance of the pulse echo testing techniques has been slowed down for that reason.

The first account known to the author of pulse echo testing techniques being applied to lines of small bandwidth was published in 1945 (Ref. 1. This reference gives a very useful general introduction to pulse echo testing on lines of restricted bandwidth). The pulse echo testing principle was explored early also in Australia, and a significant amount of effort has been put into the development of suitable instruments for this type of fault location. The earliest efforts led to the stage that a suitable instrument for use on pure open-wire lines became commercially available in 1947 (the F.L.O.S. Locator made by A. H. Reid, Melbourne, see Ref. 2). In the P.M.G.'s Department, two instruments were constructed by the State Engineering Divisions, one in Adelaide attributed to the efforts of W. O. Gibberd and one in Melbourne attributed to B. Miller. A prototype instrument designed by the P.M.G. Research Laboratories was subjected to Field trials in Queensland (Ref. 3) in 1949.

The F.L.O.S. Locator being almost the only commercially available instrument, came into quite extensive use in Australia, but as its name implies (F.L.O.S. = Fault Locator Open-Wire Systems) its use is in the main limited to the location of faults on pure open-wire lines. Improvements aimed at making it more universally applicable have been devised by K. J. Boyle of the N.S.W. Engineering Division.

The experience gained from the practical use of the above instruments led to the formulation of a design specification for a universal type of pulse echo tester and tenders were called for designs to meet this specification. A prototype instrument submitted by Telephone Manufacturing Company (Australia) was subjected to extensive laboratory and field tests. Minor modifications to the specification and to the instrument were suggested by the tests and contracts were consequently placed for nearly 150 of these instruments to the revised specification. This new instrument, known as Pulse Echo Tester, Type PET 100A/B, Photo in Fig. 1, has a much wider range of application than any other instrument known to the Department, and this article is intended to outline the operating principles, the principal improvements over the types hitherto used and to illustrate its use by the presentation of some camera-recorded line echo traces. For comprehensive information regarding the instrument and its use reference should be made to the handbooks (Refs. 4 and 5).

OPERATING PRINCIPLES

The operating principles may be explained by reference to the simplified block schematic, Fig. 2. The instrument is operated from the A.C. mains (50 or 60c/s). The (pulsed) operations of the instrument are synchronised to the frequency of the A.C. mains by means of various voltages derived from the A.C. mains as indicated on Fig. 2. A square-wave "master control" signal, synchronised with the A.C. mains, is used to control all the functions which require rigid timing control, that is:

(a) the Pulse Generator, which generates the pulse transmitted to line,
(b) the Time Base for the Cathode Ray Tube.
(c) the Brightening Pulse, which ensures that the Cathode Ray tube is blanked out during the fly-back of the electron beam. (Not shown in Fig. 2.)

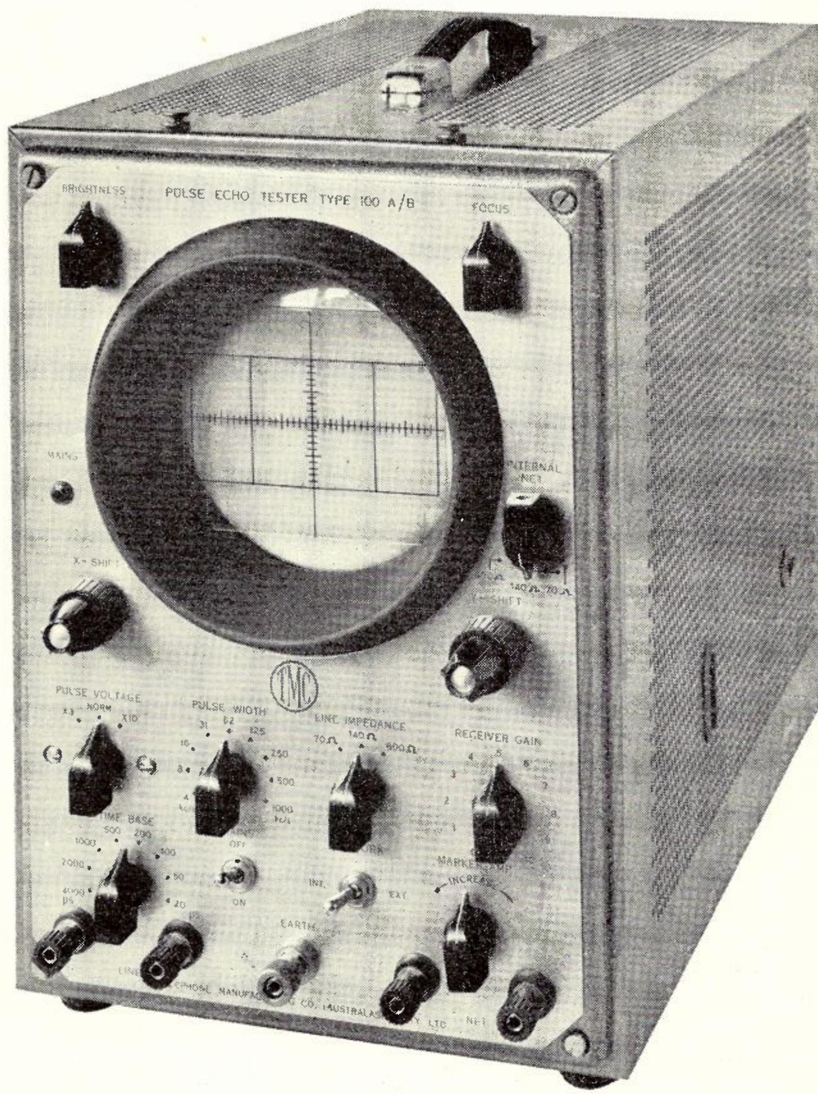

Fig. 1.—Photo showing PET 100 A/B

* See page 377.

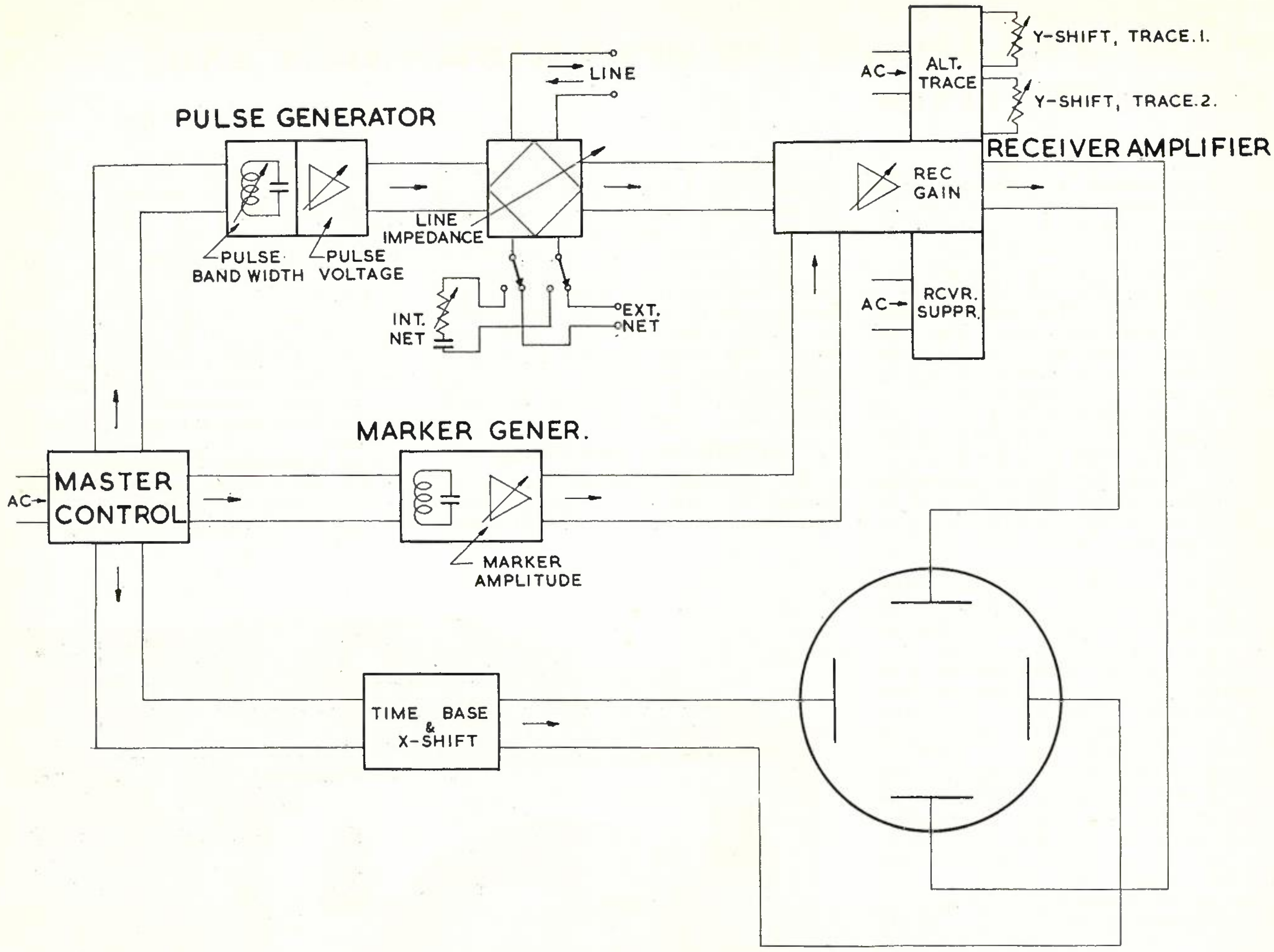

Fig. 2.—Simplified Block Schematic, PET 100 A/B.

(d) the Marker Generator, which generates "marker pips" (timing marks at intervals of 20 and 100 microseconds) on a second trace of the C.R.T. and enabling echo-times to be determined with a high degree of accuracy.

The trace on which the marker pips are displayed is separate from that on which the received echoes are displayed. The two traces are obtained by the "alternate trace" method, the necessary switching functions being carried out by transistors and controlled by voltages derived from the A.C. mains. The gain of the receiving amplifier is suppressed during the time the marker trace is being drawn; the suppression is carried out by a transistor under the control of the A.C. mains.

PRINCIPAL IMPROVEMENTS

The principal improvements and features of the instrument are:

Streamline Pulse of Variable Bandwidth. If a pulse is to be transmitted over a line without suffering serious distortion of its shape, it is necessary that the line transmits all the components of the frequency spectrum of the pulse with a uniform (flat) attenuation and that the propagation time is the same for all the frequencies concerned. Pulses of square shape, triangular shape and pulses obtained, for instance, by discharging a capacitor, exhibit "sharp corners" and the frequency spectra associated with such pulses cover a very wide frequency band. The pulse used in the PET 100 A/B is streamlined (raised cosine or sine-squared shape) and the associated frequency spectrum is very much smaller than that of the sharp-cornered type of pulse. As a result the streamline pulse may be faithfully reproduced after transmission over a line having an effective bandwidth very much smaller than that required for the faithful reproduction of a sharp-cornered pulse. Any of nine different pulse-lengths, that is, nine different bandwidths of the associated frequency spectra, may be selected by operation of a switch. The bandwidths of the frequency spectra range from 4 Kc/s to 1 Mc/s, and it is thus possible to select a bandwidth suitable for the line under test, whether it be a voice-frequency loaded line or a pure open-wire line. The selection of the proper bandwidth is extremely important, to avoid ringing, which would otherwise obscure the trace, particularly in case of loaded lines and lines equipped with low-pass filters.

Transmit/Receive Hybrid. The transmitted pulse is applied to the line under test via a hybrid, see Fig 2. Thus, if a suitable balancing net is used, the transmitted pulse will be "balanced-out" in the hybrid and a small residual pulse only will enter the receiver. This arrangement has a number of advantages over instruments where the transmitter, the receiver and the line are in simple parallel-connection. The hybrid arrangement permits the receive gain to be made very large without the transmitted pulse entering the receiver at such a high level that the trace on the Cathode Ray Tube is "bent" away from the centre for a significant period of time. In more serious cases the receiver could be paralysed (or saturated) for a sufficient period of time to prevent the reception of echoes returning from the line under test.

The large receive gain possible permits:

(a) the detection of weak echoes received from small irregularities on the line or from faults at extreme long distances.

(b) fault detection to be carried out efficiently with a transmitted pulse of low voltage so that the risk of excess interference (crosstalk) into radio and wire communication systems is much reduced. Under normal conditions the amplitude of the transmitted pulse is 3 Volts, but amplitudes of up to 100 V may be used where the risk of interference is small (for instance, on single submarine cables).

A further advantage of the hybrid arrangement is that a faulty line may be balanced with an identical fault-free line. The echoes reflected from identical irregularities in the two lines will cancel in the hybrid, and the trace on the Cathode Ray Tube will, therefore, show the points of differences only between the two lines. This is a very powerful approach to the location of faults on lines of very complex and irregular composition. The method may also be used for such problems as the location of splits in cable pairs (see Ref. 5).

Variable Line Impedance: Three different line impedances, namely, 600, 150 and 70 ohms, are obtainable by means of a switch. This enables the appropriate matching of the instrument to a large variety of lines, so that misleading effects caused by "ghosts" or "re-echoing" are minimised (see Figs. 5 and 6). A variable compromise network covering the range from a few ohms to about 1,500 ohms is provided.

Separate Echo Trace and Marker Trace: The display of the echoes and the markers on separate traces ensures that echoes are not obscured by coincident or near-coincident markers. Of even greater significance is the fact that the markers are displayed on a straight trace, enabling them to be readily seen and counted. In instruments having the markers superimposed on the received echoes, it is often necessary to reduce the amplitude of the echoes in order to be able to recognise and count the markers.

20/100 Microseconds Marker Pips: The markers are displayed in such a manner that a short "spike" appears on the marker trace every 20 microseconds and a longer "spike" every 100 microseconds. The markers thus appear in the form of a rule, the "small" divisions being 20 microseconds and the "large" divisions 100 microseconds apart. The 20 microsecond markers enable accurate close-range locations to be made. In case of locations at long range the 20 microsecond markers are too close together to be conveniently and accurately counted without the assistance given by the emphasis on every fifth marker. The camera-recorded Line Echo Traces shown in Figs. 3-18 illustrate these points.

CAMERA-RECORDED LINE ECHO TRACES

The following series of camera-recorded Line Echo Traces and explanatory notes illustrate the application of the instrument to some typical and some extreme cases. In order to minimise the possibility of a poor photographic quality due to "noisy" traces, the pulse voltages used throughout were higher than normally used for visual location, and, as a consequence, the "Receive Gain" settings are correspondingly lower.

The line details quoted in the following have been taken from trunk line maps. Echo times have been calculated from these details using the "typical" echo times listed in the handbook (Ref. No. 4, p.8). The trunk line maps used do not give details of the extent to which loaded cables have been built-out, and an allowance of 5 microseconds has, therefore, been made to cover the "average" building-out of each 3-channel loaded cable section. No allowances have been made for the echo time of crosstalk suppression filters, since the lines tested were not equipped with such filters at the time of testing.

(a) Composite Cable and Open-Wire Lines Incorporating Filters, Loaded Cable, Unloaded Cable, Matching Transformers, etc. (Line Echo Traces, Figs. 3-8.)

The traces shown result from tests on the Gippsland route radiating from Dandenong. The lines under test were made up by patching individual lines together as required.

The lines are of varied nature and include such items as:

Balanced Cable Pairs, unloaded;
Balanced Cable Pairs, carrier loaded;
Open-Wire;
Auto and matching transformers;
33 Kc/s HP and LP Carrier Filters.

The settings on the instrument were, except where otherwise stated:

Pulse Voltage: Strapping: High
Switch: X 10
Pulse Width: 31 Kc/s
Line Imp.: 600 ohms
Int./Ext. Net: Internal
Net: 600 ohms (+2 μF)

All tests were carried out from Dandenong.

The details of the lines and calculated echo times are given in Tables I and II.

(b) Long VF-Loaded Lines (Line Echo Traces. Figs. 9-12).

The results of tests on loaded cable are best interpreted if the cable with its loading coils is considered as a low-pass filter, the loading coils being the series inductors, and the capacitances of the

(Continued on page 335)

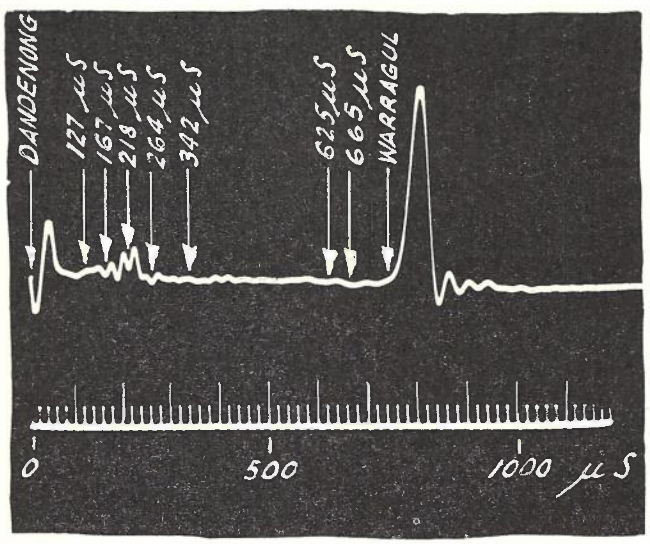

Fig. 3.—Dandenong-Warragul, Composite Cable and Open-Wire.

This line is used as bearer-circuit for a 3-ch. Open-Wire Carrier Telephone System operating on the 32 kc/s low-pass circuit whilst a 12-ch. Open-wire system operates on the 32 kc/s high-pass circuit. The tests were made on the 32 kc/s low-pass circuit (line No. 1375).

The receive gain was set at a value ("1") suitable for the location of the open-circuit at Warragul. A number of "normal" impedance irregularities are discernible along the line and may be correlated with the details of the line as given in Table 1. A higher setting of the receive gain would have caused more irregularities to be discernible.

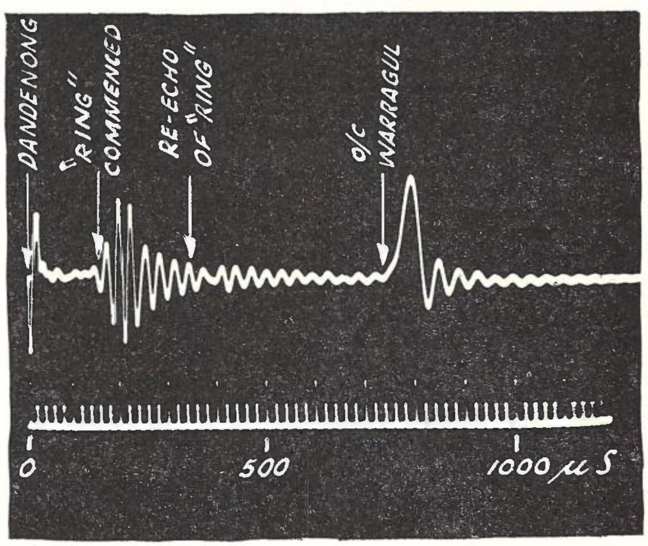

Fig. 4.—Dandenong-Warragul, Composite Cable and Open-Wire.

As for Fig. 3, except that the pulse bandwidth has been (incorrectly) increased from 31 to 62 kc/s. This has resulted in ringing in the 32 kc/s low-pass filters, making it difficult or impossible to detect echoes from the following section of the line. The ringing is similar to that which would have resulted from the use of a sharp-cornered pulse. The ringing commences at the far-end of the 32 kc/s low-pass filter that is at 167 μS. Note that one complete cycle of the ring occupies 33 μS, corresponding to a ringing frequency of about 30 kc/s, thus confirming the presence of a LP-filter with a cut-off near 30 kc/s.

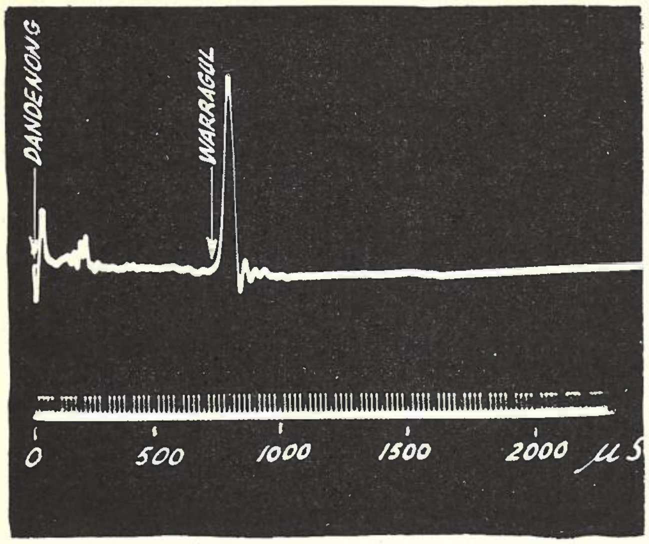

Fig. 5.—Dandenong-Warragul, Composite Cable and Open Wire.

As for Fig. 3, except that the Time Base has been altered from 1000 μS to 2000 μS, and the Receive Gain has been altered from a setting of "1" to a setting of "2".

The trace may, perhaps, with the exception of the long time base used, be described as quite normal. It has been included only to enable a comparison to be made with Fig. 6, which illustrates the effects of an inappropriate setting of the "Line Impedance" switch.

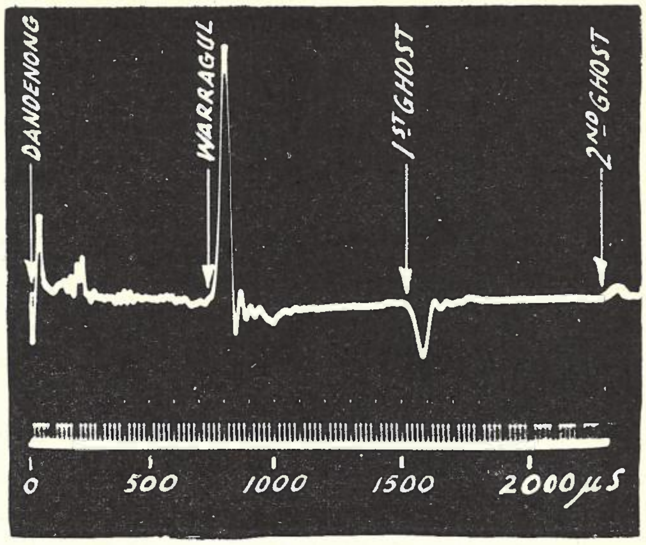

Fig. 6.—Dandenong-Warragul, Composite Cable and Open Wire.

As for Fig. 5, except that the setting of the "Line Impedance" switch has been changed from 600 to 70 ohms. The impedance of the line under test is 600 ohms. There is thus a large mismatch (resulting in large reflections) at both ends of the line (70 ohms versus 600 ohms at Dandenong and 600 ohms versus an open-circuit at Warragul), resulting in the test pulse being reverberated between the two ends of the line. This reverberation or re-echo effect results in ghosts being displayed at 2, 3, 4 . . . times the distance to Warragul.

The first and second ghosts are clearly visible in Fig. 6, whilst the first ghost only is just discernible in Fig. 5.

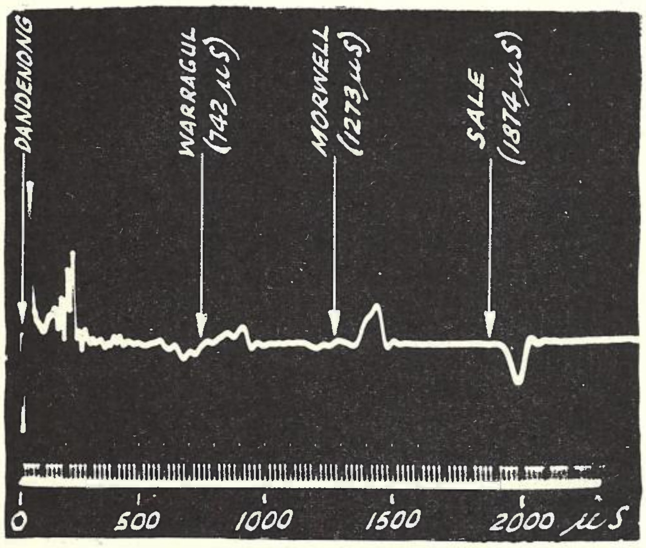

Fig. 7.—Dandenong-Warragul-Morwell-Sale, Composite Cable and Open Wire

The Dandenong-Warragul Section of the line is the same as in Figs. 3-6. The Warragul-Morwell-Sale line is of similar composition. The line details appear in summarised form in Table II. A short circuit is applied to the line at Sale.

Receive Gain: "1".

The major irregularity just past Morwell correlates with the distance calculated to a point where a fairly severe impedance irregularity may be expected from matching an unloaded cable pair to an Open-Wire Line by means of auto-transformers.

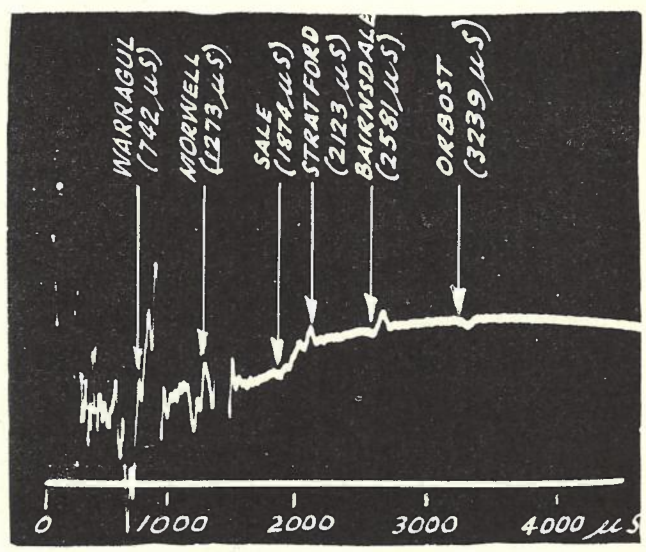

Fig. 8.—Dandenong-Warragul-Morwell-Sale-Stratford-Bairnsdale-Orbost, Composite Cable and Open-Wire.

The particulars of the line are given in Table II. The line is short-circuited at Orbost.

Receive Gain: "3".

The echo times calculated in Table II agree well with the echo times displayed. It will be noted that, although the route distance Dandenong-Orbost is 215 miles, the total echo-time is 3239 μS corresponding to almost 300 miles of pure open-wire line.

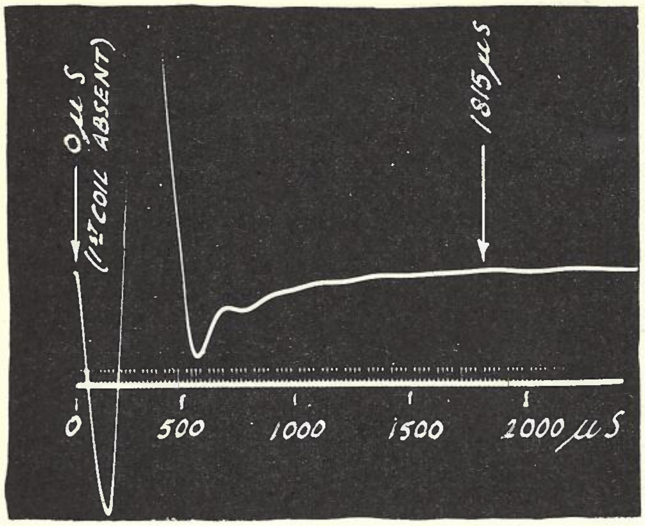

Fig. 9.—VF-Loaded Cable, 1st Coil Absent.

Note that the leading edge of the downward echo commences virtually right at the beginning of the trace. It is followed by an upward swing and a heavily damped oscillation. This upward swing and the damped oscillation is encountered whatever coil is absent, but the damping is decreased the further the coil is removed from the testing end, see also Figs. 10-12.

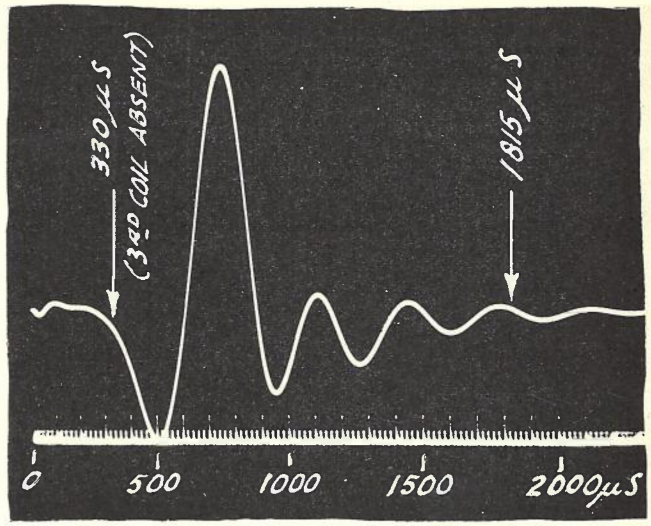

Fig. 10.—VF-Loaded Cable, 3rd Coil Absent.

It is not possible to determine exactly at which point the downward echo commences, but of the three possible choices (see Table III) of 165, 330 and 495 µS, there is little doubt that the 330 µS point is the best choice. This confirms the absence of the 3rd coil.

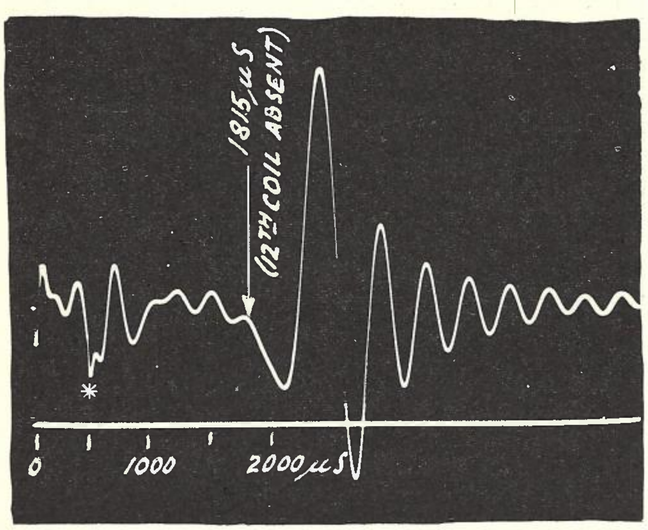

Fig. 11.—VF-Loaded Cable, 12th Coil Absent.*

The excursion of the traces at the point marked with an asterisk on Figs. 11 and 12 is not due to echoes from the line, but due to a resonance effect at the trailing edge of the transmitted pulse. (The pulse bandwidth of the pulse used is 4 Kc/s, corresponding to a pulse length at the half amplitude points of 250 µS. The length measured at the base of the pulse is consequently 500 µS in agreement with the fact that the excursion commences at the 500 µS point on the trace.)

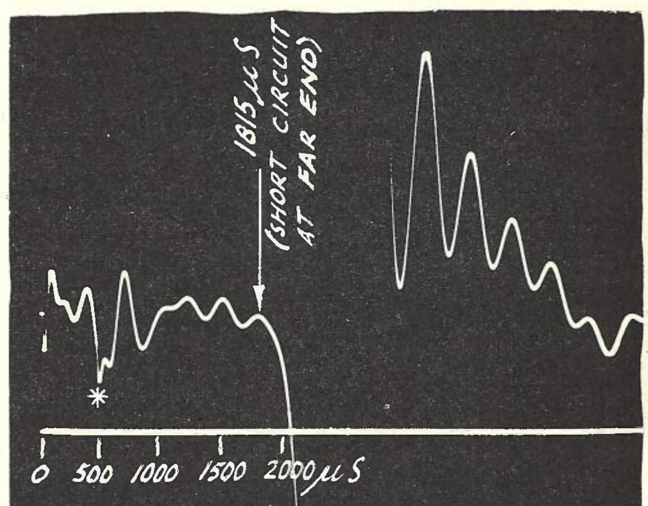

Fig. 12.—VF-Loaded Cable, Far-end Short Circuited.*

Illustrates that the downward echo caused by a short circuit at the far-end of the line is situated at the same point (1815 µS) as the downward echo due to the absence of the last coil (No. 12 coil). The echo due to the short circuit is, however, of much greater amplitude than that due to the absence of the last coil.

*Marker pips were lost in the reproduction of both Figs. 11 and 12.

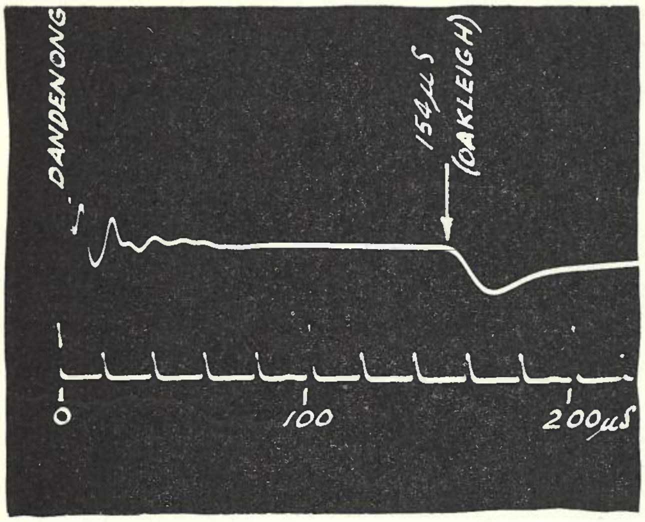

Fig. 13.—Dandenong-Oakleigh, 10.15 mile Unloaded Cable-pair.

The cable is a 20lb/mile, Multiple-Twin type cable. The "Line" terminals of the instrument were connected to one pair (Pr. 34). and the "Net" terminals to another pair (Pr. 31). When connected in this manner, the echoes from identical impedance irregularities in the two pairs cancel out and echoes are displayed only if the impedance irregularity at the point considered is not the same in both lines.

The trace illustrates typical differences between the impedance irregularities in two cable pairs (Receive Gain Setting "2"). At Oakleigh the "Net" pair is terminated in its normal repeating amplifier and the "Line" pair is short-circuited, hence Oakleigh is clearly discernible.

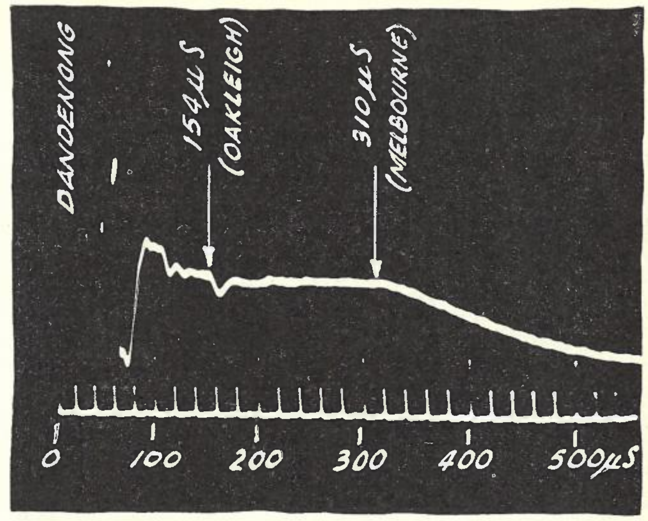

Fig. 14.—Dandenong-Oakleigh-Melbourne, 20.52 Miles Unloaded Cable Pairs.

The Dandenong-Oakleigh Sections (as in Fig. 13) were patched (clear of the amplifiers) to Melbourne; the Oakleigh-Melbourne sections consisting of 10.37 miles of 40 lb/mile, Multiple-Twin type cable.

Connections to the instruments are as in Fig. 13. The Receive Gain Setting has been increased from "2" to "6". The "Line" pair is short-circuited at Melbourne, whilst the "Net" pair is open-circuited.

Note that the higher receive gain used has increased the amplitude of the close-in echoes by comparison with Fig. 13. A substantial echo from Oakleigh is probably caused by differences in the wiring of the two pairs in that office.

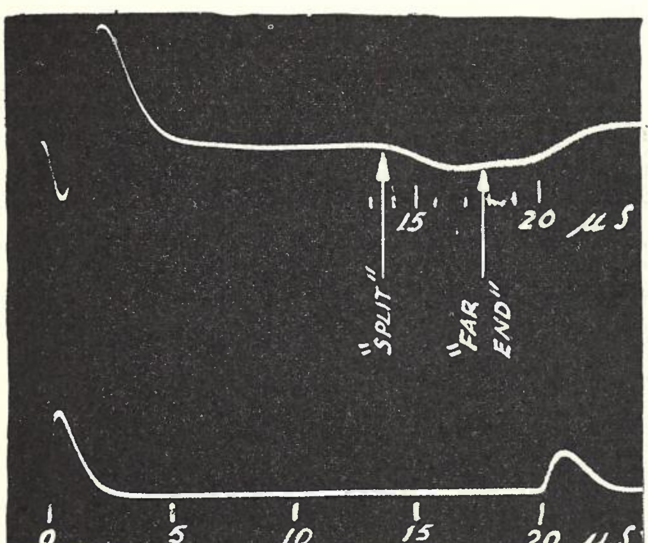

Fig. 15.—Split Pair in Short Non-loaded Cable.

Test object: 1.135 miles, PIQL Cable (Split from ¾ x 1.135 mile to far-end). The excursion at the start of the trace is due to the unbalanced manner in which the instrument is connected to the two pairs. The magnitude and shape of this excursion varies with the type of connection made to the pairs.

The far-end of the quad is evident from the bend on the trace commencing at the 17.7 µS point. The split is evident from the bend on the trace commencing at ¾ x 17.7 = 13.3 µS. The Receive Gain was set at "6" and the Time Base: 20 µS.

All wires of the two pairs were left open-circuited at the far end. By connecting two or more wires together at the far-end a clearer echo may often be obtained.

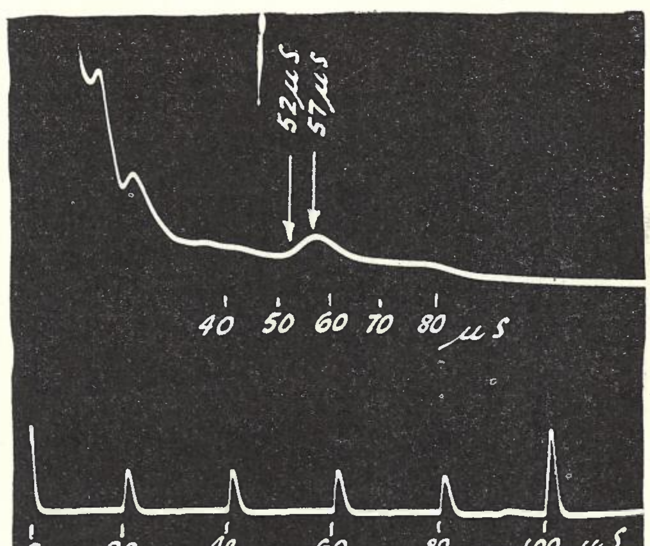

Fig. 16.—Split Pair in Short Non-loaded Cable.

Test object: 4 x 1.135 mile PIQL Cable. (Split from 2¾ x 1.135 to 3 x 1.135 miles).

The echo-time to the far-end, as determined by a separate test is: 76 µS. The splits are evident from the bends on the traces commencing at : ¾ x 76 = 57 µS and 2¾/4 x 76 = 52 µS.

Due to the slowing-down effects the echo time of 76 µS is slightly larger than would be expected from the measurement on the 2 x 1.135 mile length (36.4 µS).

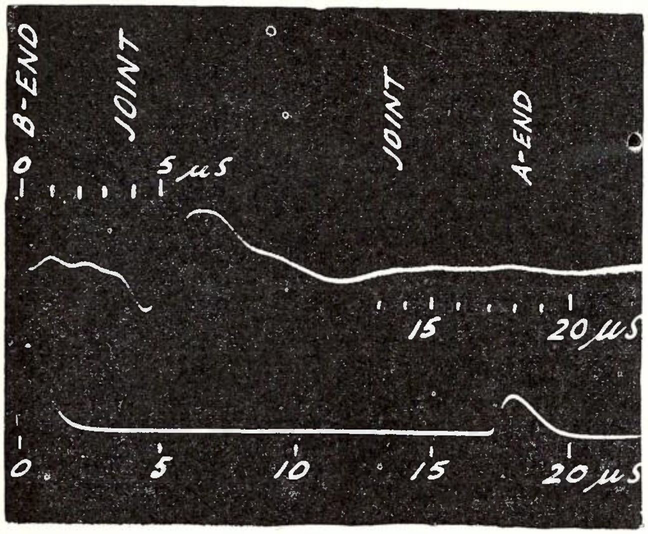

Fig. 17.—Near-end Crosstalk Location in Short Non-loaded Cables.

Crosstalk from Phantom 43/44 into Phantom 49/50.

Crosstalk at the B-end joint is clearly displayed. Opening the joint it was found that the two quads concerned had been joined with some slack, and instead of lying neatly in their appropriate positions, they crossed at two points inside the joint. Before closing the joint, each of the quads concerned was wrapped individually over the length of the joint with metallised paper recovered from old capacitors, and care was taken to ensure that the quads were put back into their "incorrect" position. (See Fig. 18).

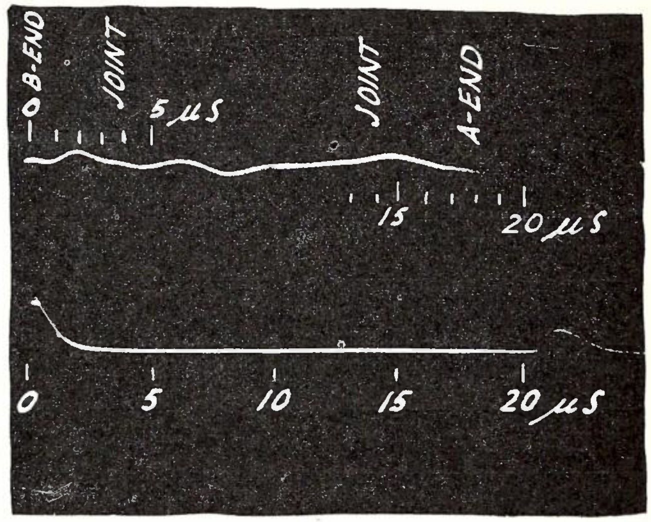

Fig. 18.—Near-end Crosstalk Location in Shore Non-loaded Cables.

As Fig. 17, but after screening the quads in the B-end joint. The large reduction of crosstalk at this point is apparent. For comparison the following near-end crosstalk attenuations (ratio in db between transmitted and received powers) were measured at 550 kc/s.

	Before Screening	After Screening
Near-end Crosstalk, A-end	97 db	95 db
,, ,, , B-end	86 db	105 db

(Continued from page 331)

sections of cable between the coils being the shunt capacitances of the filter. This means that in most cases it is possible only to pin-point a fault to a particular loading coil or capacitance (the capacitance representing about 2,000 yards of cable in the case of VF-loading).

Table I. Line Details, Dandenong-Warragul, and Calculated Echo Times.

	Cumulative Echo-times µS
1.52 miles 3-Ch. loaded entrance cable from Dandenong Office, echo-time 1.52 × 80 = 122 µS	122
Allowance for Building-out, 5 µS	127
33 Kc/s Line Filter (LP-Sect.), 40 µS	167
4.55 miles Open Wire Line to Pole L 117, 4.55 × 11.2 = 51 µS	218
3.98 miles Open Wire Line to Beaconsfield, 3.98 × 11.2 = 46 µS	264
6.96 miles Open Wire Line to DISQ-cable section, 6.96 × 11.2 = 78 µS	342
119 yards (0.07 miles) DISQ-cable	343
25.21 miles Open Wire Line to Cable Pole at Warragul, 25.21 × 11.2 = 282 µS	625
33 Kc/s Line Filter (LP-Sect.) at Filter-hut, 40 µS	665
0.91 miles 3-Ch. loaded entrance-cable into Warragul, 0.91 × 80 = 73µS	738
Allowance for Building-out, 5 µS	743

Total Route mileage: approximately 43 miles.

Faulty loading coils or a point where a loading coil is missing can thus be pin-pointed directly. Similarly, faulty cable-sections (the length of cable between two loading coils is here referred to as a cable-section) may be pin-pointed directly, but if it is desired to locate a fault on a particular section, it is necessary to get direct access to that section of the cable, and locate the fault in the same manner as for unloaded cables.

In order to obtain a reliable location it is imperative that the operator knows from experience or from a study of recorded traces and the circumstances under which they were recorded, the appropriate setting of the "Receive Gain" control. The following series of traces provides this information for the location of a point where a loading coil is missing on VF-loaded cable. For the location of faults on other types of cable, the necessary operating experiences may be acquired on a model of the loaded cable, the model being a low-pass filter, in which loading coils of the appropriate type are used as series-inductors, and the shunt-capacitances being fixed capacitors of the appropriate value (associated with resistors to account for the resistance of the cable-pair).

The traces presented in the following are from tests on a 10 lb./mile P.I.Q.L. cable, mid-section loaded by 88mH coils spaced 6,000 feet (corresponding to 0.087 µF and a loop resistance of 200 ohms). The following instrument settings were used:

Pulse Voltage: Strapping: High
Switch: Normal
Pulse Width: 4 Kc/s
Line Imped.: 600 ohms
Receive Gain: Settings given in Table III
Time Base: Settings given in Table III
Ext./Int. Net: Ext.
Net: The network given in Fig. 2, page 6, of the Instruction Book (Ref. No. 4) was used
Test Object: Cable-pair as detailed above, having a total of 12 loading coils, that is, a length of 12 × 6,000 ft. = 24,000 yds. = 13.65 miles. The far end is terminated in a second network to Fig. 2, page 6, of the Instruction Book

The line echo traces shown illustrate the echoes caused by the absence of loading coils at various distances from the testing end of the cable. It should be noted that short-circuited turns or incorrect poling of the two halves of the loading coil cause an echo virtually identical to that caused by the coil being absent. This is due to the fact that short-circuited turns and incorrect poling render the coil virtually ineffective, that is, equivalent to the absence of a coil.

When a coil is ineffective (or absent) two cable-sections are joined together, and the resultant capacitance in the low-pass filter is twice that of the normal capacitance. This results in an apparent lowering of the impedance at that point in the filter. A low impedance causes a downward echo (this compares with the fact that a short-circuit causes a downward echo). The downward echo is followed by a damped oscillation caused by resonances in the filter.

The leading edge of the downward

Table II. Line Details, Dandenong Orbost, and Calculated Echo Times.

	Dandenong-Warragul, Line 1375		Warragul-Morwell, Line 1375		Morwell-Sale, Line 1377		Sale-Stratford, Line 6350		Stratford-Bairnsdale, Line 6350		Bairnsdale-Orbost, Line 6350		Dandenong-Orbost, Totals.	
	Length Miles	Echo-time μS	Length Miles	Echo-time μS	Length Miles	Echo-time μS	Length Miles	Echo-time μS	Length Miles	Echo-time μS	Length Miles	Echo-time μS	Length Miles	Echo-time μS
3-Ch. loaded entrance cable, 80 μS/mile	2.43	195	1.73	138	0.75	60	0.60	48	—	—	—	—	5.51	441
Average allowance for building-out : 5 μS	2 off	10	2 off	10	1 off	5	1 off	5	—	—	—	—	6 off	30
32 Kc/s Line filters, each 40 μS	2 off	80	2 off	80	2 off	80	2 off	80	2 off	80	—	—	10 off	400
D.I.S.Q. cable, 15 μS/mile	0.09	1	0.01	—	0.01	—	0.01	—	0.01	—	—	—	0.13	1
Transformers, each 1 μS	—	—	—	—	2 off	2	—	—	—	—	2 off	2	4 off	4
Unloaded Cable, 18 μS/mile	—	—	—	—	1.62	29	—	—	—	—	1.46	26	3.08	55
Open-Wire Line, 11.2 μS/mile	40.70	456	27.04	303	37.95	425	10.35	116	33.74	378	56.25	630	206.03	2308
Route Distance (Miles) and Echo Time (μS)	43.22	742	28.78	531	40.33	601	10.96	249	33.75	458	57.71	658		
Cumulative Route Distances and Echo Times			72.00	1273	112.33	1874	123.29	2123	157.04	2581	214.75	3239		

echo is used to identify the point where the coil is missing. If the first coil is missing, Fig. 9, the leading edge of the resulting downward echo is situated right at the beginning of the trace. If the 12th coil is missing, Fig. 11, the leading edge of the downward echo is situated at approximately 1815 μS. Thus the leading edges due to the absence of any of the 12 loading coils may be expected to be situated at intervals of $\frac{1815}{12-1} = 165$ μS.

The distances thus calculated to the leading edge of fault-echoes caused by the absence of loading coils are quoted in Table III, together with a reference to the appropriate Figure, Time Base speed and setting of the Receive Gain control.

Consequently, when looking for the point where a coil is missing it is only necessary to determine at which multiple of 165 μS the leading edge of the downward echo is situated. (Note: A somewhat different figure may apply to other types of VF-loading.)

(c) Long Unloaded Cable Lines. (Line Echo Traces, Fig. 13 and 14.)

The traces shown result from tests on unloaded pairs (used for programme transmission) in the Dandenong-Melbourne trunk line cable.

The settings on the instrument were:
Pulse Voltage: Strapping: High
Switch: X 10
Pulse Width: 250 Kc/s
Line Imped.: 140 ohms
Int./Ext. Net: External

All tests were carried out from Dandenong Trunk Test Board.

(d) Split Pairs in Cable Lines. (Line Echo Traces, Figs. 15-16).

For the location of the point(s) where a split occurs in a cable pair, special use is made of the inbuilt hybrid in the locator.

For the purposes of explanation, the four wires of the quad suspected for split pairs are referred to as W1, W2, W3 and W4. This numbering does not necessarily agree with the usual numbering: 1, 2, 3 and 4 of the wires in a quad.

The "Line" terminals of the PET 100

Table III. Location of Absence of Loading Coils in VF Loaded Cable.

Absent Coil Number	Distance in μS to leading edge of echo	Fig. No.	Time Base in μS	Receive Gain
1	0	9	2000	3
2	165		,,	,,
3	330	10	,,	,,
4	495		,,	,,
5	660		,,	,,
6	825		,,	,,
7	990		,,	,,
8	1155		,,	,,
9	1320		,,	,,
10	1485		4000	6.5
11	1650		,,	,,
12	1815	11	,,	,,
Far end short-circuited	1815	12	,,	,,

will be referred to as L1 and L2, the "Net" terminals as N1 and N2 (it is immaterial which terminal is designated "1" and "2"). The "Int./Ext. Net" switch is thrown to "Ext."

To carry out tests the following connections are made:

Connect Terminal L1 to W1
" " N1 to W1
" " L2 to W2
" " N2 to W3

No connection is made to W4.

This scheme of connection is in the following indicated by: "W1-2 versus W1-3". When connected in the above fashion the echoes returned from the impedance irregularities at the point(s) of the "split" will add in the instrument to produce a well-defined echo. (Note: The magnitude of the echo from the split varies somewhat with the choice of W1, W2, W3 and W4, and it may therefore be opportune to try various combinations of connections.)

The settings of the instrument were:

Pulse Voltage: Strapping: High
Switch: Normal
Pulse Width: 1000 Kc/s
Line Imped.: 140 ohms
Int./Ext. Net.: Ext.

The line echo traces shown were obtained from tests on a 10 lb./mile P.I.Q.L. cable of length 2,000 yards (1.135 miles). Where greater lengths were desired, such 2,000-yard pairs were connected in tandem as required. The cable consisted of a 500-yard length joined to a 1,000-yard length which, in turn, was joined to another 500-yard length.

A normal echo test (trace not shown) gave the following results:

2,000 yards (1.135 miles)

Wires 1 and 2 (that is, a pair): 18.2 μS.
Wires 1 and 3 (that is, a wire from each of the two pairs): 17.7 μS.

4,000 yards (2.27 miles)

Wires 1 and 2 (that is, a pair): 37.3 μS.
Wires 1 and 3 (that is, a wire from each of the two pairs): 36.4 μS.

These results are illustrative of the slowing down of the pulse the further it travels. They further illustrate that the speed of propagation is not very dependent on which two wires of the quad the instrument is connected to.

(e) **Crosstalk Location.** (Line Echo Traces, Figs. 17 and 18.)

The Pulse Echo Tester may be used for location of near-end crosstalk on cable and open-wire routes. In general, the best results are obtained if the crosstalk considered is at a high carrier frequency, but useful results may also be obtained in some cases if voice-frequency crosstalk is considered. Thus, for instance, if a 1-mile length of cable is considered, the propagation over this cable is such that the wavelength of a 120 Kc/s signal is equal to the length of the cable. If now crosstalk is measured in the ordinary fashion using, for instance, a 40 Kc/s test tone, the cable length is about one-third only of the wave-length. As a consequence it is readily possible that two serious sources of crosstalk may exist at different points, but the two crosstalk paths could be of opposite phase resulting in negligible overall crosstalk. In order to obtain sufficient resolution using a Pulse Echo Tester for the location of the points of crosstalk it is necessary to use a pulse of wide bandwidth, say, 1,000 Kc/s (that is, 1 μS duration), and points of serious crosstalk would be displayed. However, due to the possibility of cancellation, the overall crosstalk at low frequencies might still be reasonably good. The same possibility exists, of course, if crosstalk at higher frequencies is considered. However, due to the substantially higher attenuation per mile and the shorter wavelength associated with the higher frequencies, cancellation is less likely to occur.

It will thus be understood that the Pulse Echo Tester is, in the main, more suitable for crosstalk location at higher frequencies than at lower, but useful results may still be obtained at the lower frequencies provided the display is carefully studied and interpreted. Indirectly the instrument may be used to locate far-end crosstalk by virtue of the fact that, particularly at higher frequencies, excess far-end crosstalk is often accompanied by excess near-end crosstalk, and detection of the latter may reveal the location of the point at which the far-end crosstalk occurs.

When used for crosstalk location, the instrument is connected on a 4-wire basis, that is, the transmitting portion of the instrument is connected to the disturbing pair, whilst the receiving portion is connected to the disturbed pair.

The following example illustrates one use made of the instrument for crosstalk location. To ascertain the practicability of a proposed new type of short-haul carrier telephone system employing line frequencies up to 550 Kc/s on junction cables (Ref. 6), crosstalk measurements were carried out at this frequency (using ordinary sine-wave methods) on selected phantoms of a 2,000-yard length of a 54 pair, 10 lb./mile P.I.Q.L. cable. The 2,000-yard length was made up by straight jointing of three lengths of 500 + 1000 + 500 yards.

Initial measurements indicated excessive crosstalk in the cableheads and associated silk/cotton tails. These were therefore removed and direct access to the cable pairs and phantoms was arranged.

A study of the sine-wave crosstalk results and of the corresponding crosstalk traces on the pulse echo tester indicated that the combinations of phantoms possessing the worst crosstalk at 550 Kc/s exhibited traces indicating the worst crosstalk couplings. The traces indicated, furthermore, that the locations of the crosstalk couplings were at the joints.

Figs. 17 and 18 give examples of results obtained.

CONCLUSION

The history of fault location employing the pulse echo principle for the location of faults on lines of relatively small bandwidths has been briefly recapitulated with special emphasis on the efforts made in Australia. This is followed by a brief description of the new versatile pulse echo tester designed to meet the specifications of the P.M.G.'s Dept. Special mention is made of the principal improvements relative to other instruments hitherto used. As a guide to some of the potential applications of the instrument, a series of camera-recorded line echo traces illustrating widely-differing applications is shown.

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(3) P. M. Hosken, The Application of Pulse Technique to the Location of Faults on Telephone Circuits, Telecommunication Journal of Australia, Vol. 7, No. 3, February, 1949.

(4) T.M.C. Instruction Book 238R. Line Fault Locator (Pulse Echo Tester), Type PET 100 (A/B).

(5) TMC Instruction Book 1-238R. Line Fault Locator (Pulse Echo Tester), Type PET 100 (A/B). Camera-Recorded Line Echo Traces.

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THE AUSTRALIAN ALUMINIUM PUBLIC TELEPHONE CABINET

*H. J. LEWIS**

INTRODUCTION

Public Telephone Cabinets are one of the three prominent structural facilities which the Postmaster-General's Department provides for public use. The other two are Post Offices and street Letter Receivers.

Not only is it essential that these facilities are efficient in their use and aesthetic in their appearance, but they must be durable and economical to provide and maintain.

This latter aspect has always presented a difficult engineering problem in regard to telephone cabinets, due to the number of variable influences such as climate, location, vandalism, and durability of materials.

In 1957, a committee was established to examine this problem and provide a cabinet suited to the Australian conditions. The original committee consisted of:—

Chairman: Mr. B. Edwards, Supervising Engineer, Telegraphs and Workshops.

Members: Mr. R. Lamb, Supervising Engineer, Melbourne Workshops; Mr. W. Murrell, Assistant Controller, Telecommunications Division; Mr. W. Waterworth, Senior Buildings Officer; Mr. A. McPherson, formerly Sectional Engineer, Telephone Equipment, now Superintending Engineer, Services, Victoria.

Mr. Edwards and Mr. Murrell have retired recently and Mr. McPherson transferred to other duties. These members have been replaced by:—

Mr. K. Smith, Sectional Engineer, Telephone Equipment.

Mr. L. Garrioch, Sectional Engineer, Workshops.

Mr. K. Richardson, Assistant Controller, Telecommunications Division.

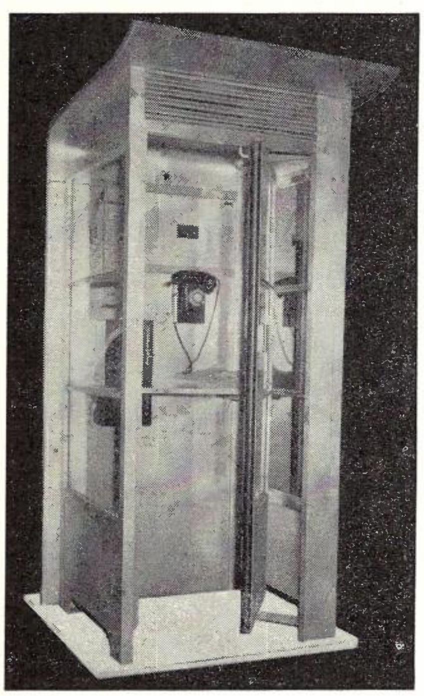


Fig. 1.—The Australian Aluminium P.T. Cabinet. This cabinet is at present installed at the corner of Spring and Collins Streets, Melbourne.

* See page 379.

PREVIOUS TYPES OF AUSTRALIAN CABINETS

Before describing the aluminium cabinet, a brief look at some of the previous designs and their weaknesses is of interest.

Early cabinets were usually built as attachments to post offices. They were made solidly with a small amount of glazing, poor lighting and ventilation, and, because of their bulk, were unsuitable for installation in residential streets. Fig. 2 shows a typical cabinet of this era.

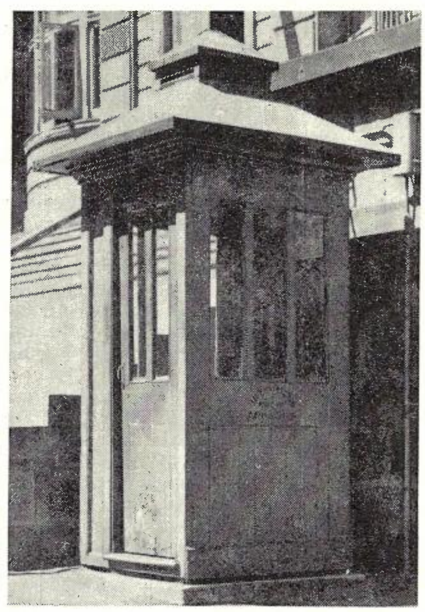


Fig. 2.—Early Wooden Half-Glazed Cabinet.

Subsequently, several designs of reinforced concrete were tried, some of which are still in existence (see Fig. 3). However, this material failed either due to corrosion of the reinforcing material, the weight of the cabinet causing subsidence of the footpath, the difficulty in repairing the concrete if damaged by a vehicle, or impossibility of moving it to a new site.

Pressed steel cabinets were also tried, but they cannot be considered successful due to the high cost of combating corrosion. In 1935, a wooden cabinet with fixed glazing in four styles was produced.

Style (a) Glazed all sides full length.

Style (b) Glazed three sides full length.

Style (c) Half-glazed all sides.

Style (d) Half-glazed three sides.

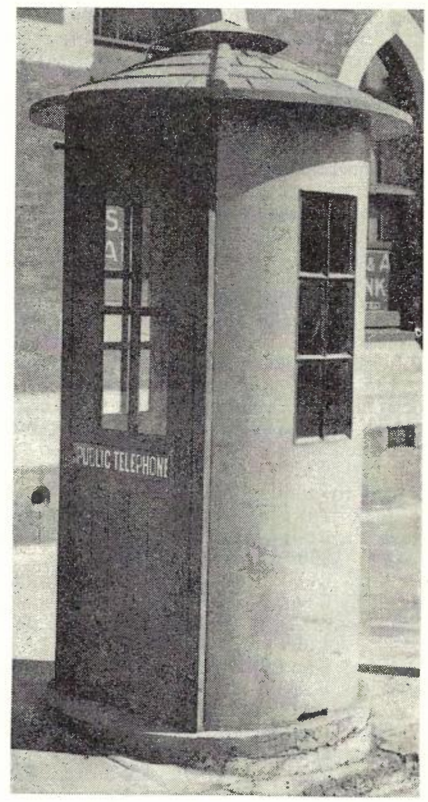


Fig. 3.—Reinforced Concrete Cabinet.

This type of cabinet originally had a hip-type roof with a lofted ventilator and wide eaves. Later models had a domed roof of either lead-covered timber, aluminium or asbestos-cement.

The cabinet was poorly ventilated, had a wooden floor which was subject to rot, particularly if the cabinet was mounted on wooden plinths and required frequent repainting to preserve it. Even so, the joinery in the lower portion of the sides and back failed due to capillary entry of ground moisture.

Many of the faults of the early wooden cabinets were reduced or eliminated in 1956, in the present wooden louvre-glazed cabinet. The wooden floor was omitted and the cabinet mounted on four metal angle brackets 1½" above the concrete floor-base. Durable timber was specified, iron-work protected, and the lighting and acoustics improved with a flush-fitting and acoustic lining in the ceiling. The louvre glazing provided most of the ventilation, and was assisted by ventilation through the ceiling and under the 1½" gap between sides and floor.

However, it is still necessary to repaint these cabinets at regular intervals to preserve their appearance and ensure long life for the joinery.

Fig. 4.—Wooden Cabinet with Fixed Glazing, Style (a).

DEVELOPMENT OF THE ALUMINIUM CABINET

In the light of this experience, the committee examined many overseas designs of cabinets, new materials (including plastics), and methods of manufacture which would allow "packaging" of a cabinet for long-distance transport.

At the outset, the requirements of a cabinet were determined by the committee, and are listed hereunder:—

Economics.
- (i) Low maintenance costs.
- (ii) Long site life.
- (iii) Low installation, transport and storage costs.
- (iv) Minimised first cost.
- (v) Restriction of types, preferably to one.

Design.
- (i) Easy to use.
- (ii) Good ventilation.
- (iii) Effective lighting, natural and artificial.
- (iv) Readily discernible to the public.
- (v) As good acoustic properties as possible.
- (vi) Door to provide protection and privacy.

Technical.
- (i) View into cabinet from at least three directions.
- (ii) Design to suit shaded locations.
- (iii) Provision for tidy and easy cable entries.
- (iv) Protection of equipment.
- (v) Easy access for coin clearance.
- (vi) Built-in notice and directory shelf.
- (vii) Cabinet to be easily cleaned.

A range of designs was prepared to enable the committee to consider this technical information in relation to both the desirable features, previously listed, and aesthetic, manufacturing, installation and usage viewpoints.

The previous practice of colouring departmental cabinets red was, by permission, departed from in the design of the new cabinet. This removed one of the main restrictions which had previously limited the improvement of cabinets. After survey of available materials aluminium was chosen as the material which fulfilled most of the requirements. This material blends well with present-day architecture, is readily procurable and workable, and offered a durable finish at reasonable cost.

Fig. 5.—Louvre-Glazed Wooden Cabinet.

The committee's first design of cabinet had a curved roof, solid back, fixed glass panelled sides and door, the latter folding into the cabinet, and a concrete base forming the floor.

Fig. 6 is an architectural sketch first depicting the new design.

Trial folding doors were fitted to wooden cabinets in service and their operation studied. Due to the strains that are placed on this type of door, the fault incidence was high and the welded joints tended to fail. It was observed that if a user had collapsed in the cabinet it was a near impossibility to gain access without dismantling or damaging the cabinet. Also, extra floor space is required for this type of door.

However, one feature which proved its worth was the partial opening of the door in its normal position. This feature has been retained on the present door but folding action has been abandoned.

A major contribution was made to the design of new cabinet by the development of a special door by Mr. L. C. Gemmell, then Sectional Draftsman of the Melbourne Workshops. The body of the door is a single panel which is pivoted on cantilever arms in such a way as to allow the door to swing inside and along the right hand wall of the cabinet. The door is stabilised and its movement controlled by an arm fixed to it and sliding in a track above the door frame. Fig. 7 shows the various positions of the door. A spring in the upper door pivot returns the door to its normal position. The door may be closed completely by a gentle push from the inside. No lubrication is required for the mechanism as Nylon is used for the bearings and slipper.

A spring at the hinge end of the guide track absorbs the opening jar of the door. The spring at the other end of the guide track normally holds the door partly open, but when the door is fully closed it acts to locate it in that position.

The aluminium-sheathed plywood used on the back and roof consists of waterproof plywood with a heat-bonded aluminium sheath. An aluminium capping, applied with aluminium screws and epoxy resin, seals the edge of the plywood. The surface of the aluminium on the inside of the cabinet is embossed with

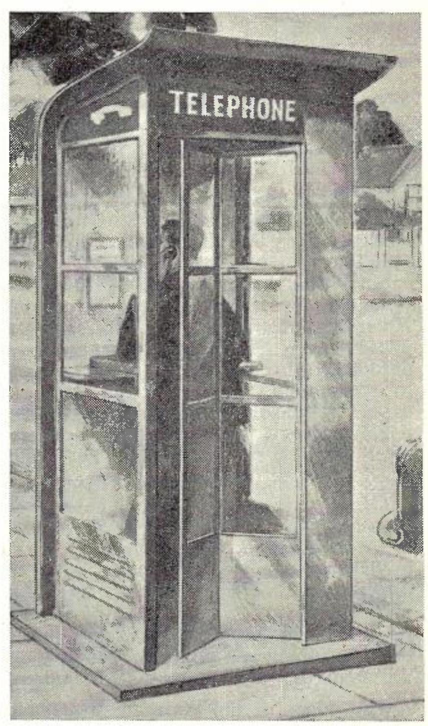


Fig. 6.—Sketch of the First Design of Australian Aluminium P.T. Cabinet.

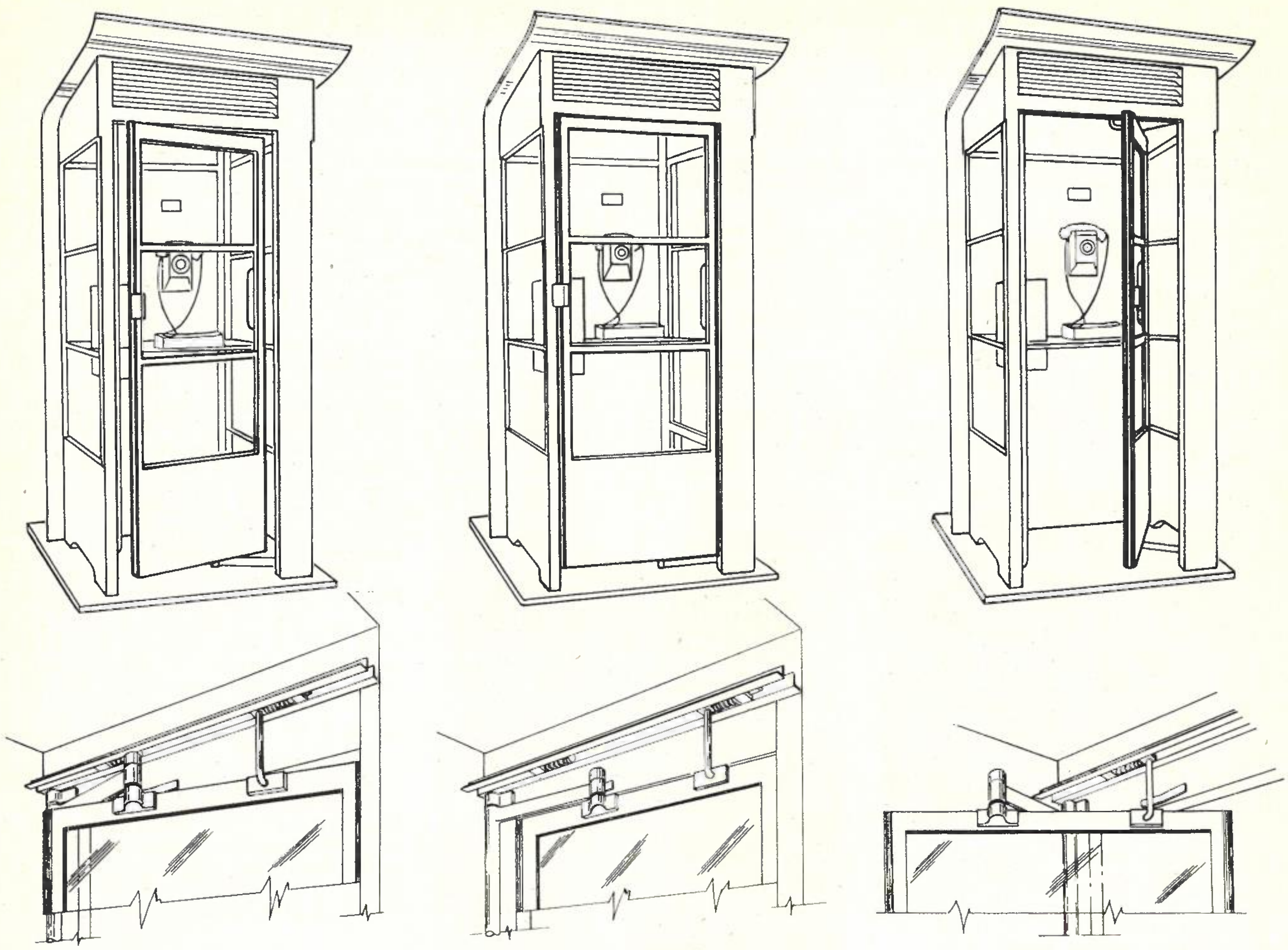


Fig. 7.—Various positions of the Gemmell Door.

(A)—Normal Position. (B)—Fully Closed Position. (C)—Fully Open Position.

a mesh pattern to restrict writing thereon, and the exterior is wire-brushed to give a satin finish.

The sides, floor, and door frame are constructed of special aluminium sections made of alloy AA 50S-T5, and ⅛″ sheet aluminium alloy AA 65S-T6. The first cabinet was made by welding these sections to form the desired framework. However, distortion was difficult to avoid and a fabricated assembly was designed, using the shapes of the sections to lock them together. The top and lower ⅛″ panels of the sides are respectively screwed and rivetted in position after the horizontal members have been fitted using self-tapping screws.

Glass in the sides and door is mounted and held in position by a "Neoprene" Strip designed for the purpose. This strip holds the ¼″ plate glass firmly but without pressure. The Neoprene strips and glass panels are held in position by aluminium strips which lock each other in turn, the final one being secured by one screw in the top strip of each panel.

The edges of the door are fitted with a rubber buffer strip. This eliminates any possibility of injury to fingers caught in between the door and the door frame. Also, it provides a weather seal when the door is closed.

The directory shelf is made of plywood with a mottled grey synthetic veneer covering on the face and edges. The shelf is mounted on right-angle brackets fixed to the back of the cabinet.

The coin attachment is mounted on a metal backplate previously screwed to the aluminium-sheathed plywood. One of the advantages of the latter material is that its wooden core provides a good medium for mounting the instrument, notice frame, ducting, etc.

Communication wiring is brought into the cabinet at ground level and runs in an aluminium duct up the right-hand back corner of the cabinet and across the back face to the wall-mounted telephone instrument and coin-attachment.

Lighting is provided, at present, by an incandescent lamp fitting centrally mounted on the ceiling. Supply wiring enters the cabinet at ground level passing up ducts in the left-hand corner of the cabinet, then across the back of the cabinet to a small switchboard, and then across to the light fitting. It is hoped to use fluorescent lighting when arrangements have been made regarding lamp replacement.

Ventilation is obtained in two ways. The door remains partly open when the cabinet is not in use and allows fresh air to continually enter the cabinet. When the door is closed, the 4″ gap between the sides and floor, and the louvre ventilator over the door, continue to provide ventilation to the user.

A fused ceramic symbol on the upper glass pane of each side provides an international notice for the public of the purpose of the structure.

Twelve of these cabinets have been made and are being field-tested throughout the Commonwealth. Six of the

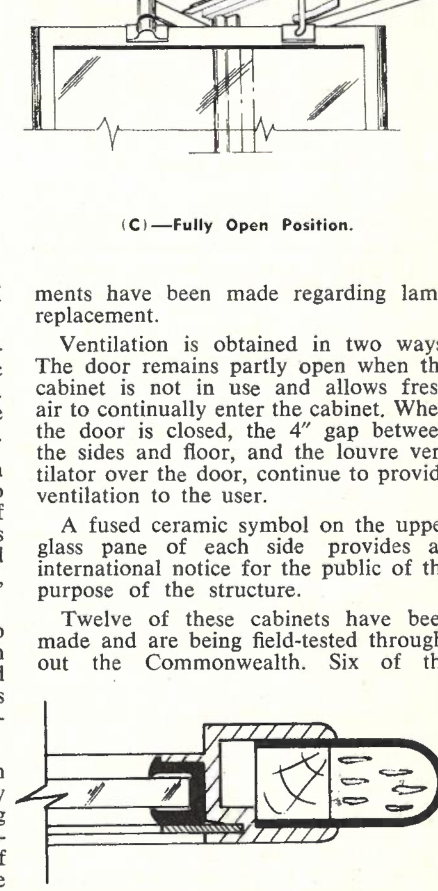


Fig. 8.—Section Through Door style showing "Neoprene" Glazing Strip Rubber and Buffer Strip.

twelve are finished with an anodised surface and the other six have a coating of Butyrate lacquer. Whilst the anodising process provides a very hard and durable surface, it is expensive and may not be justified, but the field tests will decide this matter.

PROPOSED MODIFIED DESIGN WITH FLAT ROOF

Examination of the costs of the present design of cabinet has led the committee to the development of a modified version with a flat roof without the overhanging back and roof. The louvre ventilator above the door has been omitted, and ventilation is provided by suspending the roof on angle brackets 1½" above the sides of the cabinet. Storm water is shed at the back of the cabinet.

Fig. 9 is a sketch of the proposed new model. The committee is continuing

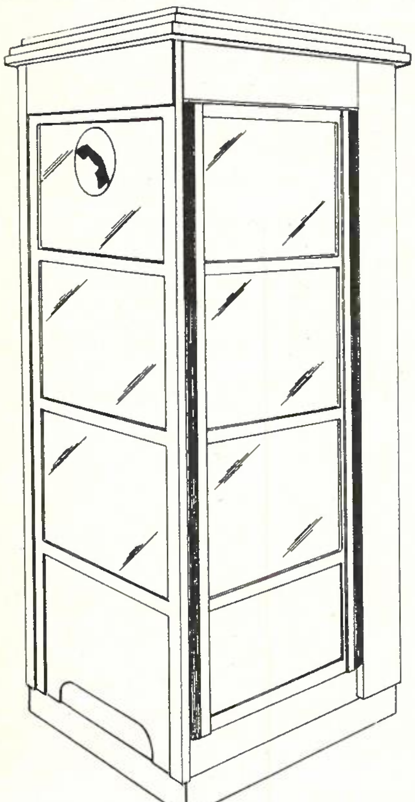


Fig. 9.—Proposed Flat-roofed Aluminium Cabinet.

development of this cabinet during the field trials of the other twelve. Reports and observations on the first cabinet have indicated that a big step has been taken towards the design of a cabinet which will meet the requirements of Australian conditions, be a serviceable cabinet, and have minimum maintenance requirements. No doubt further improvements will be made after the field trials, and another article will be published when design is finalised.

Acknowledgment

The author wishes to thank Mr. L. C. Gemmell for his assistance in preparing this article.

P.O.A. AWARD OF MERIT

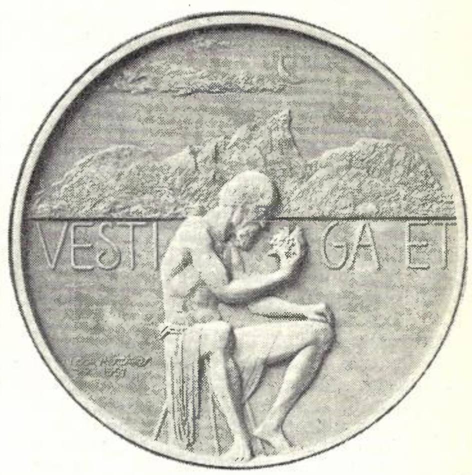
R. W. Turnbull

The Professional Officers' Association have announced that their 1960 Award of Merit has been shared by Mr. R. T. Simmons, Consultant, Commonwealth Serum Laboratories and Mr. R. W. Turnbull, Superintending Engineer, P.M.G.'s Department. The award to Mr. Turnbull is of particular interest to members of the Telecommunication Society, especially those who have followed the series of articles on the National Telephone Plan which he and his colleagues in the A.N.S.O. Committee have written in recent issues of the Journal. (Details of his departmental career appeared in Vol. 12, No. 4.)

The award to Mr. Turnbull is in recognition of the part he has played in the development of the new National Telephone Plan. The citation of Sir Mark Oliphant, adjudicator for the Award, runs as follows:—

> "The sheer complexity of the work for which Mr. Turnbull has been responsible demands a degree of technical knowledge, judgment and skill which is very impressive. The thoroughness with which the task has been done and the lucidity of its exposition deserve the highest praise.
>
> Mr. Turnbull's work is in the field of critical assessment of equipment and systems in which it is incorporated rather than in the creation of new knowledge. Nevertheless, the magnitude of the problems tackled in the Australian environment, which differs greatly from that under which the major overseas systems have been developed, and the positive success achieved, make Mr. Turnbull's work quite outstanding.
>
> It will be seen that in my view Mr. Turnbull scores heavily under the criteria which govern the Award and there is evidence of real originality in the way in which some of the conclusions have been reached."

Mr. Turnbull has taken an active interest in the Journal both as an author and as a member of the Board of Editors. It is with very great pleasure, therefore, that we now offer him our congratulations on winning this Award.



The obverse and reverse sides of the Award of Merit medallion designed by Andor Meszaros.

The obverse of the medal pictures the thinker pondering over the natural world of river, mountains and sky. Within them he perceives possibilities, and he sees visions. On the reverse stands the man of action, in full vigor of manhood, with his working drawings in his hands. The same river winds across the landscape, with a background of the structures he has brought into being. The caption, *"Vesiga et confice"*, has a meaning in accord with the scenes it accompanies; "Search into and then bring to fruition". This illustrates the dual nature of the professional man, who studies the possibilities of his raw material, and then carries his operation to completion.

WORK STUDY

*K. A. McDONALD, A.M.I.E.Aust.**

INTRODUCTION

The maintenance of a high rate of productivity and the continued improvement of that rate to increase our standard of living is the aim of both private industry and public utilities. Business managers strive to increase productivity in order to compete successfully on local and overseas markets, whilst public utilities, such as the P.M.G.'s Department, strive to give maximum service with their available funds.

A high rate of productivity has long been the concern of both industry and government in countries such as U.S.A. and, more recently, European countries such as Germany have greatly increased their productivity and, as a result, their standard of living has improved markedly. Australia's continued economic well-being and prosperity depend also on her level of industrial productivity. This high productivity is frequently considered as attainable largely through increased effort by workers, but it is management's obligation to create conditions in an organisation under which production can be increased. It is also management's obligation to protect the interests of their employees by reducing fatigue and ensuring fairness in the establishment of performance standards for workers.

Towards these ends, most of the industrial activities of man have been closely examined to produce simpler and less arduous ways of performing their work. In recent years organised studies of this kind, using specially-developed techniques, have been given a variety of names such as Work Study, Motion Study, Methods Engineering, Time and Motion Study, Methods Time Measurement, Work Simplification, Work Improvement, Organisation and Methods Investigation, Systems Study, etc. In the Commonwealth Public Service the study of office and clerical procedures and staff organisation is generally known as Organisation and Methods Investigation; the study of manipulative methods and associated procedures is known as Work Study, whereas in industry in Australia and the United Kingdom the study of all types of work, both clerical and manipulative, is generally called Work Study.

This paper attempts to explain some of the techniques used in Work Study. For this purpose the term is used to refer to the combined use of:

(a) method study to improve methods of production;
(b) work measurement to assess human effectiveness.

In this sense, Work Study is the study of work in its broad industrial setting and is primarily concerned with human work in the actual situation where it is performed, together with the associated procedures which affect such work directly.

By critically examining the present methods and organisation, Work Study ensures the best possible use of human and material resources. Whilst this technique is not the only management tool which can be used as a means of reducing costs, it is an important one because it can achieve a rapid increase in productivity without large capital investment. It is a systematic, accurate and penetrating tool of investigation.

This paper consists of an elementary description of Work Study designed to introduce the subject to persons who have had little contact with it, but who wish to gain some understanding of its ramifications. Not all of the techniques discussed in the section on Work Measurement are used by the P.M.G.'s Department nor are they all likely to be used in the near future, but they have been included to help present the subject in its true perspective.

HISTORY

We are in a period of intense interest in the problems of Management — a great deal of effort is being devoted both here and abroad to its development as a science. Much has been written about "scientific management" over recent years and Work Study has been classed as one of its tools. Two of the early pioneers of Work Study, Taylor and Gilbreth, of U.S.A., are referred to as amongst the fathers of scientific management. In fact Work Study is one of the more effective tools of this scientific approach to management in which executive action is based on quantitative analysis.

Frederick W. Taylor (1856-1915), who held a variety of positions in the steel industry in the U.S.A. before qualifying as an Engineer (M.E.), added the study of management to his other pursuits and wrote books on a variety of subjects from "the art of cutting metals" to "production control". An analytical approach to operators' methods of work was developed by him and he did considerable research in the shovelling of coal and handling of pig iron at the Bethlehem Steel Company in U.S.A. Taylor's idea of forced rest periods at precise intervals between the handling of quantities of pig iron raised the daily rate by 300%. Although Taylor realised the importance of the method of performing work, his development of time study using a stop watch was misapplied by managers who used it solely to raise and set very high standards of performance, ignoring the inefficient methods and ineffective time outside the workers' control. As a result of this abuse of time study there was a rider in U.S. Federal Budgets from 1913 to 1949 preventing the use of stop watches in Government employment or in factories supplying goods on Government contracts.

Frank B. Gilbreth (1868-1924), who was originally a builder and later became an engineer, and his wife, Dr. Lillian Gilbreth, an educationalist, began investigating the performance of work at the turn of the century. Their work resulted in the development of motion study, although in the early stage it was primarily a laboratory technique. Dr. Lillian Gilbreth commenced training courses in Method Study in 1924, carrying on until this day; from the early work of Frank and herself much of Work Study has developed today. The reader may recall that these two pioneers, Frank and Lillian Gilbreth, were the subjects of the book and film "Cheaper by the Dozen". The use of Work Study has expanded immensely since then, and other techniques have also been developed.

In the twenties and thirties the emphasis was on Time Study of a sort. Management employed rate fixers to establish times, mostly incorrectly and unfairly, and these were progressively cut down. In depression years basic principles of Work Study appear to have been forgotten and it fell into disrepute. Mr. R. M. Currie, C.B.E., the leading British authority on Work Study had this to say on that period:—

"Looking back over those days we can see clearly now how little both management and men understood the importance of the attitude of mind which we nowadays call Work Study. There was a poor conception of the dignity of work; there

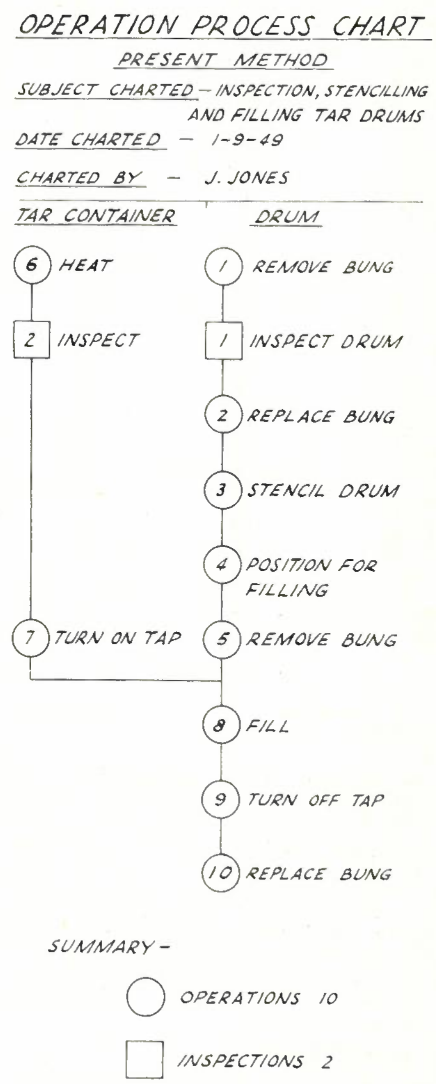


Fig. 1.—Operation Process Chart.

*See page 378

were but few reaching for justice in industry and no real attempt to extend to the widest possible horizons what has since proved to be the fastest and most economical means of increasing productivity."

After a rough start in the interval between the two world wars, the last 10 years have seen progressive managements and unions overseas actively applying Work Study as part of a plan for production improvement through new and better methods and incentive schemes. Today, in an endeavour to control costs, more Australian firms are turning to Work Study. In the U.S.A. many Universities conduct courses in Work Study, whilst in the United Kingdom the field is covered by Technical Schools, Institutes sponsored by Government and Industry, and a few Universities. There is a steady demand for training in this field in the U.K. where there are many Management Consultants applying Work Study and most larger firms are now using it. In the thirties Predetermined Motion Time Standards were developed; the most universal of these, Methods Time Measurement, originated in U.S.A. during World War II under the sponsorship of the Westinghouse organisation.

Perhaps the organisation which has done the most in this field in the U.K. is the Imperial Chemical Industries Ltd. with whom Mr. R. M. Currie, C.B.E., M.I.C.E., is the head of the Central Work Study Department. Much of Mr. Currie's work has greatly influenced the thinking in this field in Europe, England and Australia. Over recent years in Australia, the application of Work Study in industry has developed considerably, particularly since a number of unions and many people have come to understand it and, perhaps, even to trust Work Study Analysts. In the Commonwealth Public Service, "Organisation and Methods Investigation", a modification of Work Study, consisting of the use of some of the tools of Methods Study in the study of clerical and administrative procedures and organisation, has grown since 1948, when the Commonwealth Public Service Board and the Postmaster-General's Department commenced in this field. At present there are some 25 officers engaged on this work in the office of the Public Service Board and a further 100 in the Commonwealth Departments, contributing to a substantial annual improvement in efficiency and effectiveness of the Service.

INCREASING PRODUCTIVITY

Five of the usual lines of attack to improve productive efficiency are:—

(i) Improve plant and equipment by research and development;

(ii) Simplify and improve the product or service and reduce the variety;

(iii) Improve the methods of operation and degree of utilisation of existing plant, tools or mechanical aids;

(iv) Improve the planning of work and the utilisation of manpower; and

(v) Increase effectiveness of employees.

The first is a long-term policy requiring considerable capital, the second is an intermediate-term policy which may require capital, but numbers three, four and five are improvements which can require little or no capital and which can often be introduced quickly. It is in these three approaches that Work Study can play a major role.

In this paper emphasis is being laid on the techniques currently in use in Australia and England. To a large degree, as discussed above, a great deal of credit is due to Imperial Chemical Industries Ltd. (U.K.) for the development of Work Study in U.K. and similar leadership has been shown by I.C.I.A.N.Z. in Australia.

The major difficulties encountered in applying Work Study are human rather than technical. As discussed earlier in this article, the tendency to associate Work Study solely with time study or incentives has reacted against its ready acceptance by both management and workers in industry, yet time study and incentive planning are only two of the aspects of Work Study. Frequently, workers are apprehensive of and resist Work Study because of dislike of change, opposition to being timed, dislike of being watched at their work and fear of becoming redundant. Resistance to Work Study is also found at management levels. Extreme care in the establishment of Work Study in an organisation is therefore necessary to dispel this fear and a number of approaches have been developed. In England it is the practice to consult workers over such things as Work Study and to develop in them an understanding of the techniques and objectives of the subject. In fact, several Unions in the U.K. conduct their own Work Study courses. In U.S.A., Work Simplification, whereby staff participate in the development of new methods after some basic training in the elements of Method Study, is employed to gain management/worker enthusiasm for, and participation in, Work Study. Without the interest of line management and the co-operation of field staff, Work Study cannot succeed.

The two techniques embraced by Work Study are Method Study and Work Measurement. Usually, Method Study comes first and Work Measurement follows. The co-ordinated procedure is shown in chart form in Diagram A.

METHOD STUDY

Method Study, which should be the first task in Work Study, is the systematic recording, analysis and critical examination of existing and proposed ways of doing work and the development and application of easier and more effective methods. A simple systematic approach called the six-step plan has been evolved and, even in the more sophisticated Work Study techniques, it is essential that these six steps be followed with none being excluded:—

SELECT the work to be studied.

RECORD all of the relevant facts of the present method by direct observations.

EXAMINE critically those facts in correct sequence.

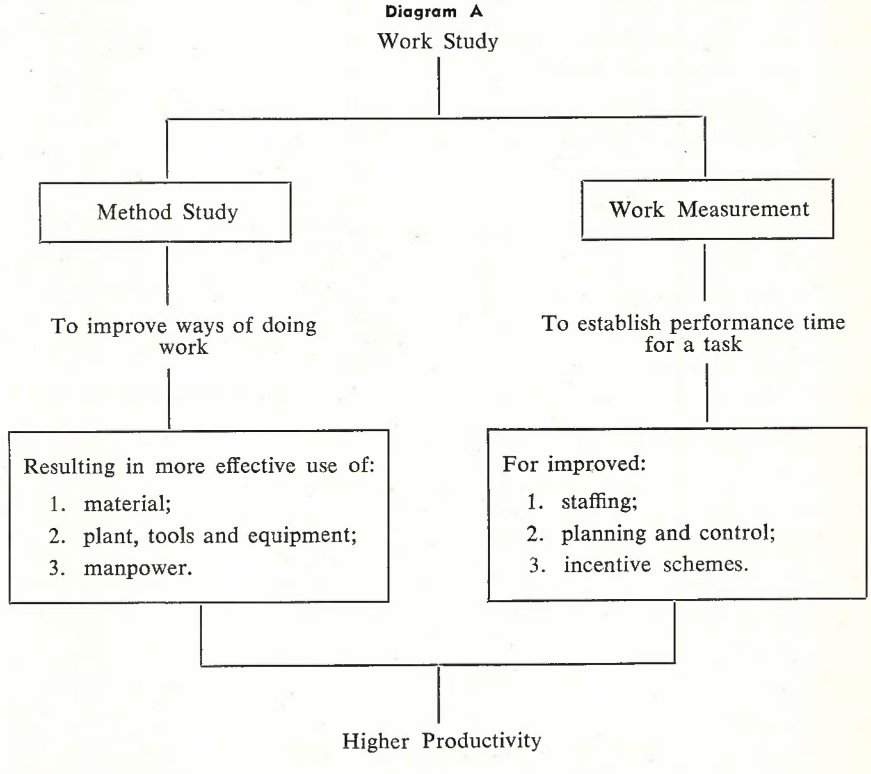
DEVELOP the most practical, economic and effective method.

INSTALL the new method as the standard practice.

MAINTAIN the standard practice by regular routine checks.

This is a simple statement of Work Study but it is also a statement of the steps followed by anyone who is critically examining any process by any means other than Work Study. The reader should not be deluded, however, into believing that Work Study is, therefore, a rather elementary technique already fol-

Diagram A



lowed by all technical people. This simplicity serves to highlight the essentially practical and thorough approach of Work Study but should not be allowed to hide the need for special training and experience for carefully selected personnel to ensure good results from its full-time application.

Selection of a process for Method Study, the first stage of the six-step plan, will be guided by technical and human considerations and economic factors, probably the most important of which is to reduce overall production costs. Factors through which overall production costs may be attacked include excessive handling and movement, improvement in safety and reduction in fatigue, poor use of labour, material and equipment, bottlenecks in production, large amounts of repetitive work, and the need to provide a better service.

Recording in Method Study is done in various forms of "shorthand" which in some cases are pictorial. The simplest charts in use employ five symbols for basic types of events into which all work can be broken down. These symbols and the various charts are amongst the basic tools of method study, but more recent developments in the field, and the early work of Gilbreth, established other symbols which have their uses in situations to be discussed later. At this stage we will confine ourselves to a discussion of the five basic symbols which, with appropriate charts, are adequate tools for extensive Method Study. These symbols are:—

○ — OPERATION — Produces or accomplishes

□ — INSPECTION — Verifies

⇨ — TRANSPORT — Moves

D — DELAY — Delays or interferes (temporary storage)

▽ — STORAGE — Holds or keeps (against unauthorised removal)

In the recording process these symbols are used on a variety of charts designed for various situations. There are different charts for recording the work done by or, if desired, done to —

1. A man
2. A piece of material
3. Gangs of men
4. Several pieces of material, showing their relative position at various stages
5. Man or material related to stations
6. Man or material movement on a plan
7. Each hand of a man
8. Interrelation of a number of men
9. Interrelation of a man and a machine.

Charts 1 and 2 are called "flow process" charts, Charts 3, 4 and 5 "multi-column or gang charts", Chart 6 "flow diagrams", Chart 7 "right and left hand charts" and Charts 8 and 9, "multiple activity" charts. These charts are usually printed and headed for easy and quick preparation.

Generally, before a specific chart on which to study the process is chosen, the process is set out in a simple form using the two symbols for operation and inspection only. This chart, called an "operation process" chart, is a graphic representation of the sequence of all operations, inspections and entry points of materials involved in a process or procedure. Such a chart, shown in Fig. 1, presents a "bird's eye view" of the whole process, highlighting the important features. It will usually indicate to the person experienced in the use of the charts the part of the process needing detailed examination and the type of chart necessary for the examination, but it is not sufficiently comprehensive for detailed analysis.

The Flow Process Chart is a graphic representation of the sequence of all operations, transportations, inspections, delays and storages occurring during a process or procedure and includes information desirable for analysis, such as time taken and distance moved. The "material type" flow process chart, shown in Fig. 2, presents the process in terms of events which occur to the material, whilst a "man type" chart presents the process in terms of the activities of the man.

The Multicolumn Chart, shown in Fig. 3, is designed to show a number of individual flows related to one another. They have their greatest application in the office where there is usually more than one copy of a document in flow at once. The several uses of this chart are:—

Multicopy — to record the flow of several copies of a document, showing their simultaneous locations

Station to Station — to record the flow of a piece of paper or a person in progress through various work stages.

Gang — to record the activities of a team of people and their relation to one another whilst engaged on a common activity

A Flow Diagram is a scale plan of the work area on which is recorded the route of a man or material between work places. This diagram is usually used to supplement another chart, such as a Flow Process Chart showing activities in detail. The symbols for the type of activity at each work place may be shown on the flow diagram.

A Right and Left Hand Chart, also called a Work Place Chart, a Two-

FLOW PROCESS CHART NO. 1 PAGE 1 OF 1

JOB: CUTTING OVER 10 WORKING JUNCTIONS

☒ MAN OR ☐ MATERIAL: TECHNICIAN MALVERN

CHART BEGINS: CABLE JOINTER STARTS NEW 10 PR.

CHART ENDS: CABLE JOINTER FINISHES SAME 10 PR.

CHARTED BY: S. STEVENS DATE: 7-6-59

SUMMARY

	PRESENT		PROPOSED		DIFFERENCE	
	NO.	TIME	NO.	TIME	NO.	TIME
○ OPERATIONS	14	7·7				
⇨ TRANSPORTATIONS	15	2·7				
□ INSPECTIONS	1	0·6				
D DELAYS	2	7·0				
▽ STORAGES						
DISTANCE TRAVELLED	·240 FT.		FT.		FT.	

	DETAILS OF (PRESENT / ~~PROPOSED~~) METHOD	DISTANCE IN FEET	QUANTITY	TIME	NOTES
1	TALK TO HAWTHORN TECHNICIAN			·28	
2	WALK TO SWITCH	50		·17	
3	IDENTIFY WITH HAWTHORN			·07	
4	WALK TO 2ND SWITCH			·21	
5	REPEAT ITEMS 3 & 4 ANOTHER 8 TIMES			2·27	
6	WAIT FOR HAWTHORN TECHNICIAN			1·00	
7	WALK TO INTER-COM. SET	50		·17	LOUDSPEAKING SET.
8	TALK TO HAWTHORN TECHNICIAN			2·41	
9	WALK TO SWITCH	50		·17	
10	IDENTIFY WITH HAWTHORN			·25	
11	WALK TO TABLE	50		·17	
12	CHECK LIST AGAINST CARDS			·57	
13	WALK TO CARD BOX	20		·07	
14	REPLACE CARDS		10	3·25	REPLACED IN PRESCRIBED ORDER.
15	WALK TO TABLE	20		·07	
16	SELECT NEXT 10 CARDS		10	·88	SELECTS FROM BUNDLE ON TABLE.
17	WAIT FOR CABLE JOINTER			6·00	
18					
19					
20					
21					
22					
23					
24					
25					

Fig. 2.—Flow Process Chart (Actual size 8" x 11")

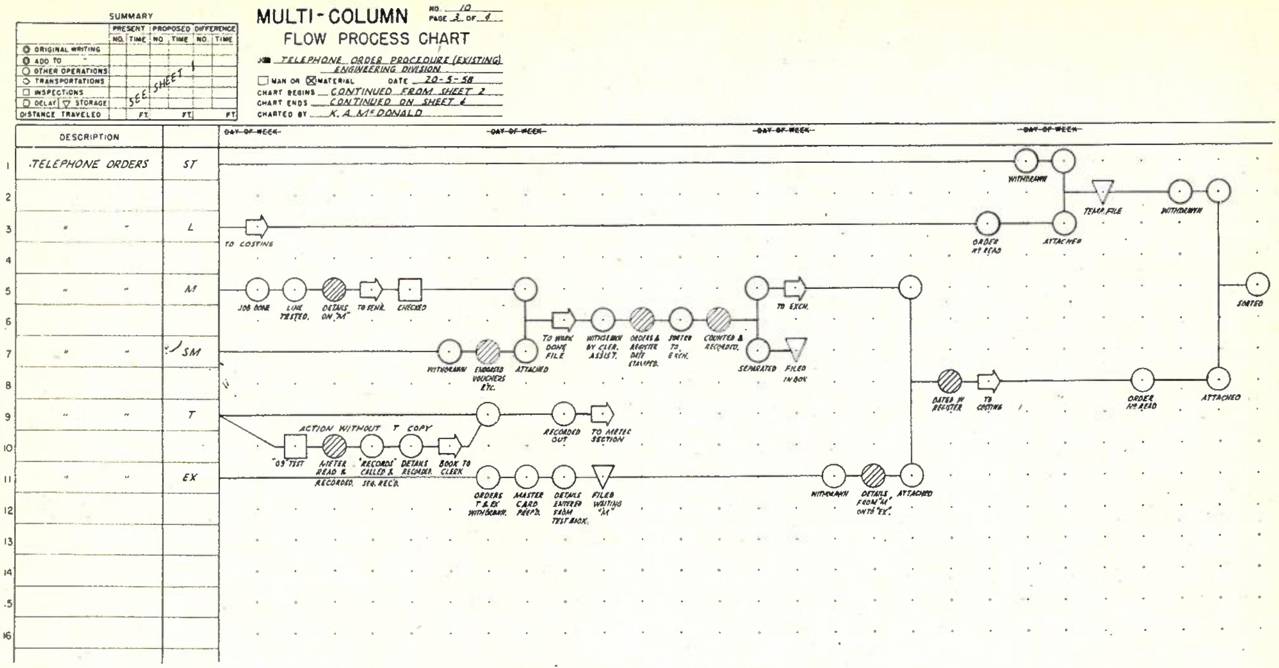


Fig. 3.—Multi-column Chart (used as Multi-copy Record), (Actual size 11" x 21").

Handed Process Chart or an Operator Chart, is shown in Fig. 4. This chart, which is used in studies of the work of a person at his work place, shows the corresponding activities of two hands and in some cases the feet. The chart uses only four symbols — ○ operation, ⇨ transport, ▽ hold (storage symbol), and D delay.

A Multiple Activity Chart, shown in Fig. 5, facilitates consideration of several simultaneous activities performed by different persons or machines. A typical operation charted in this way would be the excavation of a trench involving the activities of an operator of a compressor, a man shovelling and a truck driver, all engaged together. Similarly, it helps to distinguish between operating time of a machine when operating independently of an operator or when being operated or serviced by the operator. It is also useful to distinguish between the time when a machine is waiting to be serviced and when it is being set up, loaded or unloaded. This type of chart does not use the symbols described above but uses colours or hatching to indicate periods spent on independent work, combined work and waiting.

It will be seen from a study of completed charts that processes or procedures consist of three stages —

"Make Ready", which is the preparation of material or the work place for the work. The contribution of this stage is indirect and is considered as unproductive.

"Do" operation, which is the performance of work on the material resulting in a change in its properties or characteristics. This is a productive stage in the process.

"Put Away" operation, in which the work is moved aside, transported to the next stage, etc., after a "do" operation. Like the "make ready" operation, it is an unproductive stage.

Examination (or critical analysis), the third step of the six-step plan, will be directed firstly towards establishing the need for the "do" operations at all or in their present form and then towards similarly simplifying the unproductive "make ready" and "put away" operations, so reducing their proportion of the whole process and increasing the effective "do" content of the worker's time. This examination of the "operations" in a procedure should be made in order of their importance to the procedure. Critical examination is a careful and systematic stage in which every step is thoroughly questioned in a standard pattern. The following sequence is adhered to for each step (see Diagram B).

Primary questions indicate the facts and ensure that every facet of an existing method and the reasons underlying them are clearly understood; secondary questions indicate the alternatives from which the means of improvements are selected. This is an organised approach leaving nothing to chance, concentrating attention on particular aspects to bring up ideas and alternatives. The questions which are designed to focus attention on

Diagram B

(1) Purpose —	What is the purpose? Why is it necessary? What else could be done? What should be done?	To eliminate any step that is not essential in the process or procedure.
(2) Place —	Where is the step performed? Why is it performed there? Where else could it be performed? Where is the best place to perform it?	Re-arrange or combine to improve sequence, utilisation of skills, location of work place.
(3) Sequence —	When is it done? Why is it done then? When should it be done? When else could it be done?	
(4) Person —	Who performs this step? Why does that person perform it? Who else could perform it? Who should perform the step?	
(5) Means —	How is the step performed? Why is it performed this way? How else could it be done? How should it be done?	Simplify the operation.

This examination consists of primary and secondary questions—

e.g., Purpose —	What is the purpose? Why is it necessary?	Primary questions
	What else could be done? What should be done?	Secondary questions

the various aspects of each and every step may appear to the person inexperienced in Work Study to be absurdly interests of thoroughness of the examination and effectiveness of the end result each is extremely important. In handling the "examination stage" the analyst looks for reasons not excuses and he must distinguish between fact and opinion. Of course, at this stage the Work Study Officer must enlist the aid of everyone who may be able to help, particularly the person doing the job.

Develop New Method. — Once the questions below have been answered the Work Study Officer is able to begin developing the new method from all of the ideas which will have been listed in response to the questions —

What should be done?
Where should it be done?
When should it be done?
Who should do it?
How should it be done?

The examination stage will have indicated the need to eliminate, combine, rearrange or simplify "make ready", "do" or "put away" operations and a new process can be developed with the participation of those concerned in the work. The first step is to arrange in their correct sequence the essential "do" operations which are to remain. At this stage a knowledge of the job can greatly aid the development of a method in which the work is done by the most appropriate people, in the most convenient place and by the simplest means. During the questioning and recording stage many bright ideas will, no doubt, have been presented to the Work Study Officer and, wisely, he would have recorded them but deferred consideration until this stage, when ideas can be examined in truer perspective. By doing this the objective "critical examination" discussed above would have proceeded unhindered.

Install — Participation in development of the method by persons affected by it will bear fruits in more rapid introduction of a new process or procedure. This participation enables the Work Study Officer to incorporate in his developed method some of the ideas of the people doing the work and, through discussion, to avoid proposing changes which conflict with satisfactory existing arrangements.

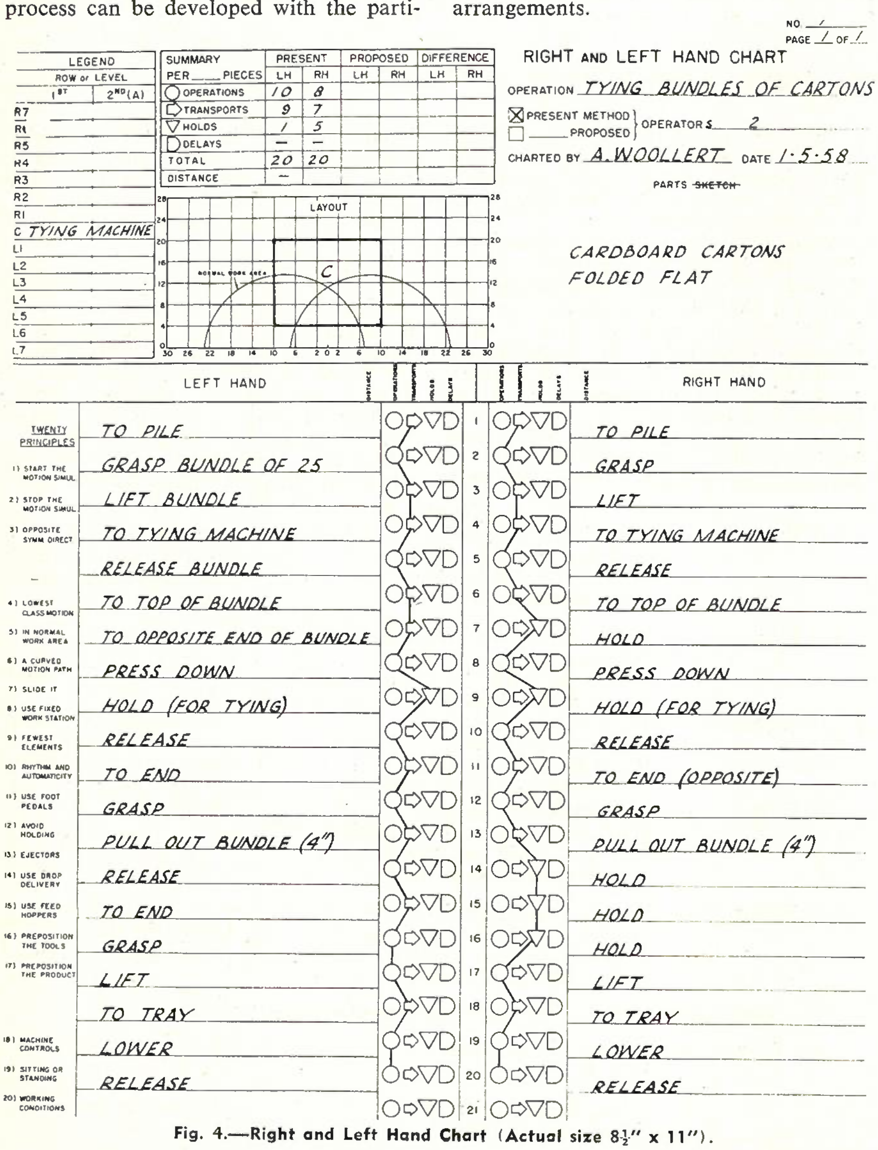


Fig. 4.—Right and Left Hand Chart (Actual size 8½" x 11").

MICROMOTION STUDY

The symbols used in Right- and Left-Hand Charts described above permit only a rather crude analysis of the motions of an operator at a work station but they simple, tedious and tiresome, but in the are quite suitable for achieving very good results where a motion pattern is not very involved. However, to study a complex motion pattern such as that found in cable jointing, automatic equipment installation and maintenance, etc., there are other more suitable techniques such as Micromotion Analysis.

Back in the early days of Work Study, Gilbreth, the founder of motion study, developed a very comprehensive list of elements of physical movements to which he assigned symbols and abbreviations and to which specific pencil colours have subsequently been allocated. These elements, called therbligs (Gilbreth spelt backwards), are shown in Fig. 6; in spite of the expansion of Work Study since Gilbreth's early pioneering work, only one change has been made to his original list. The technique using therbligs as a basis for analysis is called Micromotion Study. It uses charts, called Simo Charts, on which therbligs for each element are recorded against a time scale, the unit of which is 1 wink (1/2000 minute). Much of Gilbreth's early detailed analysis of motions in repetitive work of short-cycle duration was done by studying films of the work in progress. The examination step in motion studies using Right and Left Hand Charts, described earlier in this article, has the same aim as Micromotion Analysis using a Simo Chart and therbligs; this aim is to ensure economical use of the human body, sound arrangement of the work place and design of suitable tools and equipment. A number of principles concerning economy of movements were developed by Gilbreth and a few of the most important are as follow:

A. Start and stop hands simultaneously using symmetrical motions in opposite directions — this balance between the hands, where both are kept active. induces the least fatigue.

B. Use lowest class motions — the choice of movements involving the least possible number of body members ensures that the minimum effort is used in a job. Body movements are classified one to five as follow:

Class	Pivot	Body members move
1	Knuckle	Finger
2	Wrist	Hand and Fingers
3	Elbow	Forearm, hand and fingers
4	Shoulder	Upper arm, forearm, hand and fingers
5	Trunk	Torso, upper arm, forearm, hand and fingers.

C. Use smooth, curved motions—this type of continuous motion, preferably with a rhythmic pattern, involves minimum muscle tension and loss of time.

D. Employ natural movements — by spreading motions amongst the limbs to those best fitted to do the work, strain and fatigue is reduced.

E. Work in the Normal area (see Fig. 7) — this involves movements of No. 3 classification or lower, whilst the maximum work area is determined by movements of No. 4 classification. The area immediately in front of the operator, where the normal work area arcs overlap, is the most suitable place for operations involving both hands. Principles applied to the study of the working area include —

(1) fixed work and tool locations;
(2) prepositioned tools;
(3) prepositioned article;
(4) drop delivery;
(5) attention to seating, illumination, noise, dust, etc.

WORK MEASUREMENT

As discussed earlier in this paper, Work Study involves the co-ordinated use of Method Study to improve methods of doing work and Work Measurement to assess human and operational effectiveness; the diagram in Fig. 8 shows the relationship between the two. Work Measurement is the application of techniques designed to establish the time for a qualified operator to carry out a specified task and, by relating this to a definite standard of performance, to translate it into the work content of that task.

In the past a great deal of emphasis has been laid on the use of Work Measurement to establish time standards (performance standards) to enable management to fix incentives, but over recent years Work Measurement has been used increasingly to provide more reliable data for estimating, planning and staffing and for comparing two or more methods. Apart from these and other uses for time standards, the analysis of an operator's time spent on work serves to highlight ineffective time due to the various causes, enabling the study to be directed towards reducing these at the critical examination stage. Work measurement can, therefore, be a most useful tool in studying work of the type undertaken in the telephone engineering field. A variety of Work Measurement techniques in use include Time Study, Random Observations, Analytical Estimating, Synthesis from Standard Data, Predetermined Motion Time Standards, etc., each of which has its specific field of use and advantage.

Briefly, the approach to Work Measurement is shown in Diagram C.

Fields of application of Work Measurement include:—

- Provision of a basis of comparison for determining operating effectiveness;
- Comparison of alternative methods developed during a Work Study.
- Establishment of performance standards which can be used for:—
  - Determination of equipment and labour requirements;
  - Balancing of work of parties;
  - Measurement of actual output against possible output of staff;
  - More accurate estimating;
  - Improved scheduling;
  - Balancing of manpower and workload through effective staffing.

Before the work is measured to establish time standards for these purposes, it is important to study the work methods using the method study techniques already described, to ensure that the job is performed by the best possible method and by personnel suitably trained in the method.

Time Study, the first of the measuring techniques mentioned above, consists of measurement by direct observation using a stop watch. The much-dreaded stop watch of the past has a rather unpleasant history and it is little wonder that the stop watch user is still regarded with some fear in sections of industry today, even though most skilled Work Study Engineers use stop watches with scrupulous fairness. As far back as the nineteenth century, "ratefixers", often sworn to secrecy by the management, were using stop watches to establish some sort of performance standard for operators. About fifty or more years went by before an allowance for fatigue was added to the measured performance time to make the performance standard for the job. Very much later, around 1920, Bedaux developed a system which facilitated the estimation of a "normal" performance standard from the measurement of any operator at work; this system was based on assessment of the operator's skill and effort as the work is measured. The Time Study Officer makes a rating of the operator's speed and effort against a "normal" speed and effort and records this against the time measured for the element of work. This is called rating.

The "rating" is the comparison of the performance of an operator under observation with normal performance for a given method. Normal performance is the working rate of the average worker working under capable supervision but without stimulus of an incentive wage payment plan; it is the equivalent to a person walking at 3 m.p.h. This working pace can be easily maintained day after day without undue physical or mental fatigue and is characterised by the fairly steady exertion of reasonable effort.

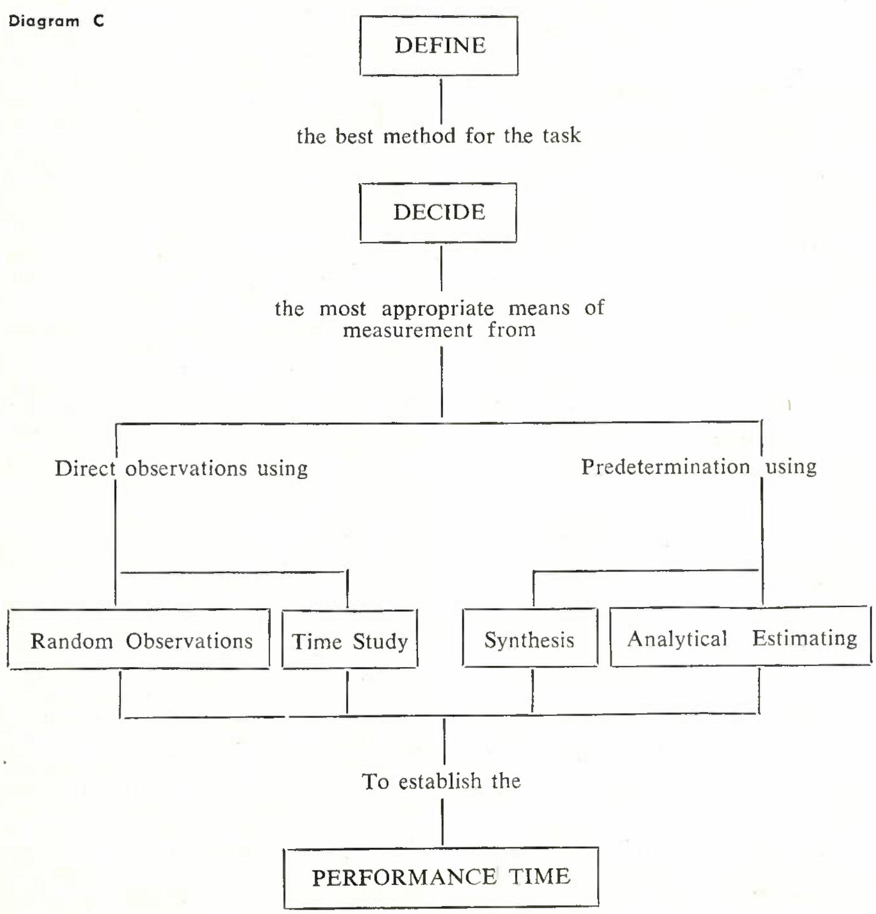
The observed time for a particular operation multiplied by the rating of the operator equals a constant for all operators. The adjusted time for a normal performance, referred to as "normalised time", is, therefore, calculated by the following method:—

$$\text{Observed time} \times \frac{\text{Rating}}{\text{Normal Rating}} = \text{Normalised time}$$

The Time Study is made by breaking down the work into elements which are convenient for being individually measured over a complete work cycle or number of cycles; each element is composed of one or two fundamental operations. The criterion is that the element time is convenient for being individually measured and that the group of motions form a true element of work in which the operator's skill and effort are not likely to vary within the element.

Various scales of rating have been developed and these include the 60/80, 75/100 or 100/133 scales, also called the 60, 75 and 100 normal scales, respectively. An average trained worker on piece work, with the stimulus of incentives, operating continuously in a brisk business-like manner, producing articles of

Diagram C



the necessary quality and accuracy, would be rated as about 80 on the 60/80 scale. Relating this to the rate of walking, for example, for which the normal or 60 level corresponds to walking at 3 m.p.h., the 80 rating is comparable to the effort expended by a person walking unloaded on level ground at 4 m.p.h.

When the elements of a job have been measured and checked over a number of work cycles, the recorded time will be adjusted or normalised by factors which depend on the rating of the operator during the study, as in the example below:—

A	B	C	D
Element No.	Rating 60/80 (Scale)	Observed Time	Normalised Time
1	70	22 secs.	25.7 secs.
2	70	15 secs.	17.5 secs.
3	65	18 secs.	19.5 secs.
4	70	21 secs.	24.5 secs.
5	65	6 secs.	6.5 secs.

The measured time for the work in a cycle (Elements 1 to 5 — Column A), consisting of the sum of the observed element times for the individual elements of work (Column C above), has no direct bearing on the expected output of an operator. Two factors are involved in the development of a performance time; the first, the adjustment of the observed time to a normalised time by the element rating, as discussed above, and the second, an adjustment of performance time to a degree which is dependent on working conditions.

An additional percentage of time is added to the normalised time in the form of an allowance for recovery from the psychological effects of expending energy and for attendance to personal needs. This variable allowance, based on an established scale, is called a Rest Allowance, and is made up of a number of separate quantities which are dependent on a variety of things such as work place conditions, temperature, type of work, sex of operator, companionship, etc. Such allowances vary from 2½% to 20% for particular conditions in extreme cases; total figures of above 20% suggest difficult working conditions. We now have a performance time for a task built up in the following manner:—

$$(1 + \text{Rest allowance } \%) \times (\text{Observed time} \times \frac{\text{Rating}}{\text{Normal Rating}})$$

It will probably be necessary to add to this adjusted time a further allowance to compensate for enforced idleness through inspection, work place cleaning, tool maintenance, etc. The extent of this allowance will be determined by observations of the process on the job.

As mentioned earlier in this article, there is a variety of techniques in use for measuring work, in addition to Time Study using stop watches, each of which is applicable to particular types of work or work situations. These are discussed in the following paragraphs.

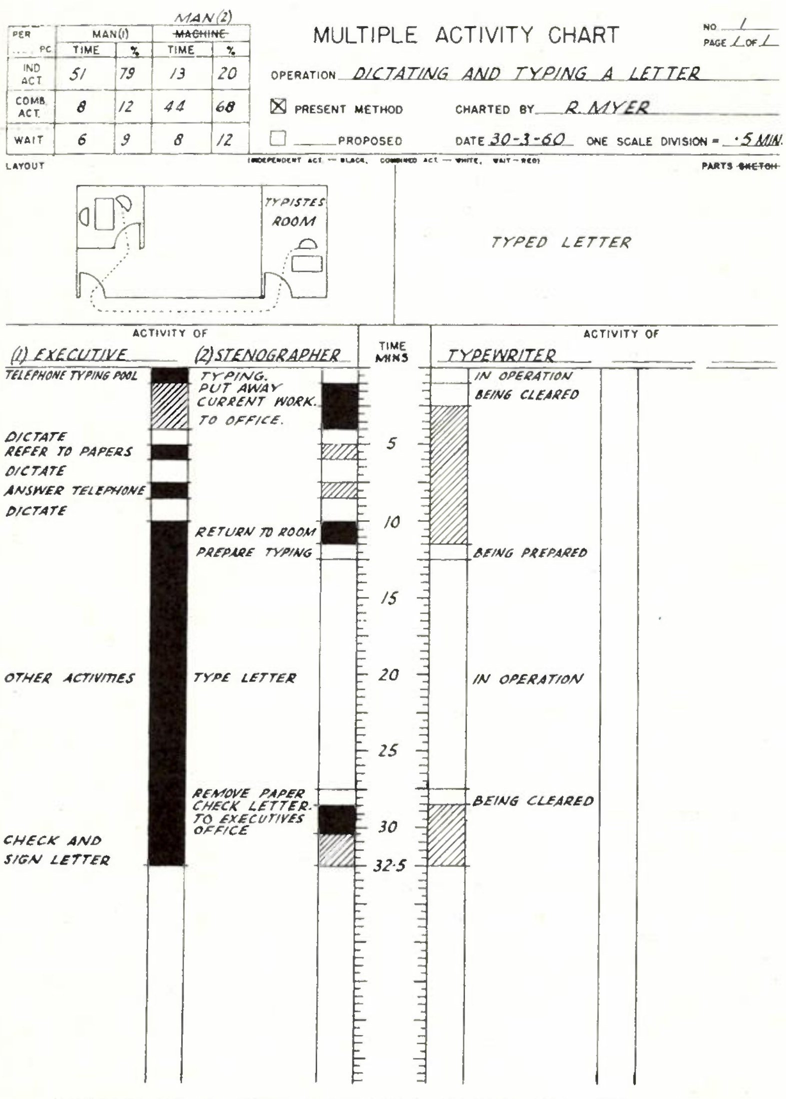


Fig. 5.—Multiple Activity Chart (Actual size 8" x 11").

Work Sampling, sometimes called random observation sampling, activity sampling or delay ratio, involves observations of the process or operator to determine the percentage of time which is spent on any portion of the operation or the time which is spent on rest or which is ineffective, etc. Whilst work sampling is not used for setting standards, it is a useful weapon with which to probe suspected sources of inefficiency, such as ineffective time due to various causes.

Synthesis of Times is possible when a great deal of standard time data for the most common elements of work has already been built up from previous time studies. Such data would normally be available in a work study department of some long standing, and would include standards for operations which occur in a variety of work in the organisation. This saves a great deal of the Work Study Officer's time in studying a complete operation and developing a time standard to cover the whole operation.

Predetermined Motion Time Standard Systems, involve the consideration of manual work as a series of basic elementary motions, the times for which have been accurately measured at normal rating. These systems have the advantages of the synthesised time system with the benefit of an established set of predetermined times which are applicable wherever a motion occurs, irrespective of the organisation or the work place location. The technique does not involve the use of stop watches to assess performance times and removes from the Methods Engineer the need for rating the operator.

The desire to have a reliable method of establishing performance times without the use of stop watches for work involving short cycle operations led to the development of predetermined motion time standard systems involving standard data and time formulae. One such system, now widely used in Australia and at present being applied in the P.M.G.'s Department, Engineering Division, is Methods Time Measurement.

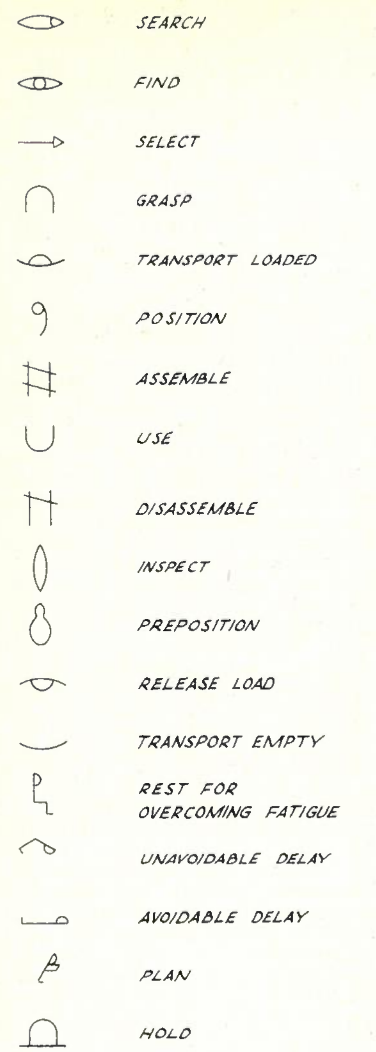


Fig. 6.—List of Symbols (Therbligs) for Gilbreth Basic Elements.

METHODS TIME MEASUREMENT

This technique involves the synthesising of operation times from times already built up for elementary basic movements which are universally applicable to work patterns. These predetermined motion time standards have been developed from a large number of studies of each movement, generally by a frame by frame analysis of films of a wide range of subjects, and both men and women performing a wide variety of tasks. The basic movements are reduced to several groups such as reach (R), move (M), turn (T), apply pressure (AP), grasp (G), position (P), etc., and within these groups there are other classfications. For each basic movement and classification, times have been established in Time Measurement Units (T.M.U.); a T.M.U. is .00001 hour (.036 second). As an example of a movement classified in this notation, reaching a distance of ten inches to a very small object where accurate grasp is required is called an R10C movement and a time of 12.9 T.M.U.'s is allotted.

The M.T.M. officer observes a worker's actions, classifies the motions according to their type and records the analysis on a chart. He applies the critical analysis, previously described under Method Study, to the overall motion pattern but he is also able to examine the nature of each movement and, where possible, to substitute a motion of the same type but of a simpler nature. This is a finer breakdown of an activity than is possible with other forms of Motion Study, such as that using therbligs; Methods Time Measurement is more effective therefore than the other systems for analysing the more complex motion patterns. When a new method has been developed it is possible to establish a performance time for the old and new operation using the M.T.M. predetermined motion times, without putting the new method into practice. This facility of M.T.M. is valuable in design where performance times for estimation in connection with staffing, planning, etc., are desirable for a new process without field trials.

As well as having the advantages discussed above and that of greater accuracy than is possible by direct time study measurement, perhaps one of the greatest advantages of the system it that the Methods Engineer is forced to consider methods before setting time standards. Too often today the Methods Engineer in a factory establishes time standards, even for incentive payments, without studying methods; this either perpetuates existing inefficient methods with consequent low production or enables the operator on incentives to be paid at unwarrantably high rates. It is a fallacy to say that M.T.M. is only applicable to production lines of high output and low work cycle duration as many organisations here and abroad are successfully applying it to such work as typing, plant maintenance, etc.

It is essential that a Methods Engineer who is applying Methods Time Measurement should be trained and experienced in the technique to a greater degree than is necessary with other techniques. This generally calls for approximately 200 hours of initial training, up to 50 hours of part-time supervision on the job by a trained analyst and about 1-2 years' continuous experience. Nevertheless, once the analyst is trained, an effective, reliable and efficient system of Work Study is available to the organisation.

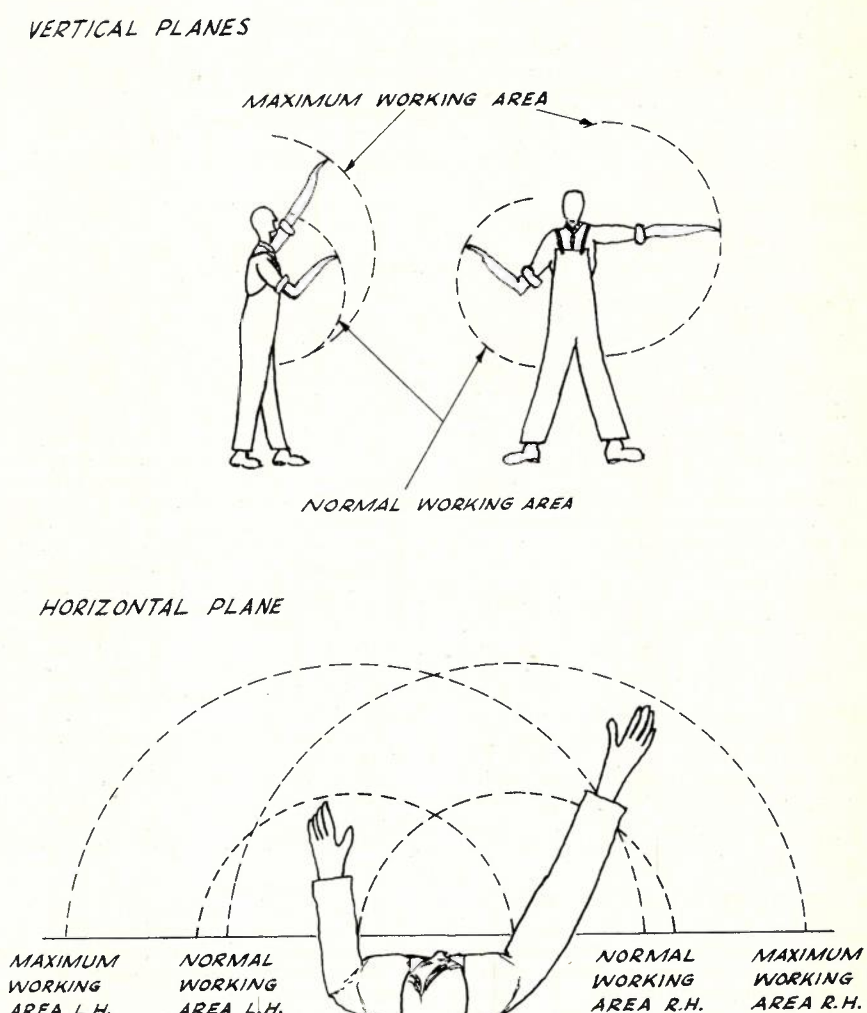


Fig. 7.—Normal and Maximum Working Areas.

WORK STUDY IN PUBLIC UTILITIES

Nearly every type of work undertaken in the field could be profitably studied using one or more of the techniques described above. Improvement in efficiency would come from improved methods, the elimination of ineffective time and the use of accurate and fair time standards as a basis for programming staffing, estimating, etc. Methods Time Measurement, currently being used in the P.M.G. Engineering Division, is proving suitable for the study of cable jointing methods and it is evident that a good many other operations could be beneficially studied.

The simpler Work Study techniques would have their uses in the P.M.G. Engineering Division for such purposes as:—

Operation	Method Study Chart or Technique	Work Measurement
Running MDF Jumpers	Flow process chart (Man)	Stop Watch
	or	
	Right and left hand chart	Stop Watch
Laying Cable	Gang (or multi-column) chart	Random observations
	or	or
	*Multi-activity chart	Watch
Terminating Wires	Right and left hand chart	Stop Watch
	or	or
	Simo chart (micromotion)	Film and wink counter
	or	or
	*Methods Time Measurement	Predetermined times
Stores Requisitioning	Multi-column chart (material)	Random observations
		or
		Watch
Installing Telephones	Flow process chart (Man)	Watch

*Preferred system, where one exists.

In the United Kingdom, public utilities involving such activities as transport fleet operation, coal mining, gas production, road making, etc., are achieving considerable success in the application of Work Study to their work and, elsewhere throughout the world, large progressive private organisations are applying Work Study with conspicuous success to such activities as sales, office cleaning, warehousing, farming, etc. Whilst sales organisations may not, at first glance, appear to be suited to Work Study, recently, one large wholesale organisation in Australia has applied Work Study with success to travelling and van salesmen. In the United Kingdom one of the world's most successful low-price chain clothing stores uses Work Study.

Public utilities in Australia which have recently introduced Work Study include Electric Authorities, Hospitals, Municipal Councils, Main Road Authorities and Commonwealth Departments.

WORK STUDY IN THE OFFICE

Whilst, as discussed elsewhere in this paper, a great deal of work has been directed to the use of Work Study to study manipulative work in industry throughout the world, with resultant rapid improvement in productivity, it cannot be said that a similar level of effort and success is evident in clerical fields; some interesting figures shown below lend weight to this point. Over the one period in the U.S.A. the following changes took place:—

Population .... increased 73%
Industrial employment increased 75%
Administrative and clerical staff .... increased 350%

Of course there are a number of very obvious reasons for this trend in administrative staff employment. Not the least of these is the development of improved management techniques and increased mechanisation, with the consequent need for greater administrative staffs. Nevertheless, it does indicate the benefits which could be derived from the application of Work Study to clerical and administrative work.

In 1948, the Commonwealth Public Service Board and Commonwealth Departments in Australia, well aware of this situation, adopted the British Treasury system of Organisation and Methods and, since then, they have achieved a good deal of success in its application and development. The term "Organisation and Methods", whilst used in U.K. to refer generally to Work Study in the office, is not used to the same extent in Australia except in the Commonwealth and State Government Service; in private industry here it is usually referred to as Work Simplification or Method Study. In the U.S.A., where the term "O. and M." is rarely used, the study of clerical work is referred to as Systems and Procedure Analysis.

The field of work covered by clerical Work Study staff consists of:—

- Office procedures or methods;
- Business form design;
- Records study;
- Work distribution, staff organisation, etc.;
- Work measurement;
- Office machine selection;
- Electronic data processing (E.D.P.).

The last activity, in particular, is causing a great deal of attention to be paid to office systems in Australia and elsewhere at present. This arises from the interest in electronic computers, the speed in processing possible through their use, and the need to review clerical methods prior to the introduction of an E.D.P. system.

Unfortunately, Clerical Work Study Analysts have been slow to adopt many of the techniques of manipulative Work Study, particularly in Work Measurement, with the result that it is often claimed that their work lacks much of the quantitative approach of their colleagues in manipulative fields. Also, Organisation and Methods Analysts frequently have to operate as experts who come in from outside and submit an extensive report to the Chief Officer, with resultant difficulties in implementation. This is not always done today as it is being found that the Organisation and Methods Analysts' participation in implementation with the management of the unit being studied greatly helps to achieve benefits from the study.

Recently, a firm of management consultants in Australia introduced a predetermined time standard system of work measurement suitable for office work in virtually any field. This technique, developed by Paul Mulligan, U.S.A., uses predetermined time standards as in Methods Time Measurement, but the times cover fairly long elements which are related more to a particular activity. This means that a much larger number of standard times must be maintained, but this in turn facilitates quicker development of a standard for performance.

Like most other Work Measurement techniques this predetermined time system may not be accepted readily, on the basis that a clerk's thinking time greatly exceeds that of a manipulative worker. This arises, possibly, because of an underestimation of the amount of thinking time of a skilled technician by comparison with that of a clerk. Some of the opposition to Work Measurement may result from the fact that those techniques which involve rating are not very reliable for clerical work. Nevertheless, Random Observations, Work Count, etc., and the more recently developed Predetermined Time Standard systems are quite suitable and useful techniques for studying clerical work.

HUMAN PROBLEMS IN WORK STUDY

It is not generally realised that one of the most important functions of the Work Study Officer is to reduce human effort involved in work as well as to achieve economy in operations. A Work Study Officer properly trained in the techniques of Work Measurement will give to Management time standards for the performance of work which are fair and which can easily be achieved by workers. In these, as discussed earlier in this paper, adequate rest allowance will have been made for difficult working conditions, etc.

The job of Work Study does not stop at developing and reporting on a new method, as success will not have been achieved until the new method has been introduced, which provides, perhaps, the greatest problem in improving work. Most people resist change and the intrusion of outsiders is often resented, consequently the Work Study Officer requires to have a sound practical knowledge of human nature. Recent developments in the field have been towards active participation in studies by the people doing the work, who can be of great assistance in the study of the existing method or development of a new one by bringing to the study their practical experience and developing an attitude which makes introduction of the new method easier. This participation, frequently called Work Simplification when on an organised basis, is used extensively in U.S.A. As well as developing new and improved methods, Work Simplification leads to a better team spirit, greater co-operation and higher morale in the organisation, as the staff are made to feel that they are part of the management team. In fact, such participation by the normal staff in the study of work methods is necessary in view of the modern tendency towards people managing their own sphere of activities.

New and more efficient methods may appear to mean that the output requirement will be produced with fewer workmen, but this is not necessarily so. The new method may enable the output or achievement to meet demand or the quality of the service to be improved. Also, a greater demand for the product or service could result from reduced costs and better service through Work Study; savings in costs could be directed to improved marketing or the development of other lines.

If a reduction in labour results from a Work Study, it is general practice to divert this labour to other work in the organisation or to gradually implement the change so that the freed labour is covered by wastage over the period. As a result of the adoption of this policy in Work Study Programmes, a great deal of co-operation between Labour and Management in the application of Work Study is now common here and overseas. The International Labour Office is training people in Work Study throughout the world and has stated its policy on the subject in their book, "Introduction to Work Study". This book is often used as a basic code in discussions and agreements between Labour and Management on matters related to Work Study. Amongst other things, this I.L.O. book states that Work Study is "the most penetrating tool of investigation available to management". It also states the other advantages of Work Study as below:—

(1) it is a means of raising productivity with little capital expenditure;
(2) it is systematic;
(3) it is the most accurate means of setting performance standards for effective planning and control yet evolved;
(4) the resultant savings start at once; and
(5) it is a tool which can be applied everywhere.

APPLICATION

Much of the development of Work Study techniques has been directed to their application to factory situations and, as a consequence, the techniques cannot always be applied directly to the field work of an organisation such as the P.M.G. Engineering Division. Nevertheless, the recent experiences of many organisations have shown conclusively that Work Study can be used to similar advantage in field work provided it is introduced more gradually and with due regard to the differences between field and factory work; during the introductory period a body of experience in the application of the techniques to the particular type of work can be built up.

As mentioned earlier in this paper, Work Study has been applied with success to such fields as outside sales, retail store operation, materials handling, electric pole route construction, factory maintenance, office work, hospital nursing and maintenance, hotel cleaning, underground cable laying, exchange maintenance and, more recently in this Department, paper-insulated cable jointing. This experience suggests that in an organisation such as the P.M.G. Engineering Division full-time Work Study Officers can be used extensively to examine the wide variety of work. The employment of such officers in the proportion of one per 100 staff can be found in several large firms in Australia and England; the proportion could be expected to be considerably lower in the Engineering Division, the total staff of which is over 40,000. The lower figure would be due to the standardisation of practices throughout the Commonwealth and the greater size of staff.

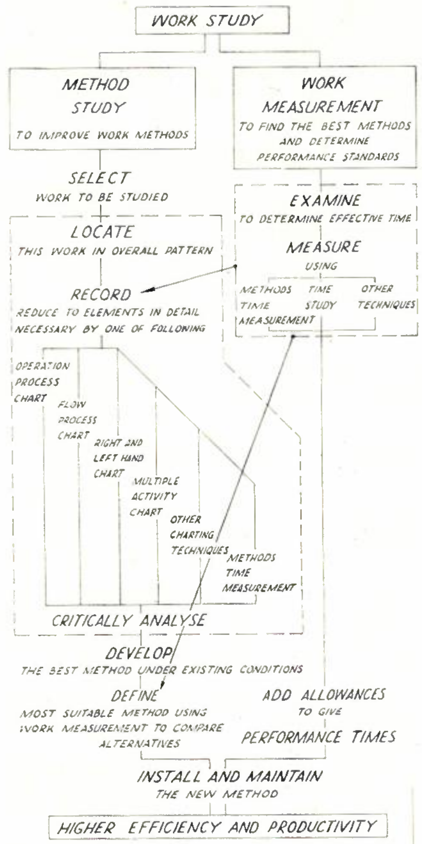


Fig. 8.—Work Study—Relationship between Method Study and Work Measurement.

Management Consultants engaged in the conduct of Work Study programmes here and abroad claim that savings of at least 20% are possible through the application of Work Study to operations which have not been examined already using these techniques. Of course, these savings would arise not only from new methods, but also from control systems, scheduling, programming, etc., based on the time standards developed through the use of Work Study. Furthermore, the precise statement of the operations involved in the study of a method, old or new, benefits the organisation in the training of operators.

It is not uncommon to find administrative, professional, manipulative and clerical staff, working in small or decentralised groups, operating at as low as 60% effectiveness, the remaining 40% being lost due to delays, excessive rest, etc. A reduction of up to 50% in these ineffective times, raising the effectiveness to 80%, can generally be brought about by improved management following the development of time standards and identification of the ineffective times and their causes. A properly designed incentive scheme will generally go much further and eliminate all of this ineffective time whether it is of worker or management origin; the effectiveness of workers on incentives will generally be raised to 125%. These figures are as follow:—

Effectiveness of staff before study, 60-70% of normal performance.
Effectiveness of staff with a control system and time standards, 80-90% of normal performance.
Effectiveness of staff on incentives, 125% of normal performance.

Work Study is best applied by analysts with sound basic technical and Work Study training followed by about a year's experience in a Work Study Team. However, the Work Study Analyst's greatest single advantage over the man who is managing or performing the work, in improving efficiency, is in the time at his disposal and the continuity of attention which he can give to the study. The manager or worker on the job generally has to apply himself to getting on with the job as at present organised and, in consequence, his efforts at improvement cannot be other than limited or sporadic.

CONCLUSION

Work Study is a tool of management which will improve productive efficiency with little capital expenditure. Used wisely, it can help make more effective use of existing resources such as plant, tools, building space, materials and labour. In this sense it will be very valuable to Government Departments, particularly the Postmaster-General's Department, in achieving higher productivity with their limited financial allocations.

It is clear that the development of Work Study has gone well beyond its application to work in factories, which is of a more continuous nature, more repetitive and performed generally in a fixed work place. It is probable that in Australia great development in the use of Work Study on low volume field work can be expected over the next few years. Also, considerable developments in the study of clerical work are highly probable, particularly in the use of techniques now used largely on manipulative work, such as predetermined motion time standard systems, etc.

Obviously, to obtain the full benefit of Work Study other aspects of management should be attended to at the same time otherwise the potential benefits may be dampened by these factors. Work Study on its own can be of considerable benefit to management but, for best results, it should be part of an integrated management improvement plan. In most organisations there is a great potential for improvement of efficiency and this can be readily tapped by an active and well-planned Work Study Programme.

In the Public Service, Work Study is an excellent tool with which management and staff can apply their efforts jointly towards their common objective — the provision of the highest standard of service to the public which is economically feasible. It is a systematic and rapid means of improving efficiency and can be beneficial to both the Department and its officers.

ACKNOWLEDGMENTS

The author desires to acknowledge the assistance of Messrs. R. J. Attkins, I. C. Smith, D. M. Deighton and L. V. Walsh in checking the manuscript of this paper.

In the preparation of this paper the author has referred to the publication of the International Labour Office — "Introduction to Work Study"—which is a most useful text on the subject for both the Work Study practitioner and the person who is generally interested in Work Study.

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ACTIVITIES OF THE SOCIETY IN QUEENSLAND

Formation of State Group: At a meeting held on 27/4/60, the Telecommunication Society of Queensland was formally terminated and the group re-formed as the Queensland Branch of the Telecommunications Society of Australia. The annual general meeting was held on 25/7/60 at which the new committee was installed. The members of the committee are: Messrs. H. W. A. Nicholls (Chairman), G. E. K. Dixon (Immediate Past Chairman), J. K. Petrie (Treasurer), B. F. Crutcher, E. C. Doherty, A. J. Farrar, J. H. D. Gill, W. C. Harris, R. D. Johnson, W. J. Powell, F. M. Scott (Secretary).

Membership: The committee has undertaken a vigorous promotion programme, the results of which are already evident in the rapid growth in the number of members and subscribers as indicated by the following figures:

	July 1960	August 1960	September 1960
Members	118	214	293
Subscribers	193	344	462

Lectures: An interesting lecture and outing programme is planned for the current year (1960/61) which will cover many of the recent developments in the telecommunications field:

September, 1960: The Townsville-Magnetic Island Submarine Cable. by D. C. Craig.

November, 1960: (a) Modern Power Rectifier Design. W. S. Trudgian. (b) The Brisbane Speaking Clock. R. W. McLennan.

December, 1960: Activities of the P.M.G. Research Laboratories. N. J. McCay.

January, 1961: Crossbar Engineering Aspects. N. D. Strachan.

February, 1961: A visit to the A.B.C. TV Studio ABQ2 and the P.M.G. Transmitter Channel 2.

March, 1961: (a) Crossbar — Installation Aspects. G. D. Cretier. (b) Crossbar — Demonstration of Equipment. G. A. Fooks.

May, 1961: Telecommunication Division Practices. W. J. Powell.

June, 1961: Wide Band Carrier Equipment. W. D. McKenzie.

Full details of the meetings will be advised by circular 14 days in advance; but as far as practicable meetings will be held at 7.45 p.m. on the 4th Tuesday in the months listed.

ACTIVITIES OF THE SOCIETY IN SOUTH AUSTRALIA

General: Membership of the South Australian Branch of the Society has at 3/10/60 just reached the 500 mark and there are now 340 contributors to the Journal in this State (including the Northern Territory).

At a recent Branch Committee Meeting it was agreed that a presentation of one year's subscription to the Telecommunication Journal be made to the Trainee Technicians gaining the highest marks in the final examination of the 2nd, 3rd and 4th year of training. Branch notes published in the next issue of the Journal will include the names of the recipients.

Keen interest in the activities of the Society has been shown by groups other than the P.M.G.'s Department and the most prominent of these have been the Weapons Research Establishment at Salisbury where Mr. H. W. Foster is the Journal agent and the South Australian Railways (agent Mr. D. E. Both, B.E., A.M.I.E.Aust.).

Lectures: The monthly lecture meetings held during 1960 have been well attended, average attendance being approximately 200 and the Branch is indebted to the lecturers on Crossbar Techniques, Messrs. L. M. Wright, L. A. Wilksch, A. R. Pennifold, K. D. Vawser and A. N. Gooley of the P.M.G. Department, and to Mr. G. Taylor of the Weapons Research Establishment for his lecture on "The Radio Control System of Australian-Based Target Aircraft."

The remaining lectures to be held in the current series are as follows:

Monday, 5th December, 1960: Crossbar Circuit Elements — Mr. L. M. Wright, B.Sc., A.M.I.E.Aust.

Monday, 6th February, 1961: Electronic Computors — Mr. K. D. Vawser, B.E.

Monday, 6th March, 1961: Recent Developments on the North-South Line — Mr. M. W. Higgins, A.M.I.E.E.; Mr. F. J. W. Gubbins, A.M.I.E.Aust.

Monday, 3rd April, 1961: Adelaide — McLaren Vale Coaxial Cable Project — Mr. J. E. Freeman, B.Sc.; Mr. L. R. Waller, B.E., A.M.I.E.Aust.

Meetings are held at the G.P.O. Cafeteria (4th Floor), and commence at 7.45 p.m.

ACOUSTIC SHOCK ABSORBERS

*R. W. KETT, A.M.I.R.E.Aust., Fell. R.M.T.C.**

INTRODUCTION

Complaints of excessively loud clicks from the Handset No. 3 (Buttinski) have been received from the field and there has been a case of an officer suffering vestibular concussion. Test desk receiver circuits are fitted with 2/2A metal rectifiers as acoustic shock absorbers or click suppressors and it has been suggested that they should also be fitted to the Handset No. 3. A new design of Buttinski submitted by the British Automatic Telephone and Electric Co. designated Type 280 uses a rocking armature receiver and it was feared that this instrument might be more objectionable than the Type 3.

Various methods of suppressing click voltages have been suggested including neon discharge tubes, non-linear resistances, for example, silicon carbide and pairs of metal rectifiers. A Type NE51 neon lamp has some effectiveness when connected across the line terminals of the Handset No. 3 but superior results were obtained by using rectifiers. Silicon carbide resistors have less suitable resistance-voltage characteristics and were therefore not tested (see Fig. 1). The most promising method was the use of semiconductor rectifiers, which have much more suitable characteristics (see Figs. 1 and 6).

Four commercial types of click suppressor were available and two or more samples of each type were measured (Fig. 1). These were the Siemens and Halske type Gg2 for mounting in a handset and type Ta1c21/1, with similar characteristics but designed for mounting on a telephone baseplate (Ref. 1). The A.P.O. 2/2A rectifier and the Western Electric type 44A, a handset mounting type, were also measured in laboratory tests.

SUBJECTIVE TEST

As it was desired not only to evaluate the effectiveness of these units, but also to derive suitable design parameters, a subjective test was devised in which combinations of these units were used to obtain different resistance-voltage characteristics. As may be seen from Fig. 1, the 2/2A and Gg2 units are almost identical; the Gg2 was used in the tests.

A test circuit was devised in which clicks of variable magnitude could be delivered to the line terminals of the instrument. The line and transmitter circuits could also be made and broken with D.C. flowing. Four conditions of suppression were possible (see Fig. 2), two 44A units being connected in parallel for position C. Since very little was known about the nature of the subjective response, a variety of impedance and voltage relationships was desirable. The Buttinski transmitter switch was normally open, but was closed when the line circuit was to be interrupted. A zero line was used as this is the worst condition, the line current being at a maximum. The Handsets No. 3 and No. 280 and a 13-4T-30 telephone (400 AT) were tested.

Clicks were generated at peak voltages of from 8 to 130V in 2 db steps and also by the line and transmitter circuits being made and broken. Thirteen listeners made three judgments of each condition selected in random order. The listeners indicated by means of lamp signals whether they considered the loudness of the click "Objectionable" (Red), "Tolerable" (Green), "Not certain" (Yellow). Two yellow indications at the same level were considered equal to one red. It was found that very loud clicks produced a certain amount of short-term deafening. After a red indication the operator always returned to very low voltages for which green indications had been given by the subject.

Rest periods were allowed when a subject became fatigued or lost confidence in his judgment. The subjects were males aged from about 20 to 60 years and all had normal hearing for their age. It was particularly noticeable that the temperament of the subject played a part in his choosing the level of tolerability. Two subjects were found who considered all but the very loudest clicks tolerable, whereas one or two others objected to the very lowest clicks when no suppressor was used. Fortunately, it was possible to use the same team to test each of the three instruments.

The results are shown graphically in Figs. 3, 4 and 5. In order to relate the line and transmitter circuit values these have been shown at their tolerance levels. It will be seen that in each circuit they approximately correspond with certain voltage levels and have been reduced in about the same ratio.

The effectiveness of any particular suppressor is a function of three parameters, its intrinsic resistance, the circuit impedance across which it is connected and the sensitivity of the receiver. The related circuit impedance at 1 kc/s is shown on each of Figs. 3 to 5, being the impedance of the receiver in parallel with its telephone circuit in the test conditions of Fig. 2. From the unsuppressed curve it is possible to read a peak click voltage which is tolerated by 90% of the team. In the absence of other data this was taken as a reasonable value of suppression for which to design and should give adequate protection against hearing damage. By measuring the ratios of the voltage at 1 kc/s, applied in place of the 10 μfd condenser (Fig. 2), and the receiver p.d., it was

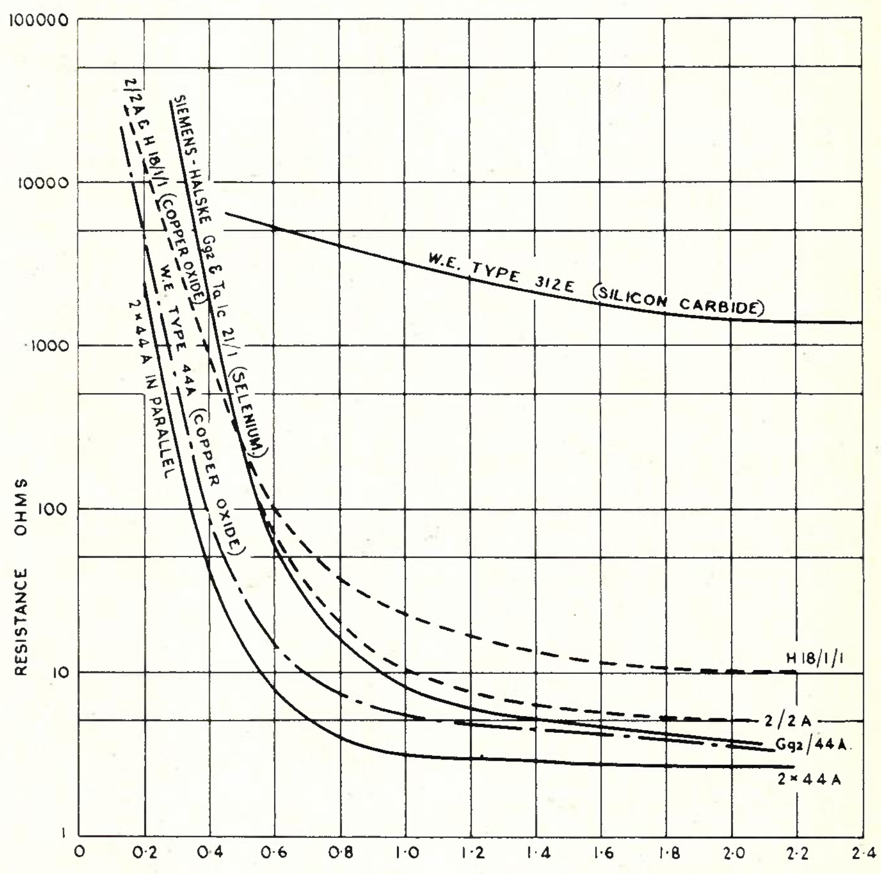


Fig. 1.—Resistance/Voltage Characteristics of Typical Non-linear Devices.

* See page 378.

possible to calculate an approximate equivalent peak click voltage at each receiver corresponding to 90% tolerability. These values are shown in Table 1:—

Table 1

Receiver	Peak receiver p.d.
1L	14V x 0.17 = 2.4V Peak
4S	10.5V x .095 = 1.0V Peak
4T	20.5V x .035 = 0.7V Peak

DESIGN CONSIDERATIONS

Maximum Shunt Resistance: Equivalent unsuppressed receiver voltages were obtained for the tolerability levels at which the curves for each of the three types of suppressors cut the 100V value, this roughly corresponding to the loudest clicks in practice. The resistances of the appropriate suppressors at these voltages divided by the receiver circuit impedance were plotted against the percentage tolerability. Although the experimental error is large, it was possible to determine that 90% or better tolerability can be achieved if the resistance of the suppressor at the voltage of Table 1 is not greater than approximately 4% of the impedance across which it is connected (Table 2).

Table 2

Tel.	Recr.	Recr. cct. Impedance	Required Shunt	Recr. peak volts	Nearest suitable suppressor tested.
No. 280	4S	50 ohm	2 ohm	1.0V	Lower than 2x44A
No. 3	1L	300 ohm	12 ohm	2.4V	Gg2 adequate
13-4T-30	4T	100 ohm	4 ohm	0.7V	2x44A adequate

Using these criteria, the choice of suppressor is confirmed by the test results within the experimental limits.

Minimum Permissible Shunt Resistance: It is also necessary to determine whether the suppressor introduces any loss or distortion at maximum speech levels. Speech clipping may occur if at the maximum tolerable speech level for a given receiver, the suppressor resistance is comparable with the receiver circuit impedance. The 1 kc/s value may be used as an approximation. Maximum speech levels have been determined for the receivers in use at present (Ref. 2) and are as shown in Table 3:—

The 5% levels shown above for the 1L, 2P and 4041A receivers have been computed to be equivalent to 125 to 127 phones. This is close to the threshold of audi.ory overload. Any clipping which takes place at these levels will not be harmful and may even be desirable. Table 3 may therefore be taken as a criterion for the maximum shunting permitted. Reference to Fig. 1 shows that even for the No. 3 Handset four 44A suppressors in parallel would be permissible on such a basis.

Table 3

Receiver	Max. speech p.d. at recr.: 5% level* m Volts	Max. click p.d. at recr. (Table 2) Volts
1L	210	2.4
2P	180	4.0†
4T	30†	0.7
4S	42†	1.0
4041A (light wt. Op's set)	48	1.1†

* Level at which only 5% of subjects considered level "tolerable".

† Calculated.

Suppressor Capacitance: Although the best possible suppression is desirable, selenium and copper oxide rectifiers have the disadvantage of high shunt capacitance. The following values were measured:

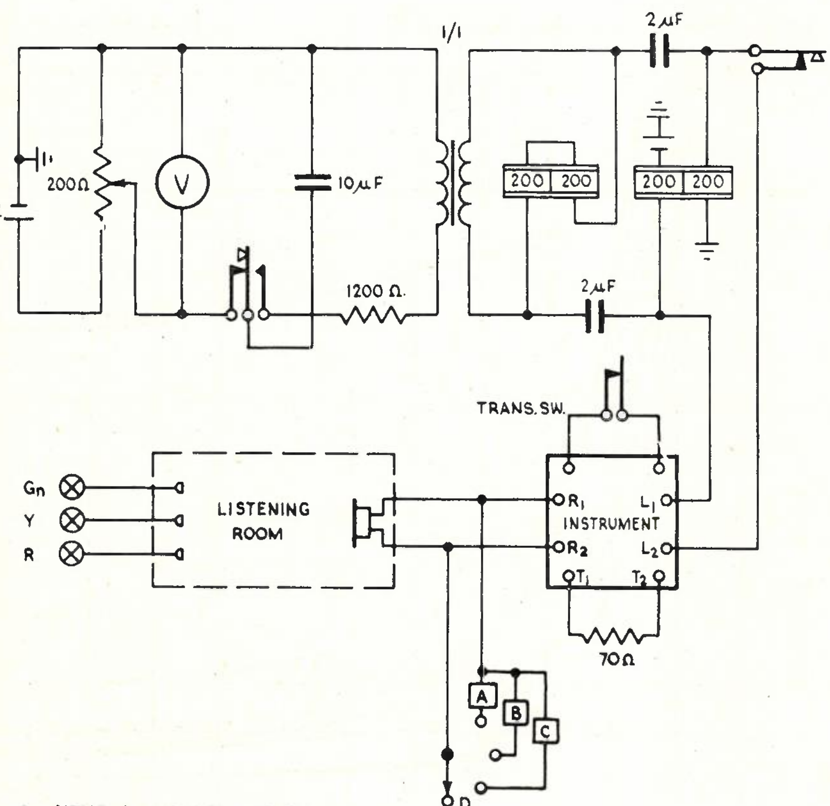
Siemens Halske Gg2 .... 0.05 μfd
W.E. 44A .... 0.03 μfd
2/2A .. .. 0.12 μfd

This order of capacitance is sufficient to resonate with the receiver inductance at audio frequencies. Provided the resonance occurs at a frequency not lower than 3 kc/s no serious impairment of transmission performance will result. Telephone Efficiency Tester receiving readings may even increase slightly when the suppressors are connected. The limiting values shown in Table 4 are recommended:

Table 4

Receiver	Max. shunt capacitance
1L	0.05 μfd
2P	0.05 μfd
4T	0.2 μfd
4S	0.2 μfd
4041A	0.2 μfd

Final design: Referring to Table 3 and allowing for a capacitance equivalent to the 44A suppressor, it appears that a unit equivalent to three 44A's in parallel would be required to deal adequately with each of the three telephones under consideration. The capacity (.09 μfd) would be rather high for the 1L receiver



A SIEMENS HALSKE TYPE Gg2
B WESTERN ELECTRIC TYPE 44A.
C 2 x 44 A. IN PARALLEL
D OPEN CIRCUIT

Fig. 2.—Subjective Testing Circuit.

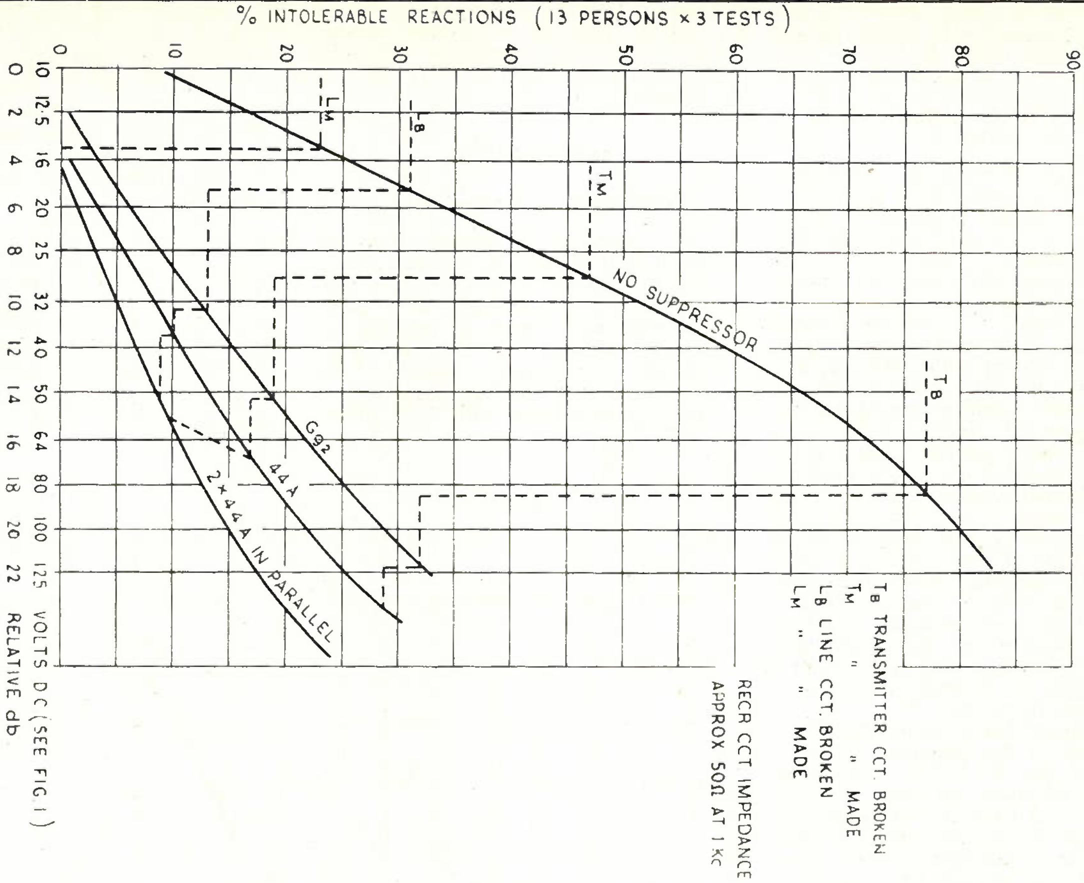


Fig. 3.—Subjective Test, Handset No. 280.

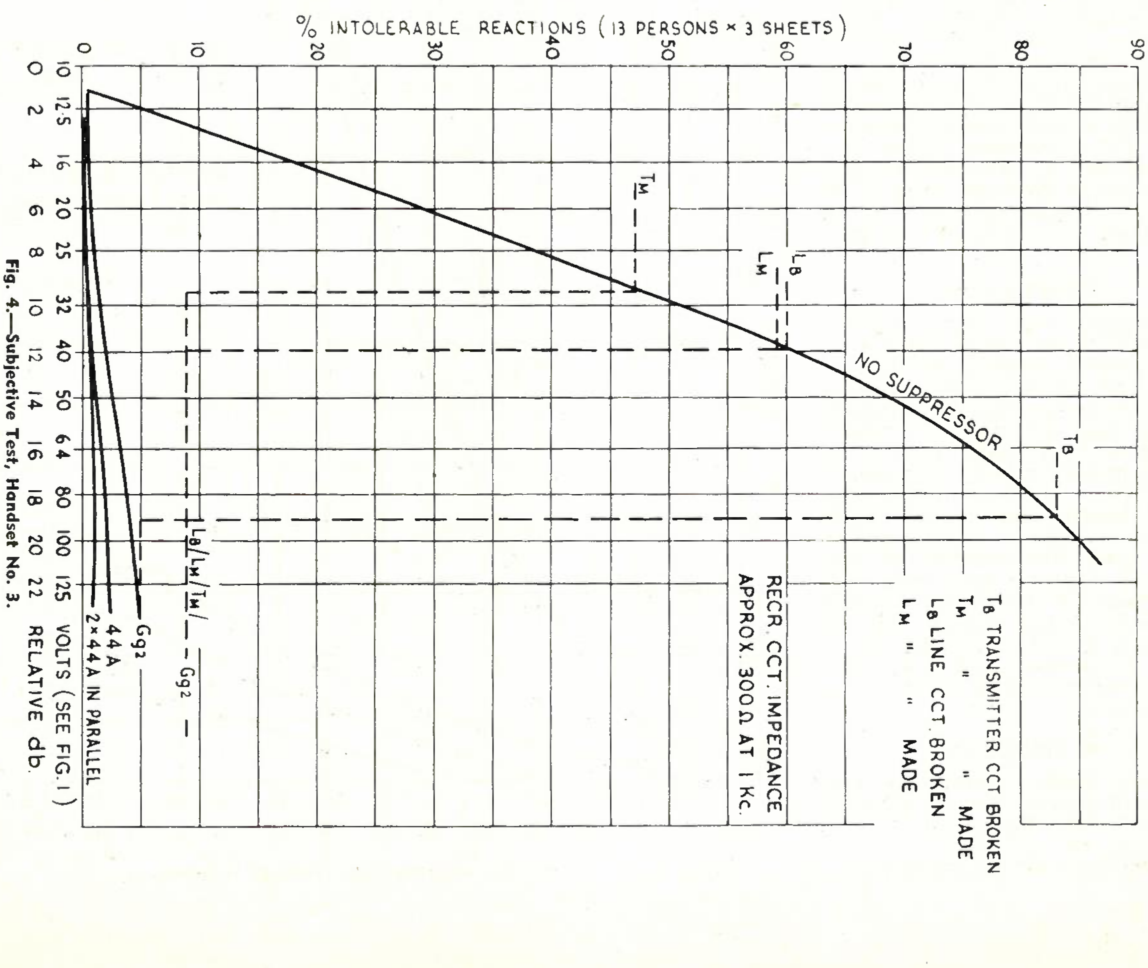


Fig. 4.—Subjective Test, Handset No. 3.

but higher values are in use at present (Para. 1). The design parameters have been summarised in Appendix I.

SILICON AND GERMANIUM DIODES

The defects of selenium and copper oxide rectifiers having been discovered, consideration is now being given to the use of silicon and germanium junction devices. At present 3.3 volts is the lowest operating voltage for which zener diodes can be obtained and this is too high for click suppression. The silicon forward characteristic however is more suitable than that of copper oxide (see Fig. 6).* Suitable silicon diode pairs could be made to give superior results to the present types of rectifier units at a comparable price and the silicon diode shunt capacitance is too low to resonate with telephone receivers in the voice frequency range.

Consideration is also being given to the possibility of constructing a zener diode with suitable forward characteristics and with a negative characteristic giving a breakdown at about 500 mV. Such a unit would give suppression of both positive and negative clicks without the necessity for connecting two units in parallel.

Fig. 6 shows that a silicon diode having one half to one twentieth of the resistance of the Z.2A.33F zener diode would be adequate for both the No. 280 and No. 3 handsets with regard to both shunt resistance and operating voltage. Fig. 7* has been drawn to show these limits as the basis for a specification for a universal suppressor. Such a specification should require that the limits be met when the unit is tested with D.C. in both directions, at temperatures up to 110°F, and that they not be damaged by a continuous application of 2 volts D.C. Hermetic sealing in a capsule capable of being mounted either in a handset or telephone would be desirable. A limiting value of 0.05 μfd shunt capacitance should also be specified.

CONCLUSION

The present commercially available suppressors are not suitable for low impedance receiver circuits as in the Handset No. 280 and a special unit would have to be constructed. It is desirable that only one unit should be stocked and if selenium or copper oxide is used there is a problem with the high capacity involved.

More suitable results could be obtained using pairs of silicon or germanium diodes and enquiries are being made as to whether a zener diode could be constructed to give suitable positive and negative characteristics in one unit. Limits have been given as the basis of a general purpose suppressor which could be met by suitable silicon or germanium diodes.

REFERENCES

1. Acoustic Shock Absorbers for Telephone Receivers. Siemens-Zeitschrift **8**, pp. 359-363, Sept., 1954.

2. A.P.O. Research Laboratory Report No. 4583. The Maximum Tolerable Listening Level for Telephonic Speech.

APPENDIX I

Summary of Design Data

1. 90% tolerance of loudest clicks in practice is ensured by designing suppressor resistance to be 4% of receiver circuit impedance at 1 kc/s (receiver and circuit in parallel) at critical voltage in Col. I. The circuit impedance should be measured with the line terminals of the circuit bridged with 1200 ohms N.R.

2. To avoid resonance below 3 kc/s, capacity of suppressor should not exceed value in Col. II.

3. To avoid speech clipping the resistance of the suppressor should be greater than four times the receiver circuit impedance at the voltage of Col. III.

Receiver	I Volts	II μfd	III Volts
1L	2.4	0.05	0.21
2P	4.0	0.05	0.18
4T	0.7	0.2	0.03
4S	1.0	0.2	0.04
4041A	1.1	0.2	0.05

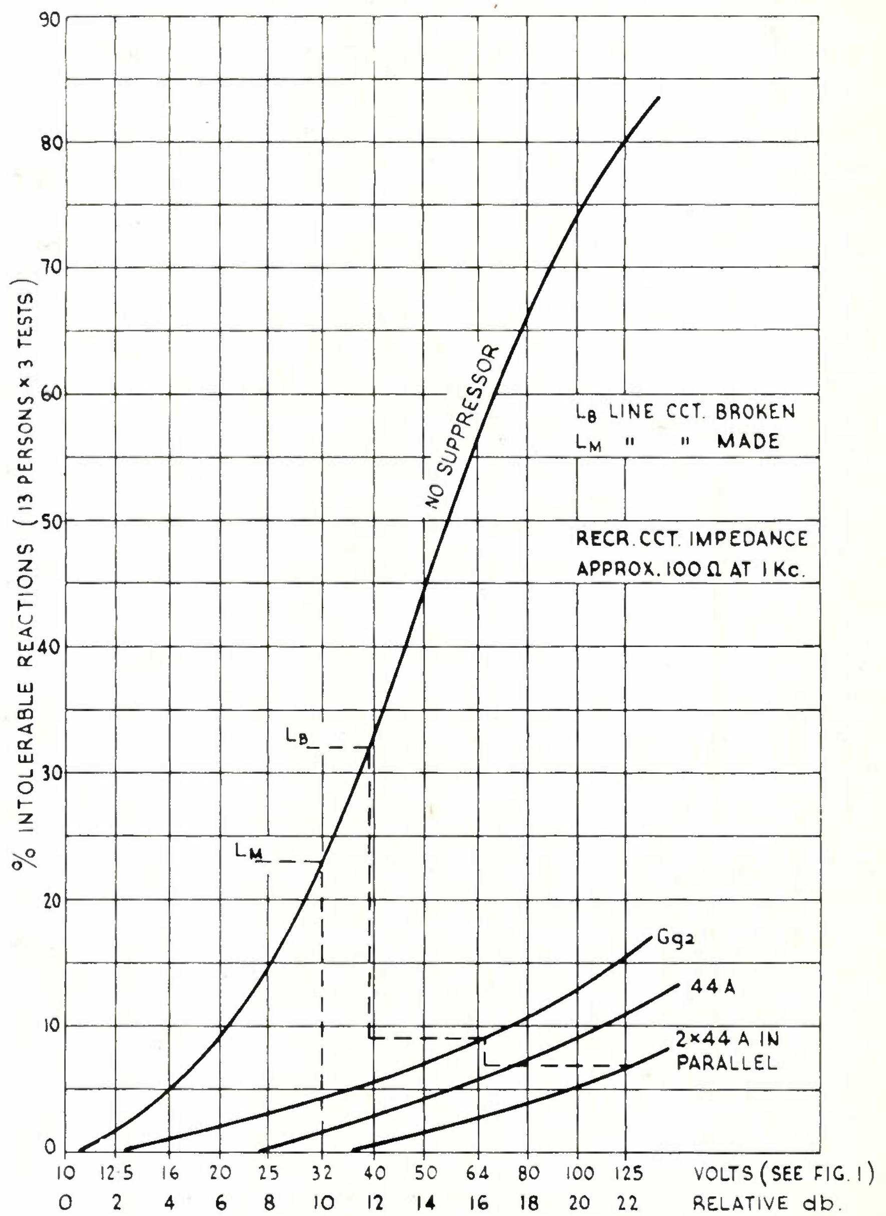


Fig. 5.—Subjective Test, 13-4T-30 Telephone.

* See page 357 for Figs. 6 and 7.

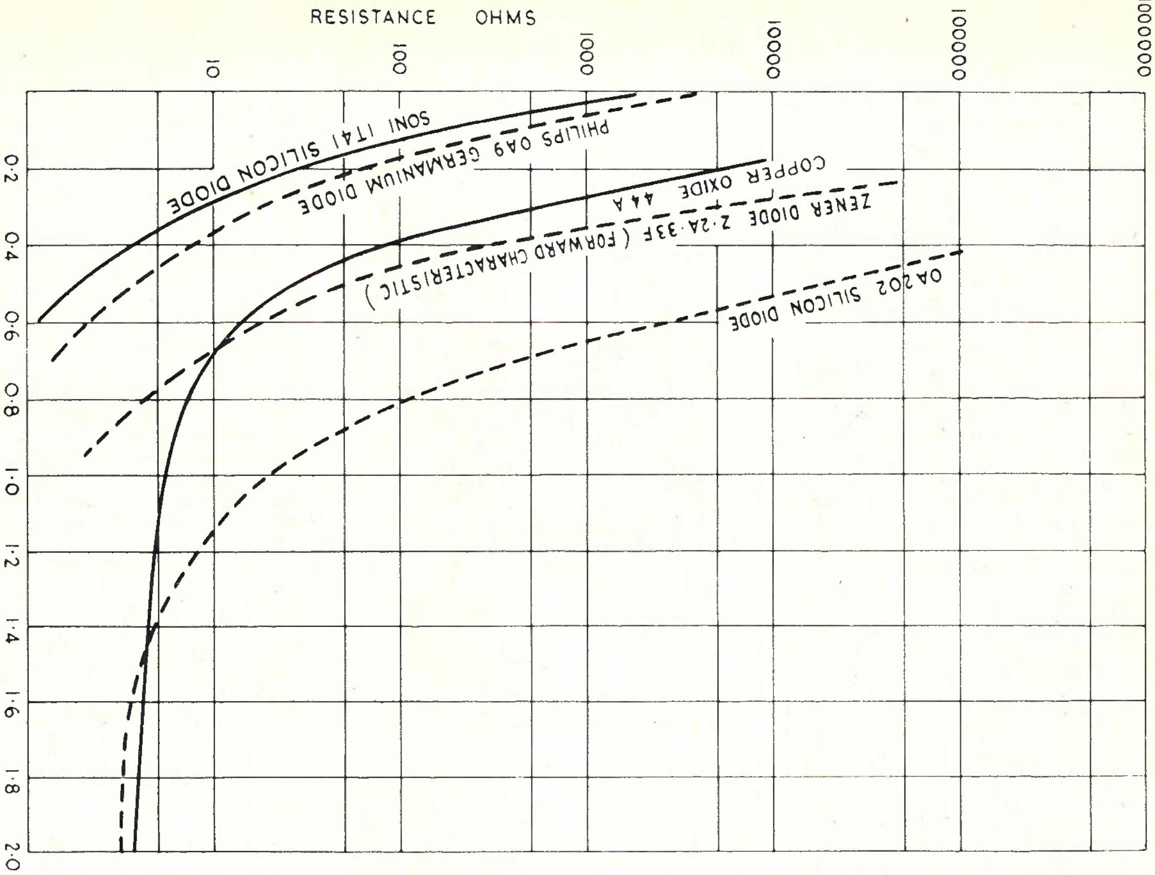


Fig. 6.—Resistance/Voltage Characteristics of Semi-conductor Devices.

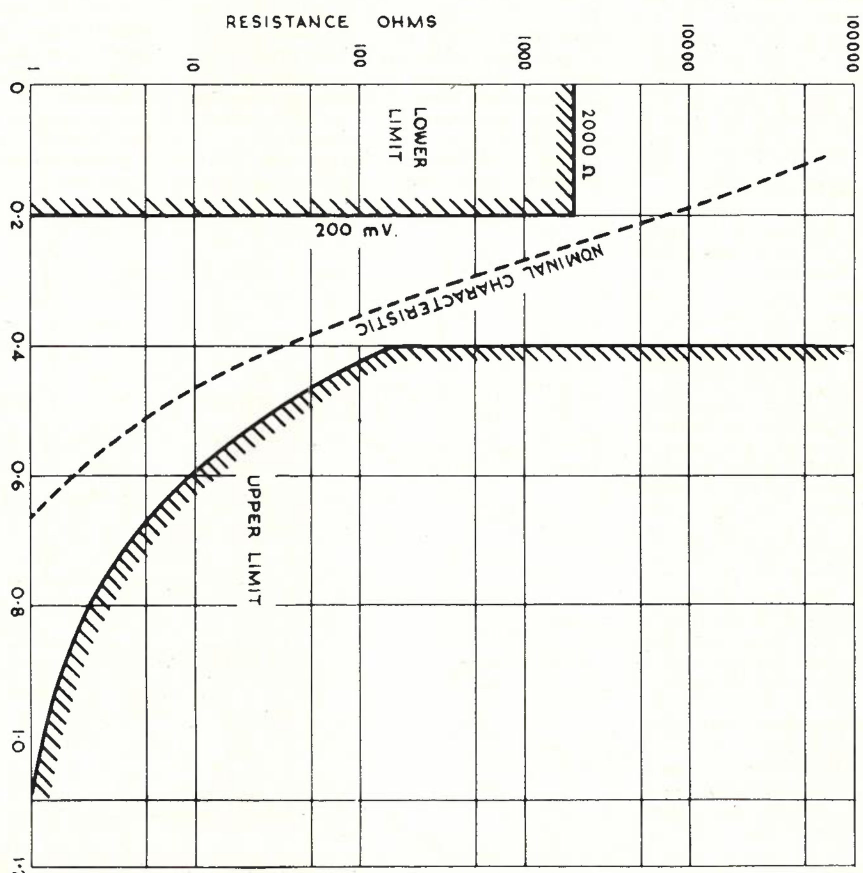


Fig. 7.—Limits for General Purpose Unit.

UNBALANCE FAULT TEST SET FOR OPEN WIRE LINES

*A. K. PIPER**

INTRODUCTION

The location of unbalance faults on open wire trunk and subscriber's telephone lines has always presented certain difficulties in the past and in more recent years the problem in respect to trunk lines has become more acute with the rapid expansion of multi-channel carrier telephone systems. In some cases owing to the shortage of suitable bearer circuits it had become necessary to restrict testing for unbalance faults to periods of light traffic to avoid expensive interruptions to carrier circuits. This procedure was costly and troublesome and delayed clearance of faults.

High resistance faults on country subscribers' lines had presented a special problem, especially in magneto areas where faults of this type may persist for long periods before being located. This was due to the absence of convenient means of testing and also to the length of time required to carry out tests using old methods. In some cases the location of high resistance faults would take several days.

It was with these problems in mind that the Test set described was evolved The Unbalance tester overcomes most of the problems associated with former methods of testing. The set is light, robust and simple and is carried by the Lineman engaged on the location of the fault. Working carrier and voice frequency circuits are not disturbed by the tests and the Faultman may carry out all tests to locate and clear faults without contacting the Technician at the testing station. This last mentioned feature results in great savings in time as each test may be completed in a few minutes.

GENERAL DESCRIPTION

The original instrument constructed by the writer was housed in a strong cast metal case about seven and a half inches square and five inches in depth, fitted with a leather shoulder carrying strap and a small canvas pouch to house the test clips and leads. Instructions for operating the Tester are typed on a card attached to the inside of the lid.

Set out on the face panel (see Fig. 1) are five lever keys, a centre zero milliammeter and three terminals. The key on the left is fitted with a white key top and the panel is marked A and B in the directions of operation. This key is the Test and Test Reverse key and in use connects the test circuit to the line and will indicate which lead of the Tester is connected to the line wire which has the highest resistance. This feature is useful when the fault has been narrowed down to a small section and in this faulty section there may be joints in each leg of the line.

The three centre keys fitted with black tops are the fault balancing keys. These keys are set out in the manner shown in Fig. 1, and allow resistance from one to twenty ohms to be inserted to balance the fault on the line. The keys are

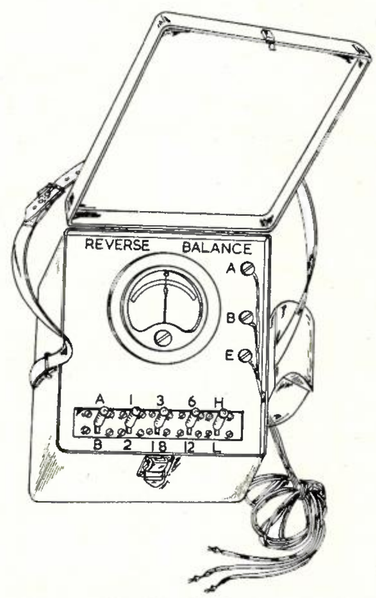


Fig. 1.—The Unbalance Line Test Set.

operated either singly or in combination to obtain the desired value of resistance.

The key on the right fitted with a red top is the meter sensitivity key and is used to increase the degree of sensitivity of the meter when testing faults of slight unbalance. Half the key plate in the direction of operation for maximum sensitivity, is painted red to indicate that caution must be used when operating the key to this position. This key is non-locking as a further safeguard.

When all keys are normal the Tester functions as a voltmeter with an approximate range of 50 volts, the purpose of this being to give an indication if connected to a working Automatic or C.B. exchange, junction or Subscriber's line so that the user will not operate the Tets key and cause damage to the meter.

The contacts of the balance resistance keys are connected in parallel to ensure positive contact when closed. The springsets of the Test and Reverse key are so adjusted that the contacts in the line circuit close fully before those in the earth circuit. This is necessary to prevent interfering clicks on the circuit being tested and violent deflection of the meter with consequent risk of damage.

Perhaps the most important feature of the Tester is that it may be used to test working circuits, this is accomplished by the incorporation in the circuit of a 3/48A transformer with windings arranged as a choke connection in each leg of the test circuit. In practice it has been found that when connected across the circuit with test keys normal the bridging loss is less than 1 db. to signals from 200 c/s up to 150 Kc/s and with the Test key operated the loss is less than 2.5 db at 150 Kc/s. It was found that the inclusion of RF chokes in the circuit did not result in any improvement in this regard.

CIRCUIT DESCRIPTION

The instrument employs the Wheatstone bridge principle in its operation and this is illustrated in Fig. 2.

Resistors R1 and R2 of 200 ohms each constitute the two fixed arms of the bridge across which is connected the milliammeter in series with multipliers R5 and R6 of 900 and 9000 ohms respectively.

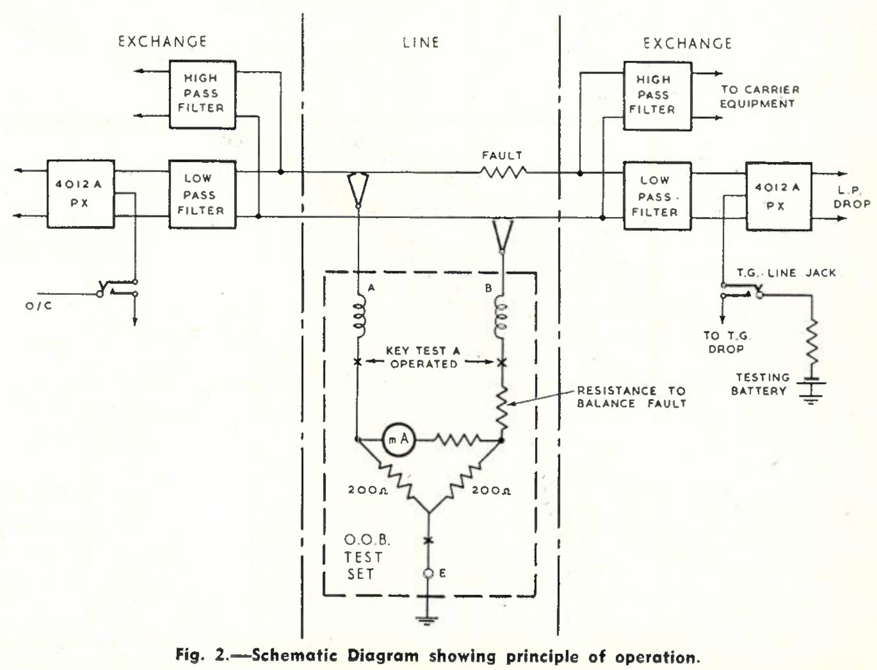
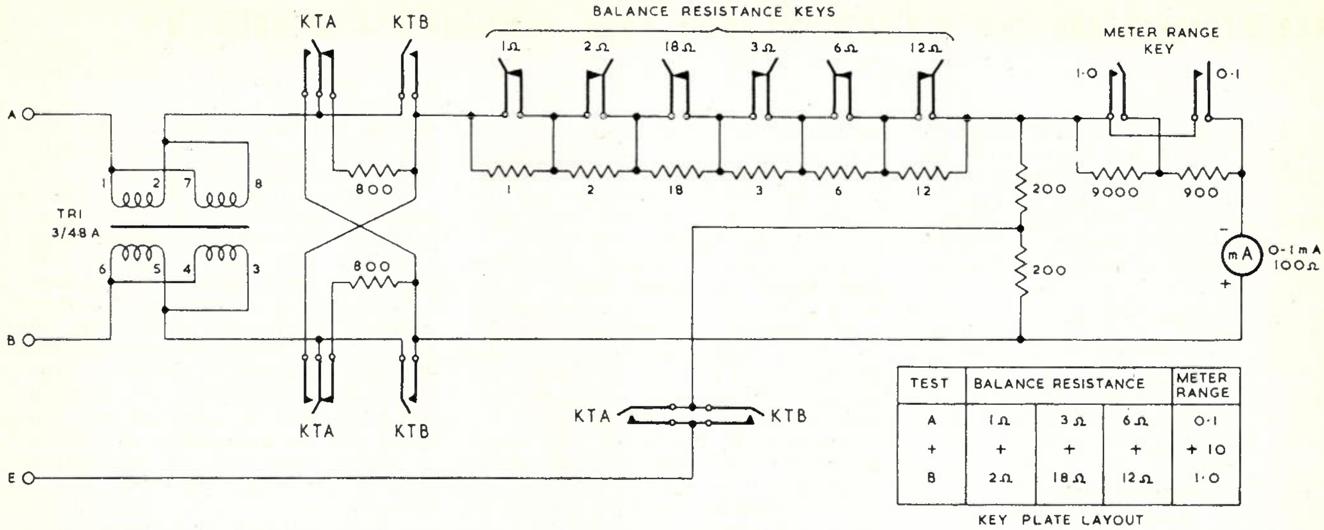


Fig. 2.—Schematic Diagram showing principle of operation.

*See page 378.



TEST	BALANCE RESISTANCE			METER RANGE
A	1Ω	3Ω	6Ω	0·1
+	+	+	+	+ 10
B	2Ω	18Ω	12Ω	1·0

Fig. 3.—The Test Set Circuit.

Resistors R3 and R4 of 800 ohms each are normally in circuit and extend the meter range to 50 volts approximately. These resistors are out of circuit when the Test key is operated in either direction and therefore their accuracy is not critical.

Balance resistances of values 1, 2, 3, 6, 12 and 18 ohms were wound on to ceramic formers and are located between the Balance keys as shown in Fig. 3. Operation of the Balance keys inserts these resistances into the bridge circuit in such a way as to balance the fault on the line under test.

OPERATION

Generally tests are carried out by Technicians to prove the existence of unbalance faults and to localise such faults to a particular section of trunk line or to a particular Lineman's district. Having done this the Line Faultman will proceed on the fault. The Testing Technician will first ensure that the line is free of any earth fault or Telegraph circuit connection and arrange for negative battery of from 4.5 to 12 volts to be connected to the line via the centre tap of a balanced 4012A transformer. In many cases the Telegraph Line jacks on patchboards is a suitable point for the connection of this battery and if not a suitable spare transformer may be provided to be patched into circuit as required. It is desirable that the test battery voltage be kept at a minimum in order that the high resistance fault will not be temporarily righted by a heavy current flow.

Faults on subscriber's services are treated a little differently. Generally the nature of the subscriber's complaint will indicate the presence of a high resistance fault. These symptoms are, in a magneto service, fading which may be temporarily corrected by a brief ring on the circuit or in a C.B. or Automatic area, intermittent crackling and frying similar to that caused by a defective cord or transmitter but which will be easily proved by a Technician to exist on the line when cords and transmitter are shaken.

Testing C.B. or Automatic lines will necessitate the interruption of the service and although magneto services may be tested without interruption it is generally more expedient to interrupt the service.

If the faulty subscriber's service is connected to an exchange at which there is no Technician in attendance, the Line Faultman can easily arrange for the connection of the test battery by removing fuses from the M.D.F., short circuiting the line and connecting to the negative battery terminal, the positive terminal being connected to the M.D.F. earth. A 4½ volt dry battery is usually quite suitable for this purpose.

The faultman may now proceed to the centre of the faulty section and after arranging an earth connection which may be a stay wire, steel pole or an earth stake driven for the purpose, will clean the line wires thoroughly. The test clips A and B are connected to the line wires and the clip E to earth. The meter is now observed and if any deflection is evident the test may not be proceeded with as some error in connection is indicated, if however there is no deflection the Test key is operated in each direction and the meter observed. If no deflection is evident the meter sensitivity key may be operated and the operation of the Test key repeated. When a deflection of the meter is seen, the Test key is to be operated in such a direction as to cause the meter to deflect to the right. However, if there is no meter deflection with the meter sensitivity key in the high sensitivity position, the line under test is balanced between the tester and the point where the test battery is connected.

Assuming that a fault exists, the Test key is operated to cause a deflection of the meter to the right, Balance keys are now operated commencing from the lowest value and increasing until the meter returns to the centre zero position. In a few cases where the unbalance exceeds 32 ohms a balance cannot be obtained but this is of small importance. The numerical sum of the Balance keys operated will equal the resistance unbalance of the line to the Tester and the direction of operation of the Test key will indicate to the user which of the Test leads is connected to the line wire of highest resistance.

Similar tests are carried out by the line Faultman, each test halving the faulty line section until the fault is located. It is most important that all keys are normal before connecting the Tester to, or disconnecting from the line to avoid disturbance to circuits and to prevent damage to the instrument.

CONCLUSION

The use of this Test set will greatly simplify the location of Unbalance faults and considerable savings in man-hours and trunk line time will result from its use for reasons set out below:

(a) Each test requires less than half the time formerly required.
(b) The Exchange Testing Officer's time is not required for each test.
(c) Carrier systems need not be patched to alternative bearer circuits.
(d) All testing operations may be carried out during normal working hours, thus avoiding overtime.
(e) Faultman does not require the use of a Trunk circuit for communicating with exchange when testing.
(f) No loss of Trunk line time due to interruptions caused by testing operations.
(g) The testing of trunk and subscriber's lines which do not terminate at a Technicians' station is greatly simplified and does not require the use of a trunk circuit between the minor centre and the Technician's station.
(h) The line faultman may easily identify the faulty line leg.

METHODS OF NUMERICAL FILTER DESIGN – PART V

*E. RUMPELT, Dr.Ing.**

10. DESIGN OF LATTICE FILTERS

Lattice filters are filters with the structure of a bridge network in which each pair of opposite branches has equal impedances. This bridge network is usually drawn in a folded form which gives it a lattice structure (see Fig. 4).

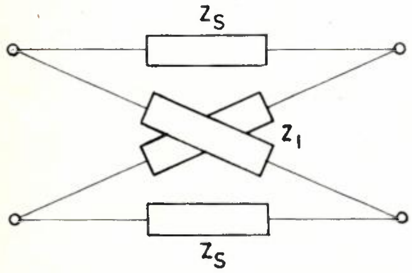


Fig. 4.—General circuit of a symmetrical lattice network.

The branches marked with the symbol Z_s are called the series arms, and the branches marked with the symbol Z_1 are called the lattice arms.

It can be seen by inspection that this network must be symmetrical. It can also be seen that interchanging of the series and lattice arms has the only effect that an additional phase-shift of $\pm$ 180° is introduced in a signal passing through the network.

A symmetrical lattice network is the most general form of a symmetrical four-pole network and for any such four-pole network exists an equivalent lattice network.

10.1. SOME GENERAL RULES FOR SYMMETRICAL LATTICE NETWORKS

10.1.1. Bartlett's Bisection Theorem. If a four-pole network is symmetrical and in addition to that has a symmetrical structure in such a sense that it can be bisected (by a vertical cut) in two halves, one being the mirror image of the other, then the series and lattice arm impedances of the equivalent symmetrical lattice network can be obtained in a simple way from impedances of any one of these halves as seen from its terminal pair. The series arm impedance is obtained when all cut straight-through connections are connected together by a short-circuit and all cut cross connections are left open. The lattice arm impedance is obtained when all cut straight-through connections are left open and all cut cross connections are connected together by a short-circuit. It can be seen by inspection that the symmetrical lattice network itself complies with this theorem (see Fig. 5).

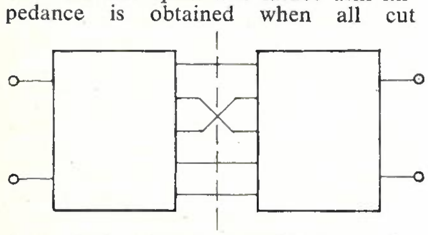


Fig. 5.—Bisection of a symmetrical network with symmetrical structure.

* See Page 298, Vol. 12, No. 4.

10.1.2. Extracting Equal Impedances from Series and Lattice Arms. If the series and lattice arms of a symmetrical lattice network have impedances which are partly equal, then these equal impedance parts may be extracted from the lattice network and connected outside to it in series, as shown in Fig. 6.

Similarly, if the series and lattice arms have admittances which are partly equal, then these equal admittance parts may be extracted from the lattice network and connected outside to it in shunt, as shown in Fig. 7.

The correctness of these equivalences may be verified by applying Bartlett's bisection theorem.

Sometimes it is possible to perform both extraction methods successively and thus simplify step by step the remaining lattice network.

10.1.3. Networks Equivalent to a Symmetrical Lattice Network. With the help of an ideal transformer with a centre-tap at one winding, equivalent networks to a symmetrical lattice network can be obtained whereby one series arm impedance and one lattice arm impedance can be spared. Not counting the transformer, these equivalent networks can be built with the minimum number of circuit elements which is required for any symmetrical network.

Whereas a symmetrical lattice network is always balanced to ground, the equivalent network (Fig. 8A) may be operated balanced or unbalanced to ground, and the network (Fig. 8B) only unbalanced to ground. (It may be modified for balanced operation.)

Network (B) in Fig. 8 is of special practical interest. It is essentially a bridged-T network and under certain conditions the ideal transformer (having infinite inductance and zero leakage inductance) can be replaced by a more practical transformer with a finite inductance and some leakage inductance. A finite inductance is possible if from the bridging impedance, $2Z_s$, a shunt inductance can be extracted and combined with the transformer. In addition, a leakage inductance can be tolerated if from the shunt impedance, $\frac{1}{2}Z_1$, a series inductance can be extracted and combined with the transformer. The equivalent circuit of such a transformer is shown in Fig 9.

L is the inductance of each half of the transformer. M is the mutual inductance between the two halves. Depending on the sense in which the two halves are connected together (series aiding or series opposing) the mutual inductance is positive or negative.

According to Bartlett's bisection theorem the network (B) in Fig. 8, with such a transformer gives the series and lattice arms of the equivalent lattice network, shown on Fig. 10.

$2Z'_s$ and $\frac{1}{2}Z'_1$ are the actual bridging impedance and shunt impedance, respectively, of the network (B) in Fig. 8.

10.2. THE IMAGE PARAMETERS OF A SYMMETRICAL LATTICE NETWORK.

The image impedances, which are equal at both network terminals, and

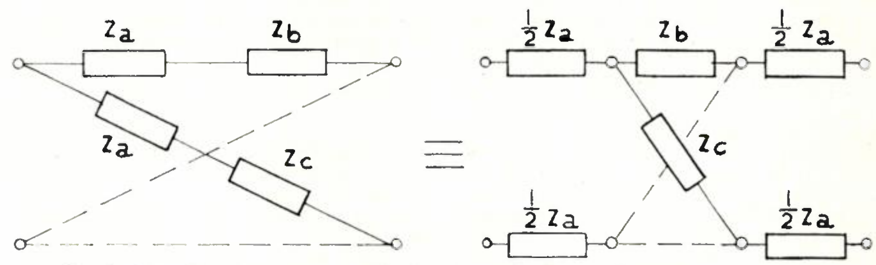


Fig. 6.—Extraction of a common series impedance from a symmetrical lattice network.

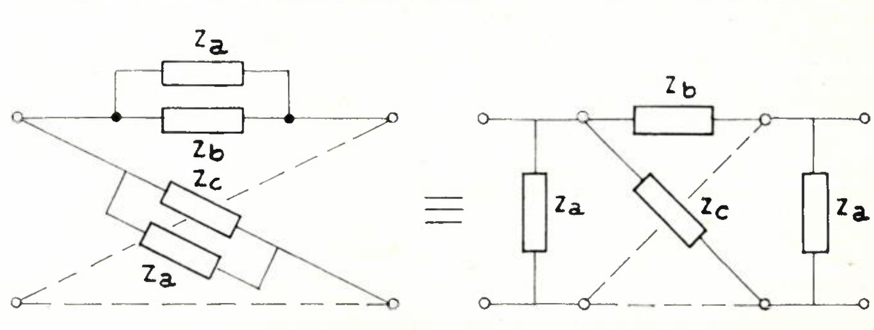


Fig. 7.—Extraction of a common shunt impedance from a symmetrical lattice network.

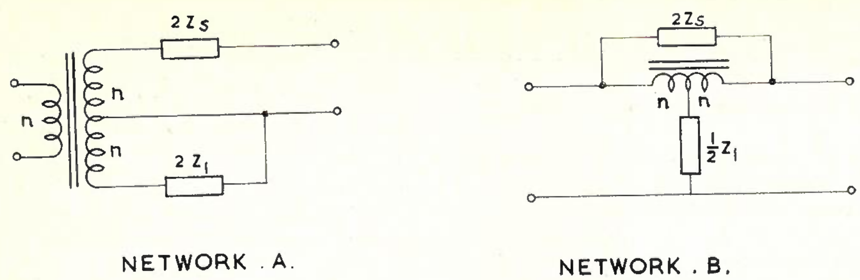


Fig. 8.—Equivalent circuits of a symmetrical lattice network.

the image transfer constant can be calculated with Eqs. (2.1) and (2.2) from the open-circuit and short-circuit impedances of a symmetrical lattice network:

$$Z_{oc} = \tfrac{1}{2}(Z_s + Z_l)$$

$$Z_{sc} = \frac{2Z_s Z_l}{Z_s + Z_l} \quad \ldots\ldots (10.1)$$

$$Z_I = \sqrt{Z_{oc} Z_{sc}} = \sqrt{Z_s Z_l} \quad \ldots\ldots (10.2)$$

$$\coth \theta = \sqrt{\frac{Z_{oc}}{Z_{sc}}} = \frac{Z_s + Z_l}{2\sqrt{Z_s Z_l}} \quad \ldots (10.3)$$

The relation between the image transfer constant and the series and lattice arm impedances can be simplified by making use of the following mathematical relationship:

$$\coth \theta = \frac{1 + \coth^2 \tfrac{1}{2}\theta}{2 \coth \tfrac{1}{2}\theta} \quad \ldots\ldots (10.4)$$

A comparison of Eqs. (10.3) and (10.4) yields:

$$\coth \tfrac{1}{2}\theta = \sqrt{\frac{Z_l}{Z_s}}$$

$$\theta = 2 \coth^{-1} \sqrt{\frac{Z_l}{Z_s}} \quad \ldots (10.5)$$

10.3 QUALITATIVE ANALYSIS OF LATTICE FILTERS

For the purpose of the design lattice filters are assumed to be pure reactance networks and the series arms and lattice arms are therefore considered as pure reactances having positive or negative imaginary impedance values at all real frequencies. According to the image parameter theory a pass-band is where coth θ is imaginary, and a stop-band where coth θ is real. Consequently, a lattice filter has a pass-band in any frequency band where the series arm reactance, Z_s, and the lattice arm reactance, Z_l, have opposite signs, in other words, where one of them is inductive and the other one capacitive. A stop-band is where Z_s and Z_l have equal signs, i.e., where both series and lattice arms are either inductive or capacitive. Attenuation peaks are situated in a stop-band at those frequencies (if any) where $Z_s = Z_l$, i.e., where the lattice filter is equivalent to a balanced bridge. A frequency where one of the reactances, Z_s or Z_l, changes its sign, but not the other one, is a cut-off frequency.

10.3.1. Foster's Reactance Theorem. According to Foster's reactance theorem the function of a reactance can be expressed in the following way:

$$Z = \frac{H(\omega_1^2 - \omega^2)(\omega_3^2 - \omega^2)\ldots(\omega_{2n-1}^2 - \omega^2)(\omega_{2n+1}^2 - \omega^2)}{j\omega(\omega_2^2 - \omega^2)(\omega_4^2 - \omega^2)\ldots\ldots(\omega_{2n}^2 - \omega^2)} \quad \ldots\ldots (10.6)$$

In this expression H is a positive constant, n is a positive integer, and between the various parameters of angular velocity the following relation must hold:

$$0 \leq \omega_1 < \omega_2 < \omega_3 < \omega_4 < \ldots < \omega_{2n-1} < \omega_{2n} < \omega_{2n+1} < \infty$$

The last factor, $(\omega_{2n+1}^2 - \omega^2)$, in the numerator of Eq. (10.6) may or may not be included in this expression. In the first case Z is infinite at infinite frequency, in the second case Z is zero there.

As $\omega_1, \omega_3, \ldots \omega_{2n+1}$ are the angular velocities where the reactance Z has zeros (i.e. values of zero), and $\omega_2, \omega_4, \ldots \omega_{2n}$ are the angular velocities where Z has poles (i.e. values of infinity), Foster's theorem says that zeros and poles of a reactance alternate along the frequency axis. At zero frequency and at infinite frequency a reactance must either have a zero or a pole. With rising frequency the value of a reactance always increases in a positive imaginary sense up to $+j\infty$ at a pole frequency. There it jumps to $-j\infty$ and increases again over zero to $+j\infty$, and so on.

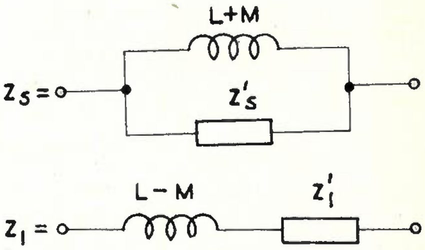


Fig. 10.—Series and lattice arms of a lattice network equivalent to network B in Fig. 8 with a non-ideal transformer.

The qualitative character of a reactance is therefore fully described by marking its zeros and poles on the frequency axis (see Fig. 11). Above a zero up to the following pole a reactance is always positive imaginary. Above a pole up to the following zero it is always negative imaginary.

10.3.2. Determination of Pass-Bands and Stop-Bands from a Schematic Representation of the Series and Lattice Arm Reactances. A representation of the series and lattice arm reactances in the schematic form of Fig. 11 gives sufficient information to determine the general character of a lattice filter, i.e., its pass-bands and its stop-bands. As in a pass-band the series arm reactance, Z_s, and the lattice arm reactance, Z_l, must have opposite signs, zeros of Z_s must coincide with poles of Z_l, and poles of Z_s must coincide with zeros of Z_l. In a stop-band Z_s and Z_l must have equal signs and therefore poles of Z_s and Z_l must coincide and so must their zeros. Any frequency where only Z_s or only Z_l has a pole or a zero is a cut-off frequency because there one of the reactances changes its sign, but not the other one.

As an example a band-pass filter is shown in Fig. 12. The imaginary regions of Z_I and coth ½ θ are marked by thick lines.

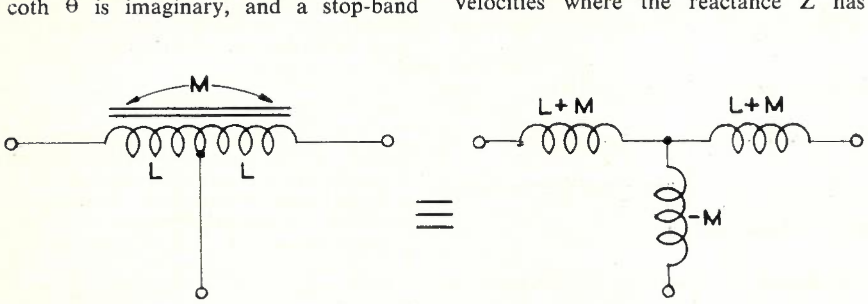


Fig. 9.—Equivalent circuits of a symmetrical transformer.

Fig. 11.—Distribution of poles and series of a reactance along the frequency scale.

10.4. SYNTHESIS OF LATTICE FILTERS.

The synthesis of a lattice filter proceeds in the opposite direction of the above qualitative analysis, i.e., the functions of the image impedance and of the image transfer constant are known from the previous design process and the series and lattice arm reactances of the filter have to be determined. This can be done by means of Eqs. (10.2) and (10.5) which yield:

$$Z_s = Z_I \tanh \tfrac{1}{2}\theta$$
$$Z_l = Z_I \coth \tfrac{1}{2}\theta \quad \ldots\ldots (10.7)$$

The function of the image impedance has been determined during the pass-band design and the function of the image transfer constant during the stop-band design. The latter is not directly known, but only indirectly through the cut-off and attenuation peak frequencies. This is, however, sufficient information for synthesising the function of coth $\tfrac{1}{2}\theta$ of the composite filter.

10.4.1. Synthesis of the Function of coth $\tfrac{1}{2}\theta$. The process of synthesis of coth $\tfrac{1}{2}\theta$ will be studied on the example of a normalised low-pass filter with two attenuation peaks, $\Omega_{\infty 1}$ and $\Omega_{\infty 2}$. The m-values of the corresponding m-derived ladder filter sections are (see Eq. (5.24)):

$$m_1 = \sqrt{1 - 1/\Omega^2_{\infty 1}}$$

$$m_2 = \sqrt{1 - 1/\Omega^2_{\infty 2}}$$

The image transfer constants of these sections are given by the expressions (see Eq. (5.23)):

$$\coth \tfrac{1}{2}\theta_1 = \frac{1}{m_1} \sqrt{1 - 1/\Omega^2}$$

$$\coth \tfrac{1}{2}\theta_2 = \frac{1}{m_2} \sqrt{1 - 1/\Omega^2}$$

The image transfer constant of the composite filter is:

$$\theta = \theta_1 + \theta_2$$

and coth $\tfrac{1}{2}\theta$ can be calculated with the help of the mathematical relationship:

$$\coth \tfrac{1}{2}(\theta_1 + \theta_2) = \frac{1 + \coth \tfrac{1}{2}\theta_1 \coth \tfrac{1}{2}\theta_2}{\coth \tfrac{1}{2}\theta_1 + \coth \tfrac{1}{2}\theta_2}$$

Introducing the above expressions of coth$\tfrac{1}{2}\theta_1$ and coth $\tfrac{1}{2}\theta_2$ gives after a slight algebraic conversion:

$$\coth \tfrac{1}{2}\theta = \frac{(1 + m_1 m_2)\,\Omega^2 - 1}{(m_1 + m_2)\,\Omega\,\sqrt{\Omega^2 - 1}}$$

Continuing in this way the function of coth $\tfrac{1}{2}\theta$ of a low-pass filter (and of any other filter) with an arbitrary number of attenuation peaks can be synthesised.

10.4.2. The Reactance Functions of Series and Lattice Arms. In continuing the above example it will be assumed that the pass-band design of the low-pass filter yielded an m-derived mid-series image impedance (see Eq. (5.4)):

$$Z_I = R_o \frac{\sqrt{1 - \Omega^2}}{1 - (1 - m_3^2)\,\Omega^2}$$

The factor m_3 need have no relationship with the factors m_1 and m_2 in the function of the image transfer constant, which are determined by the attenuation peaks. In other words, in a lattice filter it is not necessary to have an image attenuation peak at a frequency where the image impedance has a pole or a zero inside a stop-band.

The reactance functions of the series and lattice arms can now be calculated with Eqs. (10.7):

$$Z_s = \frac{R_o\, j(m_1 + m_2)\,\Omega\,(1 - \Omega^2)}{[1 - (1 - m_3^2)\,\Omega^2][1 - (1 + m_1 m_2)\Omega^2]}$$

$$Z_l = R_o \frac{1 - (1 + m_1 m_2)\,\Omega^2}{j(m_1 + m_2)\,\Omega\,[1 - (1 - m_3^2)\,\Omega^2]}$$

The sign of each reactance function follows from Foster's theorem.

10.4.3. Realisation of a Reactance Function. The realisation of a reactance function may be carried out in various structures and the possible variations increase with the degree of the function. For lattice filters the so-called partial fraction circuits are favoured. They can be realised with a minimum number of components and either their reactance zeros or their poles can be independently adjusted to the required frequencies. In the process of realisation either the reactance function (= impedance) or the reciprocal function (= admittance) is split up into a sum of simple partial fractions. These can be realised by inductances, capacities, and parallel resonant circuits or series resonant circuits, which are circuited in series or in parallel.

The general expression of a reactance function in partial fraction expansion is:

$$Z = \frac{1}{j\omega C_o} + \sum_{r=1}^{n} \frac{j\omega / C_r}{\omega_r^2 - \omega^2} + j\omega L_\infty \quad \ldots\ldots (10.8)$$

This function represents the series connection of a capacity C_o, an inductance L_∞, and a number of parallel resonant circuits with the capacities C_r and the inductances L_r resonating at the angular velocities ω_r:

$$L_r C_r = 1/\omega_r^2$$

Not all of the terms in Eq. (10.8) need be contained in a particular reactance function.

The general expression of a reciprocal reactance function in partial fraction expansion is:

$$Y = \frac{1}{j\omega L_o} + \sum_{r=1}^{n} \frac{j\omega / L_r}{\omega_r^2 - \omega^2} + j\omega C_\infty \quad \ldots\ldots (10.9)$$

This function represents the parallel connection of an inductance L_o, a capacitance C_∞, and a number of series resonant circuits with the inductances L_r and the capacities C_r resonating at the angular velocities ω_r. Here again some of the terms in Eq. (10.9) may be missing in a particular function.

The realisation of a reactance function in the form or Eq. (10.8) will be discussed in some detail. The realisation in the form of Eq. 10.9) can be carried out in an analogous way.

A reactance function is the quotient of two polynomials S (ω) and T (ω):

$$Z(\omega) = \frac{S(\omega)}{T(\omega)}$$

These polynomials may be given in ordinary polynomial form or in factorised form, as in Eq. (10.6). The zeros of the polynomial T(ω) are the angular velocities $\pm\,\omega_r$ in Eq. (10.8) and a possible zero at $\omega = 0$, and unless T(ω) is already given in factorised form its zeros have first to be calculated by solving the equation:

$$T(\omega) = 0$$

The calculation of the component values of the partial fraction circuit from the given reactance function, Z(ω), may be carried out with the help of formulae whose derivation is very straight forward if Z is considered in its partial fraction expansion.

The value of C_o is obtained through multiplying Z by $j\omega$ and evaluating for $\omega = 0$. All terms of Z in Eq. (10.8) be-

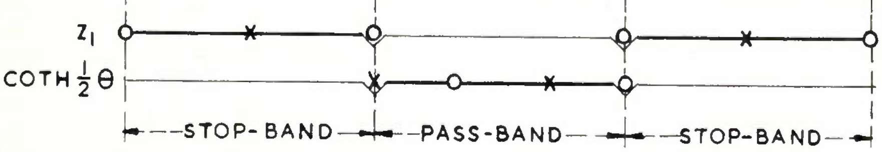


Fig. 12.—A possible distribution of poles and zeros of the series and lattice arm impedances and of the image parameters of a band pass filter.

come zero, barring the first term which becomes $1/C_o$; in other words, C_o is given by the relation:

$$C_o = \left(\frac{1}{j\omega Z} \right)_{\omega = 0} \quad \text{.... .... (10.10)}$$

The value of L_∞ is obtained in a similar way through dividing Z by $j\omega$ and evaluating for $\omega \longrightarrow \infty$. All terms of Z disappear with the exception of the last term which becomes L_∞, i.e.:

$$L_\infty = \lim_{\omega \to \infty} \frac{Z}{j\omega} \quad \text{.... .... (10.11)}$$

The value of C_r in any one of the terms comprised by the summation sign is obtained through multiplying Z by the factor:

$$\frac{\omega_r^2 - \omega^2}{j\omega}$$

and evaluating for $\omega = \omega_r$. All terms of Z become zero with the exception of the relevant term

$$\frac{j\omega/C_r}{\omega_r^2 - \omega^2}$$

which becomes $1/C_r$, i.e.:

$$C_r = \left(\frac{j\omega}{Z(\omega_r^2 - \omega^2)} \right)_{\omega = \omega_r}$$

$$L_r = \frac{1}{\omega_r^2 C_r} \quad \text{.... .... (10.12)}$$

In this formula the factor $(\omega_r^2 - \omega^2)$ cancels against a similar factor in the denominator of Z.

10.5. DESIGN OF OTHER FILTER TYPES IN LATTICE STRUCTURE.

High-pass filters and frequency-symmetrical band-pass and band-stop filters in lattice structure may be derived from normalised low-pass lattice filters in the same way as previously shown for ladder filters, i.e., by applying the proper reactance transformation to the individual elements of the low-pass filter.

If a frequency-unsymmetrical band-pass filter is required in lattice form the design procedure is analogous to the design of low-pass filters. The function of the image impedance will normally be frequency-symmetrical and can then be obtained by transforming the image impedance of a suitable type of a normalised low-pass filter with the reactance transformation of Eq. (8.2). The function of coth $\frac{1}{2}\theta$ must be built up from functions like Eq. (9.1) in the same principal way as it has been shown for low-pass filters. The rest of the design process also remains the same.

10.6. INSERTION PARAMETERS OF LATTICE FILTERS.

The insertion transfer constant of a symmetrical lattice network is given by the relation (derived e.g. in the book by F. Scowen):

$$P_L = A_L + jB_L = \ln \frac{(R + Z_s)(R + Z_l)}{R(Z_l - Z_s)} \quad \text{.... .... (10.13)}$$

A_L = insertion loss in nepers,
B_L = insertion phase-shift in radians,
R = terminating resistance (the same at both network ends).

In the case of a lattice filter the series and lattice arm impedances Z_s and Z_l, are pure reactances and may therefore be written in the following way:

$$Z_s = jX_s \qquad Z_l = jX_l$$

where the values of X_s and X_l are real and positive or negative.

Referring these reactances to the terminating resistance gives:

$$x_s = \frac{X_s}{R} \qquad x_l = \frac{X_l}{R}$$

and the insertion loss and insertion phase-shift can be expressed as follows:

$$A_L = 20 \log \frac{\sqrt{(1 + x_s^2)(1 + x_l^2)}}{|x_s - x_l|} \text{ in db} \quad \text{.... .... (10.14)}$$

$$B_L = \text{ar tan} \frac{x_s x_l - 1}{x_s + x_l} \quad \text{.... .... (10.15)}$$

By introducing the angular parameters φ and ψ defined by

$$\tan \varphi = x_s \text{ and } \tan \psi = x_l \quad \text{.... (10.16)}$$

Eqs. (10.14) and (10.15) can be transformed into the following simple formulae which are very easy to evaluate:

$$A_L = 20 \log \text{cosec} |\varphi - \psi| \quad \text{.... .... (10.17)}$$

$$B_L = \varphi + \psi + (2n-1)\frac{\pi}{2} \quad \text{.... .... (10.18)}$$

where n is an integer.

Eq. (10.17) is particularly suited for calculating the insertion loss in the pass-bands and in the transition bands of lattice filters where the values are comparatively small. For losses exceeding 20 db it is preferable to use the approximate formula

$$A_L \doteq 20 \log \left| \frac{1 + x_s x_l}{x_s - x_l} \right| \quad \text{.... (10.19)}$$

because for large loss values Eq. (10.17) needs a very accurate determination of the angles φ and ψ.

10.7 PRACTICAL SHORTCOMINGS OF LATTICE FILTERS

The image attenuation of a filter is determined by the positions of the attenuation peaks and it is therefore necessary to adjust the peak frequencies with adequate accuracy (increasing with the required attenuation) and to maintain them within correspondingly small tolerances. This constitutes no serious problem in ladder filters because here the attenuation peak frequencies are the resonant or anti-resonant frequencies of shunt or series branches, respectively, which can be independently adjusted and, if required, made fairly insensitive of temperature changes by combining capacitors and inductors with approximately opposite equal temperature coefficients.

In lattice filters the attenuation peaks are situated at those frequencies where the reactances of the series and lattice arms have identical values. The more attenuation peaks are produced in a single lattice the more difficult is their adjustment (because they cannot be adjusted independently) and the more sensitive is the adjustment to variations of the component values with time and temperature. For the latter reason alone it is impracticable to build lattice filters in one section with a large stop-band attenuation unless very stable components are used, such as quartz crystal resonators. Lattice filters seen in practice are therefore frequently filters whose main components are very stable electro-mechanical devices.

The requirement of high component stability in lattice filters may be somewhat relaxed if the filter is split up in two or more sections which are in themselves symmetrical and can individually be realised in lattice structure. This, however, is done at the cost of an increased number of circuit elements, especially when m-derived image impedances are required.

10.8. PRACTICAL ADVANTAGE OF LATTICE FILTERS

The main advantage of lattice filters as compared with ladder filters is that they give a somewhat wider range in the choice of the design parameters. For example, the equivalent of an m-derived low-pass filter π-section is a lattice filter with series arms consisting of a parallel resonant circuit each with the inductance mL_o and the capacity C_o/m, and with lattice arms each consisting of the capacity mC_o. (L_o and C_o are the elements of a constant-k half section.)

The ladder section cannot be realised for $m > 1$ because the capacity of the parallel resonant circuit in its series branch would become negative. No such restriction exists for the equivalent lattice filter. Any real, positive number may be chosen for m. Eq. (5.5) shows that for $m > 1$ the attenuation peak frequency becomes imaginary. With lattice filters of higher order conjugate complex image attenuation peaks may be produced.

The practical importance of this increased freedom in the choice of the attenuation peaks lies in the possibility of designing filters with approximately linear insertion phase-shift characteristics in pass-band and transition band. If such a characteristic is required for a ladder filter an additional all-pass net work must be provided to equalise the phase-shift, and even this is difficult if the linear phase characteristic must extend beyond the practical pass-band well into the transition band. A case like this may arise when minimum distortion of the amplitude versus time characteristic of a transmitted signal is essential.

In the design process of a lattice filter for such a purpose the specified insertion phase-shift is the predominant filter characteristic and the stop-band insertion loss near the transition band has to be accepted as it will turn out. The design is based on Eq. (10.18) which shows that for every series arm or lattice arm reactance change from a zero to a pole, and from a pole to a zero, a phase change of $\pi/2$ is produced. In the pass-band, where poles and zeros of the series arm reactance must coincide with zeros and poles of the lattice arm reactance, every section on the frequency axis between a pole and a zero, and vice versa, produces a change in phase shift of π and these sections must therefore have equal lengths on a linear frequency scale.

At the cut-off frequency only one pair of the reactances has a pole or a zero. Hence, in the section from the preceding zero or pole to the following zero or pole the total phase change is $3\pi/2$ and the length of this section on the frequency scale must be 1.5 times the length of a pole-zero section within the pass-band. The pole or zero following the cut-off frequency, which is in both series arm and lattice arm reactances, produces an insertion loss peak due to reflection loss and beyond this peak one or two further reactance zeros or poles are required in the stop-band which also produce reflection loss peaks. Their spacing along the frequency axis is determined by its influence on the phase-shift between reactance poles and zeros near the end of the pass-band and in the transition band.

In a design of this sort no image attenuation peaks may occur at real frequencies. Most of them or all of them will be situated at imaginary or conjugate complex frequencies.

ACTIVITIES OF THE SOCIETY IN WESTERN AUSTRALIA

Formation: The inaugural meeting of the Western Australian Branch of the Society was held last March, at which the State Committee was elected. This State Committee consists of the following officers:

Chairman: Mr. J. H. White;
Secretary: Mr. J. Mead;
Treasurer: Mr. J. A. Farrell.
Third Division Representatives: Messrs. L. A. Jones, J. Smith, W. L. Caudle and J. B. Minchin.
Fourth Division Representatives: Messrs. R. Wearmouth, T. Neville and L. D. Wilkinson.

At this meeting the Constitution and aims and objects of the Society were discussed. At subsequent committee meetings, a programme covering the general meetings for the Branch for the first financial year was tabled and tentatively adopted.

General: The first general meeting of the Society was held in August. This was attended by quite a good gathering of both members and visitors and it was pleasing to see representatives from many telecommunication firms. The subject for the meeting consisted of a talk on Television by Mr. G. H. Hatton, of the Perth Technical College. Mr. Hatton's lecture was well received, as was indicated in the barrage of questions directed to him at the conclusion of the paper. A tape recording was also made of the complete lecture and it is anticipated that from this recording a precis will be roneod and distributed to country members. This has to be further investigated and it is hoped that such action will be possible at all general meetings.

The second general meeting will be held on the 27th October, and will consist of a talk on "Communications in the Department of Civil Aviation," by officers of that administration. It is proposed that this paper be presented, firstly, by an Engineering officer, who will describe the technical facilities provided, and, secondly, by an Operations Superintendent, who will discuss the operational side of the network.

The general interest shown in the Society has been quite pleasing to the State Committee and further efforts are being made to expand the membership and Journal subscription over a larger area. Representations have also been made to various institutions, technical bodies and companies interested in the telecommunication field to obtain both members and guests at our meetings. The reaction so far has been one of gratitude and it is anticipated that personnel not connected with departmental activities will become more interested as the Society becomes wider known.

BACK COPIES

The Society has available in quantity, back copies of most issues of the Journal from Volume 5 onwards. Volume 12, Number 1 is out of print, but reprints of the two articles on co-axial cables may be obtained for a total cost of 3/-.
These Journals may now be supplied, on demand from State Secretaries* at 10/- per set of three or at 4/- per single copy.
Back copies of some earlier numbers are available, but it is recommended that inquiry first be made to the State Secretary,* as to the availability of any particular number. In the event of the Society being unable to supply any number, it will act as an agent to assist subscribers in obtaining a copy. The Society does not repurchase Journals, but readers having copies which are no longer required should give details to the State Secretary*, who may thus be able to advise other readers where the back copies may be obtained.

* For addresses see page 379.

QUALITATIVE MAINTENANCE IN MANUAL EXCHANGES

*W. A. STIRLING.**

INTRODUCTION

For the past two years qualitative maintenance has proved to be successful in automatic exchanges. These exchanges, particularly when random choice trunking is used, lend themselves well to the practice of qualitative maintenance, and as a result, figures are now available which show a considerable reduction in fault incidence on electro-mechanical equipment. As there is still a considerable number of manual exchanges throughout the Commonwealth, serious consideration should be given to the improvement of the grade of service by the adoption of some, if not all, of the principles embodied in qualitative maintenance.

Principles of Qualitative Maintenance: Briefly, the aim of qualitative maintenance is to measure the overall grade of service and direct attention to individual components which appear to be causing serious deterioration of this service. Indicators are used to determine the overall grade of service given by a telephone exchange, and the condition of the individual switching circuits in the exchange. The object is to perform maintenance projects according to the actual service needs of the equipment as revealed by the indicators used.

PROVIDING SERVICE IN MANUAL EXCHANGES

The method and equipment used in the larger manual exchanges to provide service to the telephone subscriber can be divided into a number of categories:

Local Calls — The method of connection is via the local "A" position and the items of equipment utilised are cords, keys, lamps, jacks, relays and dials.

Trunk Calls — Provided via "A" position and trunk position or trunk position only, the equipment consisting of cords, keys, lamps, jacks, timing devices, dials and relays.

Junction Calls — Provided by means of B positions utilising cords, keys, jacks, lamps and relay sets.

Semi-Automatic Trunk Calls — Provided by means of relay sets and electro-mechanical switches.

It can be seen that the type of equipment which is used to provide service consists mainly of cords, keys, relays and lamps.

INTRODUCING QUALITATIVE MAINTENANCE INTO A LARGE MANUAL EXCHANGE

The particular exchange where the principles of qualitative maintenance were introduced was a common battery multiple type having 2,700 subscribers connected, 110 Trunk lines and 85 junction lines. The equipment consisted of 8 C.B. multiple "A" positions, 2 C.B. non-multiple positions, 3 "B" positions and 17 trunk positions.

The first consideration, even before use was made of any indicator, was cleanliness. Floors were treated in such a manner as to prevent the accumulation of dirt and dust, and when this was done the cleaning in the equipment room was carried out by means of a vacuum cleaner to reduce the possibility of dust movement. Mats were provided at room entrances and these were cleaned daily. Staff movement in equipment aisles was reduced to a minimum and lockers and circuit cabinets, etc., were repositioned to a location remote from any switching equipment. Elimination of dust by regular dusting of the equipment was considered on its merits, and was introduced where necessary as a result of detailed fault analysis. When a state of cleanliness in the exchange had been achieved, then particular attention was given to analysing the plant performance by means of the indicators used.

The standard fault recording system for large manual exchanges was used but the information it gave in itself was found to be lacking in essential details. To obtain sufficient information to determine where maintenance activities were most essential it was necessary to make a detailed analysis of fault dockets on a periodic basis. As a result a supplementary recording system was introduced, and fault dockets were classified and sorted into groups at the end of each month as indicated in Fig. 1.

TRIAL RESULTS

After this system had been operating for a period of three months certain conditions became evident, the first being that relay faults in the later-type switchboards where relay sets and covers were provided were practically non-existent. In the boards where the relays were strip mounted and no covers provided, the fault incidence was high, and further analysis showed a predominance of dust faults.

Secondly, the number of faults on switching cords was investigated and it was found that cords were being replaced due to noise being detected when tested in the standard test circuit. A large percentage of these cords were noisy due to slight movement of the sleeve connection which was not sufficient to cause an open circuit. From this it was concluded that the cord would have given further service without any adverse effect for some considerable time.

Thirdly, the number of key faults were not excessive but in the main were caused by some dry joints and mostly by wires being broken off due to handling, installation activities, and replacement of worn keys, etc.

Fourthly, unstandard conditions were listed under cords, keys and plug shields. This analysis showed that cracked and broken shields accounted for a big percentage of unstandard conditions. Also, the incidence of frayed cords and sticking keys was high.

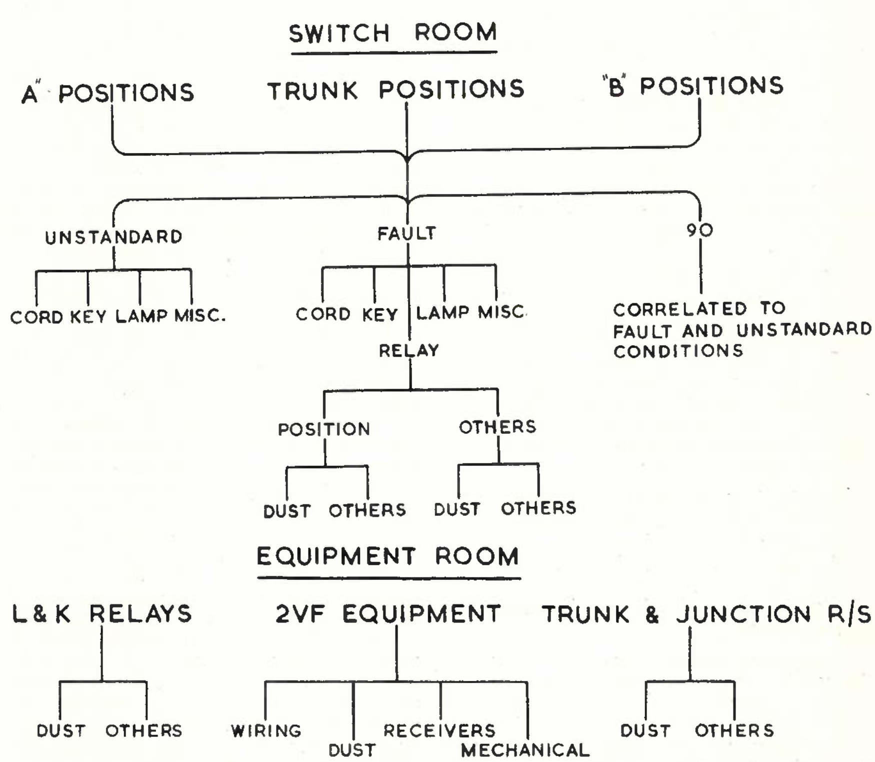


Fig. 1.—Analysis of Faults.

* See page 378.

INITIAL CORRECTIVE ACTION

Relay Faults: Where relays were mounted in strips without covers the switchboard was completely cleaned by means of a vacuum cleaner. All relays were inspected, armatures and knife edges cleaned, and contacts burnished. Following this, plastic sheets were placed over the complete relay bank, care being taken to ensure that the plastic was kept clear of equipment such as resistors, etc., which generated heat. Emphasis was placed on keeping the backs of the switchboard on, except when necessary to carry out maintenance. The area at the rear of the switchboards was kept free of equipment, etc., and the floor vacuumed regularly.

Switching Cords: The cord test circuit as shown provides for testing of all three conductors, i.e., tip, ring and sleeve, for noise. As the sleeve circuit will perform its proper function even though the sleeve connection may be noisy, a second cord test circuit was provided for use by the telephonists, this circuit providing tests for noise on the tip and ring conductors only, and sleeve continuity. Each cord was then routine tested weekly by a technician using both test jacks, and if any doubt existed after testing as to whether the cord would perform its proper function, it was replaced. (See Fig. 2.)

even though codes indicated pitted contacts, relay adjustment incorrect, etc., and faults due to dust, it was assumed that nearly all faults were due to dust, and a small percentage only due to routine maintenance and handling of the equipment. As a result all routine inspections of relays and relay sets were stopped and this was substituted by regular dusting using a cloth very slightly moistened with fine oil, which would leave an invisible film on the covers and thus trap dust particles.

The faults on 2VF equipment, when analysed, fell into two main categories, mechanical on motor uniselectors and dust in the relay sets. The relay sets were then treated in a similar manner as for the L. & K. and Trunk and Misc. relay sets, that is, regular dusting but on a daily basis.

Further analysis of the mechanical faults revealed, also, that these were due mainly to dust becoming impregnated with the lubricants and this resulted in the parts being washed in industrial solvent without completely dismantling and disturbing the initial adjustments. In the particular exchange concerned the periodicity of lubrication was laid down as three-monthly, this being determined by the number of release alarm faults which occurred when the motor uniselectors were not lubricated for a period of four months. When these were investigated it was found that the speed of rotation of the wipers was below normal due to thickening of the lubricant and to a lesser degree, dust accumulation on the banks.

Yet another condition revealed by the analysis was the greater number of release alarms in the summer compared to the winter months. The adjustment tolerance was such that with the expansion of the metal parts at high room temperatures the clearance between the latch arm and the wiper gear was reduced, in some cases binding occurred. To obviate the necessity of altering the standard adjustments, an exhaust fan was provided at the end of the equipment room and two large floor-type fans were placed in such a position to assist airflow through the equipment room without blowing directly on any relay sets, etc. Air intake was via the doors of the equipment room which opened out into a corridor on the first floor of the building.

To further assist in determining the cause of faults in the 2VF equipment and if possible, to establish a pattern, sheets were provided for entering full details of the fault condition as shown. This analysis showed that the faults fell into four main categories.

1. Pitted contacts on BA and Z relays causing the contacts to permanently make.
2. Relay timing (B relay).
3. Receivers (Valve failure).
4. Mechanical (Incorrect positioning of motor uniselector wipers in the banks).

The action instituted to correct these fault conditions was, firstly, a thorough inspection of all BA and Z relays for excessive contact pitting, and in nearly all cases it was possible to correct this condition by removal of the tip formed and burnishing, without removing the relay set from the rack.

The number of faults due to incorrect B relay timing did not warrant any special investigation as an examination of the armatures, knife edges and pole pieces did not reveal an excess of dirt which would affect the timing.

A receiver tester was provided at the time these findings were made, and since regular routine testing of the receivers has been carried out, receiver faults have been almost entirely eliminated. Even though the value of routine testing of 2VF receivers was apparently proven, still further investigations were carried out, details of which will not be discussed here, but sufficient to say that the tolerances laid down were proved to be too stringent.

In regard to mechanical faults, these were overcome by re-adjustment of the wipers, the positioning of which was found to be quite critical.

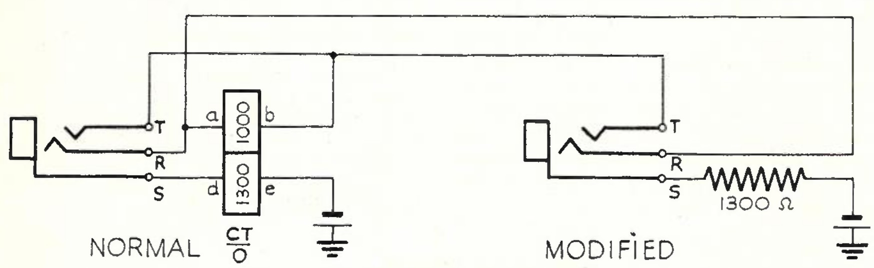


Fig. 2.—"A" Position Cord Test Circuit.

Key Faults and Unstandard Conditions: Prior to the decision to introduce a form of qualitative maintenance regular routine maintenance was carried out only sporadically due to staff shortages. As a result, the incidence of unstandard conditions on keys, cords, plugs, lamps, etc., was high. Action was taken to have all switchboard key shelves, etc., completely checked and all broken and worn parts, particularly key yokes and shields, replaced. Nearly all the shields which were cracked were of a type made from brittle plastic and these were found to be easily broken, particularly in cold weather. All of these types of shields were replaced by an improved type which was available at that time.

Routine inspections of key shelves, etc., was introduced and each board was checked on a weekly basis. Also, routine testing of all cords on "B" positions was carried out on a monthly basis, and a special cord-test circuit was installed for this purpose.

Equipment Room: Dockets relating to faults in the equipment room were grouped under three main headings:—2VF, L. & K. relays, and Trunk and Misc. Relay sets. In considering faults on L. & K. and Trunk and Misc. relay sets,

MAINTENANCE PROGRAMME ADOPTED

From the result of these findings, which were established after 12 months of investigation, a definite maintenance programme was instituted as follows —

Manual Equipment Room

Local A Positions — Routine inspection of keys, cords, supervisory lamp caps, on a weekly basis, that is, one position per week to reduce the incidence of unstandard conditions. Routine testing of cords in both test jacks, all cords on the suite being tested weekly.

B Positions — Routine inspection of keys, cords, lamp caps, all to be completed weekly. Routine testing of all cords by means of special test circuit on a monthly basis.

Trunk Positions — No definite programme was laid down for maintenance of these positions as the fault analysis showed a predominance of lamp faults which, when investigated, was not considered high for the number installed.

Equipment Room

Relay and Relay Sets.—Examinations were completely eliminated and replaced by regular dusting on a weekly basis. 2VF Receivers were tested at 3-monthly intervals, using a rapid method of testing which had previously been established as satisfactory after thorough investigation.

Trunk Selectors (Seimens motor uniselectors).—These switches were cleaned and lubricated three monthly and the mechanical adjustment checked at the same time. No attempt was made to alter the adjustment if the rotary was satisfactory.

Bimotional Trunk Selectors. — Bimotionals were cleaned and lubricated yearly and banks and wipers were cleaned and inspected at the same time.

Signalling Equipment. — 2VF outlet and poling tests were carried out each quarter. The value of these tests, where installation work is being carried out, cannot be sufficiently recommended. Their value at times other than when installation is in progress would have to be assessed according to the type and size of the transit centre.

All 2VF relay sets and associated equipment were dusted daily.

RESULTS ACHIEVED BY QUALITATIVE MAINTENANCE

To assess the results achieved it is necessary to, once again, divide the equipment into two sections, that is, firstly, manual positions, and secondly, relay set and mechanical equipment.

In regard to the manual "A" positions and trunk positions no appreciable improvement has been achieved with fault conditions under the category of Keyboard and Switchboard classification, but it has been established that at least 50% of the faults are due to cord failure. The cord life has been determined as being three months on "A" positions and it is intended to arrange to have the cords changed at approximately 3-monthly intervals on a trial basis. It is not considered that the incidence of faults on these positions is of such a nature to cause serious degrading of the service, as the cords are not used when a fault condition has been detected.

To further assist in the reduction of faults on manual "A" and trunk positions, sheets were drawn up showing the individual items of equipment on each board, and the faults code associated with the particular circuit was entered on the sheets. This enabled the recurrence of faults to be investigated, and intermittent faults to be detected and rectified (see Fig. 3).

1960	POSITION No.........																
CORD	Answer 1	Calling 1	A2	C2	A3	C3	A4	C4	A5	C5	A6	C6	A7	C7	A8	C8	MISC.
JAN	90A 90A IRP	UIFD IRP	90A IRP	UIRP	UIFD U19SR	UIFD IRP		IRP	90A 90A IRP U19SR	90A IRP	U19SR IRP		90A IRP		IRP UIZ	IRP	90A Cutting Out
FEB	IRP	UIWT UI9SR						UI9SR					UIFD			UI9SR	
MARCH		UI9SR								U19SR UI9SR							
APRIL	90A 90A IW		IRP	IRP		UIFD		UI9SR				IRP 90A			IRP UIWT		U2DM
MAY																	
JUNE																	

KEYS	Speak	Ring Monitor	SP	RM	SP	RM	SP	RM	SP	RM	SP	RM	SP	RM	SP	RM	MISC.
JAN													UI4SA				2DM 2W
FEB																UI4SA	UIIOP
MARCH	UI4SA I4KR UI4SA					I4RT											90A(Dial)
APRIL						I4RR											100 Shocks
MAY																	
JUNE																	

Fig. 3.—Present Recording System. Similar sheets are used for recording faults on timing devices, meter keys, etc.

YEAR	POSITION A1									REMARKS
1959	UNSTANDARD CONDITION				FAULT CONDITION				F.O.K.	
MONTH	Key	Cord	Shield	Misc.	Key	Cord	Relay	Misc.	100	
JULY	2	3	8	1		7		5	4	NIL
AUGUST	2	4	11		2	12			2	NIL
SEPTEMBER		3	3	2		4	1	1	3	A2 CLEANED AND RELAYS COVERED
OCTOBER	1	4	4			6			1	PLUG SHIELDS REPLACED
NOVEMBER		3	2			3		4		NIL
DECEMBER			1			4			1	ROUTINE INSPECTIONS OF BOARD

Fig. 4.—Detailed Analysis of Faults on Switchboard. Relays covered on position A1 and uncovered on position A2. Similar sheets used for all switchboard positions.

YEAR	POSITION A2									REMARKS
1959	UNSTANDARD CONDITION				FAULT CONDITION				F.O.K.	
MONTH	Key	Cord	Shield	Misc.	Key	Cord	Relay	Misc.	100	
JULY	6	4	8			5	9	2	3	NIL
AUGUST	3		8	2	3	3	13	1	3	NIL
SEPTEMBER	10	1	8			6	12		4	A2 CLEANED AND RELAYS COVERED
OCTOBER	4	2		1	1	6		1	4	PLUG SHIELDS REPLACED
NOVEMBER	1	4	2		1	8		4		NIL
DECEMBER	3	5	2			5	1	3	1	ROUTINE INSPECTIONS OF BOARD

Detailed analysis of faults on switchboards position A1, relays covered. A2 relays uncovered. Similar sheets used for all switchboard positions

With regard to unstandard conditions, which impair the efficient operation of the board and cause inconvenience to the operator resulting in loss of operating time, there was a reduction from 1,777 in 1957-1958 to 1,246 in 1958-1959 and 989 in 1959-1960, an overall improvement which has cut the number of faults in half. The trial commenced in July, 1958.

In the classification of relay faults no discrimination is made here between relays mounted in the switchboards and those in relay sets in the equipment room. The total figures for 1957-1958 were 409, 1958-1959, 206, and 1959-1960, 103, which represents a reduction of faults to only a quarter of the number experienced previously.

The fault incidence on 2VF equipment has been reduced from 194 faults in 1957-1958 to 108 in 1958-1959, and to 52 in 1959-1960. It is of interest to note that this represents a plant performance figure of less than one fault per 2VF trunk line per annum.

CONCLUSION

The results achieved have been due to careful analysis of the faults and from the indicators used, the establishment of certain patterns, enabling maintenance activities to be concentrated where most required. As corrective action has now been taken the type of fault most occurring will, to some extent, change, and those fault patterns which were not obvious at the time, due to the predominance of high fault incidence in known categories which has now been reduced, will become evident. Therefore, it will be necessary to continue investigations still further to achieve the ultimate aim of fault-free service.

ACTIVITIES OF THE SOCIETY IN TASMANIA

Formation: The inaugural General Meeting of the Tasmanian Division of the Telecommunications Society was held in Hobart on Wednesday, 8th June. The Chairman (Mr. G. W. Larsson) outlined the history, aims and proposed activities of the Society, and then invited nominations for office-bearers for the ensuing year. A ballot resulted in the following being elected:—

Secretary: Mr. A. Traill;

Treasurer: Mr. L. S. Abbott;

Committee, 3rd Division Representatives: Messrs. I. J. LeFevre, C. W. Millar, L. R. Jensen, K. C. Newham.

4th Division Representatives: Messrs. M. W. Verrier, W. E. Grubb, J. P. Stevens.

Proxy Representative to the Council of Control: Mr. A. N. Birrell.

Lectures: At the suggestion of this Meeting it was agreed that lectures would be arranged at bi-monthly intervals, although the Committee would have the power to arrange additional lectures as necessary. The first such lecture meeting was held on 2nd August, when Mr. Bryan Madeley, of Central Office, who had been in charge of acceptance testing for the National TV transmitter on Mt. Wellington (ABT2) addressed an audience of approximately 130 members on the principles of TV, TV transmitters, aerials and TV receivers.

This gratifying interest in the Society's activities was maintained on Thursday, 15th September, when, once again, an audience of some 130 members gathered to hear a lecture entitled "Introducing Crossbar," given by Messrs. L. F. Smith and J. E. A. Cross (Engineering Division, P.M.G.'s Department, Hobart). Both lecturers had attended a course on Crossbar switching equipment at Toowoomba, in Queensland, and were able to give the meeting an outline of the merits and mechanics of the new switching system.

A further series of more specialised lectures on Crossbar equipment has now been arranged and the first of these lectures is to be given by Mr. Smith and Mr. Cross on Thursday, 29th September. It is expected that these lectures will be held at fortnightly intervals over a period of approximately three months.

Lectures to be given at the next two normal bi-monthly meetings are as follows:

11th October: "The Employment of Research in the P.M.G.'s Department," to be given by Mr. N. McCay, Supervising Engineer, Research, P.M.G.'s Department.

December: "Missiles and Satellites" (Speakers yet to be arranged).

Membership: The membership of the Society has now risen to 261 members and 200 subscribers to the Journal. The increase in activity, since the formation of the Division in this State, may be gauged by comparing the increase in subscriptions to the Journal which last year stood at 71.

Although the proportion of members in Country areas is relatively low in this State, it has been possible to maintain the interest of these members in the activities of the Society, firstly, by distributing a tape recording of the lecture on TV to the Launceston and Burnie Areas, and secondly, by arranging for the Crossbar lecture to be repeated at these centres. A series of papers on Crossbar will also be distributed to all members.

COAXIAL CABLE AMPLIFIERS

*F. M. SHEPHERD, B.E., A.M.I.E.Aust., M.I.R.E.Aust.**

INTRODUCTION

Carrier telephone systems making use of a wide bandwidth signal transmitted along coaxial transmission lines are beginning to make their appearance in Australia. Since performance, to a large extent, depends on the repeater amplifiers, an outline of the problems involved and the conditions to be met will probably be of interest to technical staff, especially those stationed along the future routes of such cables.

AMPLIFIER BANDWIDTH AND GAIN

The first requirement of a repeater is that it should compensate for the attenuation of signal due to cable loss. The wideband signal to be transmitted on the coaxial line is formed by frequency changing and arranging processes so that each telephone channel is, in effect, occupying an allotted 4 Kc/s portion of the final signal spectrum, the extent of which depends on the number of channels assigned to the system design, for example, something close to 6.2 Mc/s for a 1,200-channel system or 8.4 Mc/s for an 1,800-channel system. Alternatively, a television source may produce the signal in accordance with laid down standards where bandwidths of the order of 6 Mc/s are required for the Australian Standards, the bandwidth depending, to a certain extent, on the communication system modulating processes. We will not mention systems of bandwidth reduction on which much work has been done. The cable attenuation is dependent upon frequency, increasing proportionally with its square root. The question of variations of attenuation with temperature will be mentioned later.

We can see that before further progress is possible we must have an amplifier with quite large bandwidth, and with gain dependent on the cable loss between successive amplifiers, since the general design philosophy is that each repeater amplifier should compensate for its own section of cable loss as closely as possible. This process has limits which are inherent in amplifier and system design and in manufacturing processes.

A few words regarding the design limitations in wideband amplifiers will now be in order. As an introduction to the fundamental difficulties we consider the simple pentode amplifier (Fig. 1) in which

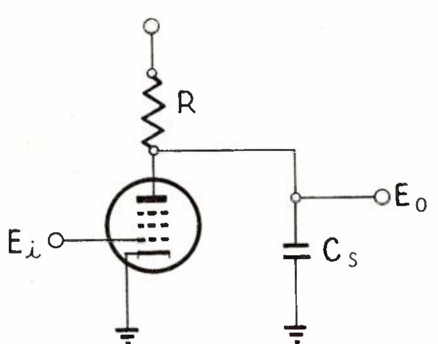


Fig. 1.—Pentode Amplifier.

* See page 378.

stage gain is approximately given by gmR, where R is the anode load resistance and gm the tube transconductance. If there were no stray capacitance between anode and ground, that is, across the output circuit, we could make R as large as we pleased (provided we had a suitable HT supply) and so increase the stage gain to any desirable figure. However, it is clear that as the frequency increases the stray capacitance will short circuit the load R more and more, for example, let gm be 10 mA/V and Cs be 33 pf. With R = 100,000 ohms at frequency 10 Kc/s, the stage gain will be 1,000. The effect of Cs will be small. At 100 Kc/s the reactance of Cs will be lower and the stage gain will be reduced to about 300 times, and at 1 Mc/s to 30 times. This demonstrates, in a crude way, that the stray capacitance lowers the available stage gain as frequency increases.

It also demonstrates less clearly a relationship between stage gain and bandwidth, which is defined in a low pass amplifier by the frequency at which the gain drops below the mid-band value by a defined amount, usually 3 db. In the case of the example above, the 3 db voltage gain point is at about 20 Kc/s, so, in general terms, it would be described as having a gain of 1,000 and a bandwidth of 20 Kc/s. However, we can show that the vacuum tube chosen is capable of amplifying over a greater bandwidth but with less gain. If the anode load is now reduced to 10,000 ohms the corresponding gain and band width will be respectively, 100 times and 200 Kc/s, and for a load of 1,000 ohms, ten times and 2 Mc/s. This point may have been laboured, but it will allow those not trained in electronics to appreciate that the fundamental limitation to conventional-type wideband amplification is the unavoidable circuit capacity, and that gain may be exchanged for bandwidth. This relationship is normally written as the gain-bandwidth product GB = gm/C radians/sec. In the simplified amplifier discussed there are two other quantities which may be varied, that is, the tube transconductance gm and the circuit capacitance Cs. Clearly, if the transconductance alone is increased, gain or bandwidth can be increased; alternatively, reduction of capacitance will result in greater bandwidth. Hence, improvement in gain and bandwidth of amplifiers has depended upon improvements in vacuum tube design to a large extent, even though these design factors conflict. In a wideband repeater amplifier the bandwidth required is given by the number of channels to be accommodated and hence, the maximum possible gain is fixed by the tube design. If, for example, we assume a 6 Mc/s bandwidth and have a tube with a figure of merit or gain bandwidth product of 66 Mc/s, then the gain of a one-stage RC amplifier could not exceed 66/6 or 11 times. The cable loss at 6 Mc/s is such that repeaters of this simple type, considered only on gain-bandwidth, would be required at about 2-mile intervals. Consideration of gain stability, regulation, tube aging, and other design margins would, of course, reduce this, while consideration of modulation products due to non-linearity may make it impossible. To increase the gain we could connect several identical stages in tandem, in which case we would find the overall bandwidth to be narrowed below that of one stage. We can see roughly that if the gain of one stage is 3 db down at a particular frequency then two stages will be 6 db down at that frequency, the 3 db point moves down in frequency for the pair. The gain-bandwidth product of such a resistance-coupled system is given by

$$GB = \frac{gm}{C}\left(2^{\frac{1}{n}} - 1\right)^{\frac{1}{2}},$$

where n is the number of stages. If two stages are used the narrowing factor is 0.64 and for 4 stages it is 0.436. This narrowing further limits design freedom as can be seen in the following example. Assume an amplifier is required with a gain of 1,000 and a bandwidth of 6 Mc/s and tubes having $\frac{gm}{C}$ of 200×10^6 rad./sec. are available. If 4 stages are used the narrowing factor is 0.43 and hence the bandwidth of each stage must be 6/0.43 = 14 Mc/s to obtain the required overall bandwidth. With a bandwidth of 14 Mc/s each stage will have a gain of $200/2\pi 14 = 2.27$ times and hence the amplifier will have an overall gain of 2.27^4 or 26 times, which is not enough. If we try 8 stages some improvement is obtained with a stage bandwidth of 20 Mc/s and an overall gain of 40 times. Increasing the number of stages to ten involves a narrowing factor of 0.268, a stage bandwidth of 22.4 Mc/s and an overall gain of 33 for a bandwidth overall of 6 Mc/s. Thus increasing the number of stages from 8 to 10 has decreased the overall gain. Clearly such a requirement as a gain of 1,000 overall and a 6 Mc/s bandwidth, using cascaded RC stages and tubes of gain-bandwidth product 200×10^6 rad./sec. cannot be met.

So far we have considered what might be called flat amplifiers of constant gain over the useful band, the upper edge of which is considered reached when the gain is 3 db below that at mid-frequencies. The usefulness of the gain-bandwidth product and its dependence on the tube design has been outlined. The effect of cascading identical RC stages has also been shown. By using successively more complicated interstage networks, successively larger gain-bandwidth products can be obtained up to 4 or 5 times that of the simple RC stage. Each type has certain limitations, the ones giving greatest GB products being more sensitive to variations in component values. The shunt peaked circuit is, however, commonly used.

AMPLIFIER GAIN RESPONSE

We will now turn to the properties required of a repeater amplifier's gain response. As noted previously the cable loss is a square root of frequency shape and is closely approximated by 3.75 $(f)^{\frac{1}{2}}$ db/mile for the ⅜ inch diameter coaxial cable being used. The low frequencies suffer little attenuation, approximately 1.2 db/mile at 100 Kc/s, but attenuation is much greater at high frequency (9.2 db/mile at 6 Mc/s). It can be taken that each repeater equipment should compensate for this loss due to system considerations. The insertion gain of the equipment must clearly be greater at the higher frequencies where it is most difficult to obtain. (An example of the Law of Universal Oussedness.) Networks of lumped circuit elements can be realised which closely approximate the shape required to level or equalise the cable loss, so that signals of any frequency within the pass band originally of equal amplitude, when applied to the cable section input, will again have equal amplitude after traversing the cable and equalising network. The design choices available for positioning this network are before the amplifier, after it, in it, or some distribution between input, output and internally. It is also possible to transmit a signal into the cable section which has had its higher frequency components made larger so that by the time it arrives at the end of the section the range of amplitudes between high and low frequency components is reduced or even equalised. Having outlined the simpler aspects of the equalisation problem we turn now to a consideration of unwanted signal or noise.

NOISE

Generally, three kinds of noise are classified; thermal and valve noise, intermodulation noise, and noise induced into the system from external sources. The third type is not of importance in coaxial cable generally, since the coaxial pair is self-shielding.

Thermal or Johnson noise is produced in any resistance due to the fact that there is a continuous random motion of electrons or ions in resistive materials, and current flow is the sum of a very large number of these small random individual pulses. The noise power in a given bandwidth is independent of the resistance, being given by $W = 4\ KTB$ watts where K is Boltzmann's constant, T the absolute temperature, and B the bandwidth. In a 6 Mc/s band and at 290°K this amounts to 9.6×10^{-14} watt, or alternatively 2.63×10^{-6} volts across 75 ohms. Noise produced by the effects of the electron flow in the valve is usually given as the equivalent resistance which would produce that noise, and it is dependent on valve design, being smaller, for example, in triodes than in pentodes. To find total noise power due to this type of noise the individual noise powers are added.

Intermodulation noise is produced by the non-linearity of the amplifier, mostly by the large signal output stage since the small signals in the input stages are amplified much more linearly. The amplifier generates harmonics of the component frequencies composing the input signal, and these again intermodulate to produce a very large number of products, for example, for 100 input components, the number of third order products is of the order of 10^6, and a wideband telephone system will have many more input components than this. Noise of this type tends to accumulate more rapidly than in proportion to the number of amplifiers in a system. This noise will vary with system loading, and the British Post Office design, for example, arranges by the use of certain transmitting levels and negative feedback applied to the amplifiers that in a busy hour the intermodulation noise power is approximately equal to the thermal plus valve noise power. In lightly-loaded periods a slight improvement will show, since fewer intermodulation products will be generated.

The transmitting level of the system is an important consideration in obtaining the signal-to-noise ratio required of a coaxial cable system. The signal becomes attenuated as it passes along a cable section. If, for example, a 60 db signal-to-noise ratio is the objective for one repeater section, the signal should be 60 db above the noise at the input terminals of the repeater, assuming for the moment no tube noise. Considering the source for the repeater as a 75 ohm generator of combined signal and noise, the noise component will produce an e.m.f. of about 3 microvolts at the input terminals and this is inextricably mixed with the signal. For 60 db signal-to-noise ratio, the signal cannot be less than 3 millivolts, hence the transmitting level must be adjusted so that despite the cable loss (and its frequency dependence) such a voltage is produced at the input terminals. If the transmitting level is too low the signal will arrive at the repeater input down in the noise, and there it will remain, as succeeding repeaters will equally amplify the mixed signal and noise. The upper limit to transmitting level is fixed by tube design, and present output tubes are in the watt power class. If it were desired to increase transmitting power levels by 20 db then the tubes would need to be in class capable of hundreds of watts output. We have outlined the arguments which show that the attainment of satisfactory signal to thermal noise ratio is to suitably choose transmitting level and cable section loss.

We now consider what was previously assumed absent, that is, tube noise represented as an equivalent resistance in the grid circuit of the first tube. For triodes it may be several hundred ohms and for pentodes three to five times this. For purposes of illustration we assume a pentode with an equivalent noise resistance of 900 ohms which would produce a noise e.m.f. across its terminals of:—

$$E = (4KTRB)^{\frac{1}{2}} = (4 \times 1.38 \times 10^{-23} \times 290 \times 900 \times 6 \times 10^{6})^{\frac{1}{2}}$$

$$= 2 \times 3 \times 10^{-7}\,(1.38 \times 29 \times 6)^{\frac{1}{2}}$$

$$= 9.3 \times 10^{-6} \text{ volts.}$$

This is approximately three times the thermal e.m.f. previously considered. The situation is that at the input terminals we have a signal to be amplified (consisting of signal and thermal noise) and this is to be applied to the first stage amplifier grid which contains its own noise source. In order to obtain the best signal-to-noise ratio at the amplifier grid we need to make the signal voltage as large as possible, since the tube is a voltage-operated device. If a transformer is used between input terminals and grid then we can step up the signal voltage with respect to the tube noise voltage by a factor dependent on the turns ratio. If, for example, the signal-to-noise ratio of the signal at the input terminals is 60 db and the signal is 3 millivolts, and the tube noise is 9 microvolts, a one to one ratio would worsen the signal-to-noise ratio to 50 db, a three to one step up would make it 56 db and a one hunderd to one will give only slight deterioration. We can show that if small ratios are used then the signal-to-noise ratio deteriorates quite rapidly. It is clear that system signal-to-noise ratio will be difficult to maintain over a hundred or more repeater sections, unless a reasonably high transformer ratio is used. At usual coaxial cable frequencies the input impedance of the tubes used can be considered to be capacitive and fixed by the particular design. At a reference frequency, therefore, as the transformer turns ratio is increased this capacitance and stray circuit capacitances will short circuit the transformer secondary more and more, so that there is possibly some optimum ratio. A theorem of Bode's, proved with the help of his resistance integral condition, gives the answer and states that the effective ratio cannot exceed that of an ideal transformer whose high side impedance, when terminated in the line, is $\pi/2$ times the absolute value of the impedance of the circuit capacity over the band considered. It can be seen that the danger points for system signal-to-noise ratio are those at which noise sources are present and the signal itself is at a low level. Standards require that each channel should meet a specified noise level, so that despite the cable loss shape and limitations to amplification at the higher frequencies the signal-to-noise ratio should not be allowed to deteriorate. Consider a signal sent over a cable section which will arrive at the receiving end with the high frequency components much more attenuated than those at low frequency. Assume, for a moment, that the signal sent was noiseless, and that it arrived over a noiseless cable. This is not a necessary assumption but it makes the argument a little clearer. There is a noise source at the grid of the first amplifying valve of the repeater. If we consider this noise in, say, 3 Kc/s bands, the signal-to-noise ratio at the grid will be worse at the high frequency end of the spectrum due to the signal being smaller there, but being mixed with noise which has equal power over the spectrum. If a noiseless equaliser were connected between the cable and the first grid, the signal (under these conditions) would be applied to the grid with equal components at all frequencies, there to be mixed with the noise source, and the signal-to-noise ratio would be the same over the spectrum. It would not be better than the equalised high frequency signal-to-noise ratio, however, but is the best that can be done. This points out what might be called a principle, that at points where significant noise sources are present, the signal applied there should be flat to obtain an even signal-to-noise ratio over the band. There will, however, be competing forms of noise, e.g., thermal noise at the input terminals, and valve noise at the first grid, to be considered in the design. It is usual to design the input transformer as an equaliser to obtain at least a part of the shaping required. Choice of a suitable turns ratio will obtain a satisfactory signal to valve noise ratio. The design for this combined input circuit equaliser could either be the reactive or constant resistance type. The latter type of design allows the transmission to be varied while circuit impedance is kept constant, the penalty being increased noise due to resistive elements. On the other hand the reactive equaliser assumed lossless will not present a constant impedance over the spectrum, but this may be overcome at a loss of 3 db in signal by using a type of hybrid transformer design which allows the correct termination to be made even though the grid circuit winding is substantially an open circuit termination.

GAIN STABILITY

The system requires of the repeater that it should reproduce the transmitted signal as faithfully as possible after transmission through a standard section of line. Consider a system of 120 sections of line where the requirement is that the overall gain should not vary, say, more than 0.25 db. Then each amplifier cannot vary by more than a few thousandths of a db in gain. However, other items in the system will vary, the main ones being cable attenuation and repeater gain, due to temperature change, and reduction of amplifier gain due to tube ageing; hence amplifiers of perfect gain stability would be useless in maintaining system gain. In general, therefore, coaxial cable systems with many repeaters in tandem require automatic regulation of gain to compensate for the above factors as well as amplifiers which are very stable and of high gain accuracy. These considerations rightly belong to system design as does the matter of equalisation. Briefly, each amplifier, generally designed to have an equalising characteristic, compensates as closely as possible for a standard length section, the repeater having a range of adjustment to artificially make the actual section length equal to the standard length, at some standard temperature. System regulation must be designed to take care of variation of attenuation due to temperature, which is complicated by differing changes with frequency. Often a pilot signal is used for regulator control and in the wider band systems several pilots may be necessary to measure the variation of attenuation at various frequencies across the band. Elementary computers are used in some cases to receive the information from these pilots and to suitably control the regulation circuits.

FEEDBACK AMPLIFIERS

The attainment of stable gain and small modulation products requires the use of feedback amplifiers, which may be regarded as an ordinary amplifier or "MU" circuit together with a passive or "beta" circuit which returns some of the output of the "MU" circuit to its input.

If Eo is the output voltage of the feedback amplifier and Ei the input voltage, these are related by $Eo = \frac{mu}{1 - (mu \times beta)} Ei$. It can be seen that if beta is zero the gain is that of the ordinary amplifier, so that feedback reduces the gain of the amplifier. This equation can be put in the form $Eo = \frac{mu \times beta}{1 - mu \times beta} \times \frac{1}{beta} Ei$. Usually the product mu × beta (called the feedback factor) is large, hence Eo is approximately $\frac{1}{beta} \times Ei$. This means that the gain of the amplifier is almost solely determined by the beta circuit, which, being constructed of passive elements, can be made very stable in its characteristics. The name "feedback" is generally applied to the term (1 — mu × beta) and this is often quoted as so many decibels, being the number of decibels by which the amplifier gain is reduced by the use of feedback. It can be shown that both the db variation in gain of the amplifier per db variation in gain of the mu circuit, and also the noise and modulation products are reduced in the ratio (1 — mu × beta) to 1. For example, let 50 db of gain be required, which will require a certain circuit complexity. Then, if a feedback amplifier using 50 db of feedback is used, the amplifier will be somewhat more than twice as complex (needing 100 db of mu circuit gain) but the gain stability and modulation products will be improved by nearly 400 times. This simplified argument outlines what general improvements can be obtained by the use of feedback: it will also be appropriate to outline the difficulties in obtaining improvement. Firstly, the "mu" or main amplifying circuit will have a gain and phase response varying with frequency, that is, the "mu" in the equations is a complex gain function, and the reduction of gain at high frequencies mentioned in an earlier section will be operative. The method of obtaining the necessary "mu" circuit gain is complicated by phase shift due to the coupling networks, and this produces a stability problem. The sign of the signal fed back to the input of the amplifier must be such that oscillation does not occur due to the feedback and input signal being in phase. The problem is easily solved in the simple cases of small gain-bandwidth and non-frequency conscious beta circuits, but where large gain-bandwidth is required together with equalisation, as is usually the case in coaxial cable repeaters, difficulty is encountered. With several stages in the amplifier a relatively small phase shift per stage will add up to a total sufficient to produce instability unless the gain is reduced to zero at the particular frequency. In the amplifier networks with which we are concerned, the phase characteristic is proportional to a weighted rate of change of attenuation (amplitude characteristic) with (log) frequency, and, importantly, depends on the slope in all parts of the spectrum, that is, not only in the pass band spectrum. When the cut-off is sharp this implies a fast rate of change of phase shift. Hence, it is the case that the out-of-band characteristic of the amplifier is a very important one from the stability point of view, since it is here that attenuation is changing with frequency, and so affecting the phase shift at all frequencies, including those in the band. As the above hints, the problem can be very complex, since the out-of-band characteristics of the amplifier must be tailored, often to special shapes, and to high frequencies, for example, in the case of the L3 system repeater which has an upper limit of about 8 Mc/s, the out-of-band characteristics as far as 200 Mc/s are important.

REPEATERS FOR TELEVISION SIGNALS

Much has been written on this subject but here it is only desired to point out the properties, peculiar to television, which are required of a repeater.

We will mention delay response first. The present philosophy of electrical representation of pictures results in a signal which is a time sequence of two types of information; one a varying voltage which sets the brightness of the particular picture element, and the other, which sets the position of the element in the picture. As is well known, the timing or synchronising signal pulses allow timing circuits in receivers to be kept in step with the picture-generating apparatus, these pulses being of specified shape, amplitude and repetition rate within certain tolerances. The brightness signals represent the average brightness of the picture element. At vertical edges in the picture there are often rapid changes in brightness from black to white or light grey to dark grey, etc., and there are also general slow changes in brightness such as may occur if a cloud slowly obscures the sunlight falling on a scene, as it passes overhead. When the voltages representing brightness of the individual element are plotted against time we get a waveshape which is characterised by various rates of change, some fast as at edges, and some very slow as the general background of illumination.

DELAY DISTORTION

The Fourier Analysis has introduced the idea, which is now thoroughly ingrained in technical thinking, of considering any particular waveform as being made up of pure sinewave components of calculable frequency and with calculable phase relations between them. The effect of not maintaining the correct relationships between the phases of the components can be seen by considering transmission of a simple picture. Imagine a sheet of corrugated iron standing vertically. The top of the first corrugation is painted black, the first trough medium grey, the next top black, the next trough white, the next top medium grey and the next trough white, the pattern then repeating. The waveform of a voltage representing the brightness of a line scanned across this sheet can be represented fairly closely by a sinewave and its third harmonic of equal amplitude and in phase, provided we assume the black to grey to white transitions are gradual, going through all intermediate shades. If this signal is applied to a transmission system which has a time delay, say, greater at the third harmonic, such that the third harmonic is delayed by half a cycle at the receiving end, then the output waveshape has the same components of the same relative amplitude but with delay distortion. The picture coming out would be as follows: first top lighter than medium grey, first trough black, next top lighter than medium grey, next trough darker than medium grey, next top white, and last trough of the pattern darker than medium grey. Fig. 2 illustrates these processes.

It is clear that the output is no longer identical with the input and the above section has merely tried to show qualitatively that a differential time delay (i.e., different for different frequency components) will result in a waveshape at the output which is different from the input waveshape. Since the reconstructed picture depends on the output waveshape, the allowable distortion will set a differential delay tolerance for each amplifier. It should be added that the signal, as a whole, will suffer an average time delay in passing through the system due to finite velocity of travel.

DIFFERENTIAL GAIN

A property of amplifiers known as differential gain is of importance and the distortion resulting is known as non-linear distortion. The effect is that the amplification will vary depending on the amplitude of the input signal. Several factors can cause non-linearity distortion, including valve curvature, power supply impedance, and variation of load impedance with output. To illustrate this, assume an amplifier has 0.5 db more gain for a large signal than for a small one, which is apparently not a large error in, say, 60 db. A television signal consists of synchronising pulses which are usually arranged to be full amplitude signal, and a brightness signal which may be small. Hence, synchronising pulses in this case may be amplified up to 0.5 db more than brightness signals. In a chain of, say, 100 repeaters it is clear that system breakdown will occur as the synchronising pulses will, in theory, be amplified 50 db more than the brightness signal. Only quite small errors in differential gain will be allowable.

RETURN LOSS

Unwanted signals mixed with television signals have varying degrees of nuisance value. Random noise only 20 db below picture signal is generally tolerable, but patterned noise is quite discernible at 40 db below picture. One particularly objectionable noise is that due to echo, where the "noise" signal is the picture signal delayed in time and (generally) attenuated. This could be due to the amplifier not terminating the line properly over the band required, when some energy is reflected back, and is re-reflected at some other point to return to the amplifier slightly later in time. Such reflection can also occur at the cable joints, as it did in some early post-war systems: the difficulty is now largely overcome by careful jointing and measuring techniques. It was found that a return loss better than 60 db was obtainable from joints in standard 3/8 inch coaxial cable laid at the National Television Centre at Gore Hill in 1957, which is quite satisfactory.

CONCLUSION

Some outline of the problems associated with repeater design for coaxial cables has been given with an attempt at considering repeaters in isolation. Nothing has been said of the very large problems of system equalisation and related subjects, but it is hoped that some insight has been given into the complexities of wideband amplifier design requirements.

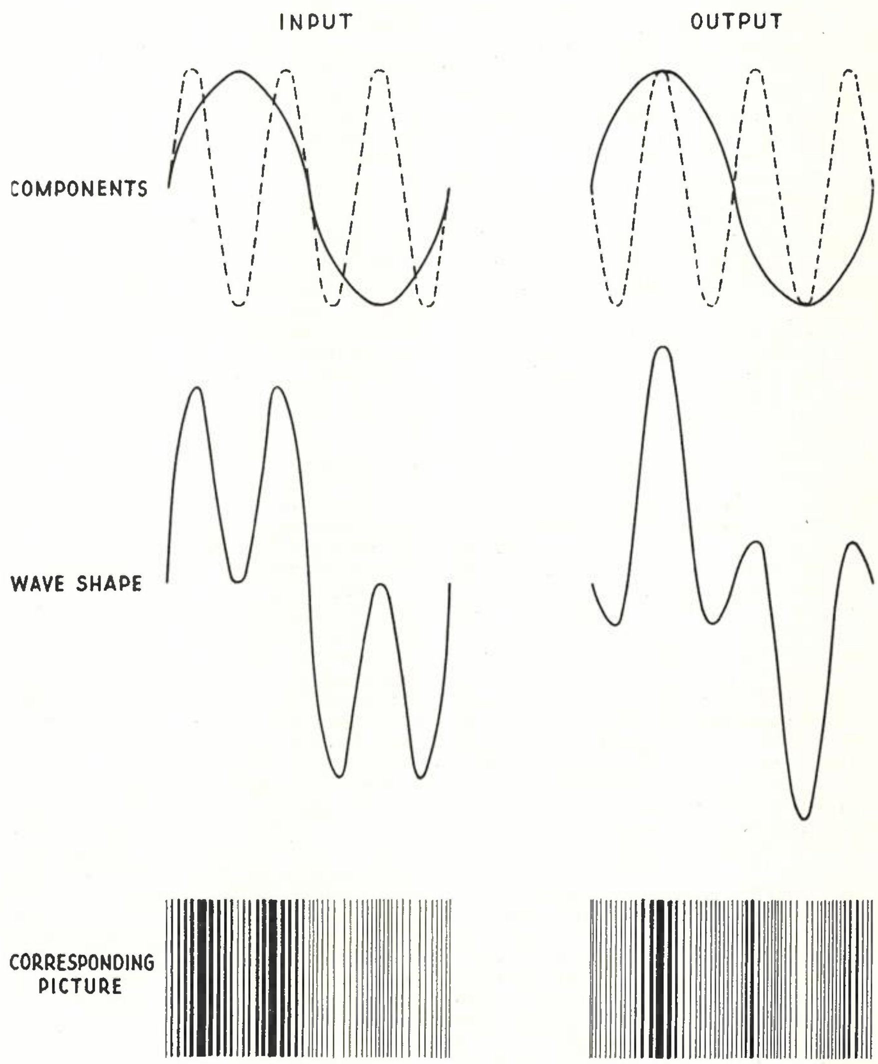


Fig. 2.—Simple Illustration of Delay Distortion.

RECORDED VOICE ANNOUNCEMENTS – MODERN TELEPHONE PRACTICE

T. F. REED, A.M.I.E.E. *

INTRODUCTION

Automatic telephone systems have been built up on the concept of replacing the human element in the switching of telephone calls and considerable ingenuity has been used in devising automatic switching equipment to achieve that end. It is natural, therefore, that telephone Engineers should seek some means whereby the human voice also could be replaced by automatic means.

Recorder-voice devices have been known for very many years — in fact such things are almost as old as the telephone art itself. Various means have been used from the early wax cylinder with its acoustic horn to the modern tape recorder, and high-quality amplifiers, to record and reproduce the human voice.

At the present time there are three basic recording media which can be used:—

(a) Optical.
(b) Mechanical.
(c) Magnetic.

The optical system makes use of a beam of light modulated by a speech pattern recorded photographically on a revolving glass disc or film and detected by a photo-electric cell. This method is used in the B.P.O.-type speaking clocks installed in Melbourne and Sydney. While good-quality recordings can be made with this method a high degree of precision engineering is involved in the construction of the machines to ensure accurate registration of the recordings. Such machines lack flexibility and, moreover, are very expensive and would only be justified for important services with high revenue-earning capacity. A serious disadvantage of this type of recording medium is that the recording cannot readily be changed. Easy duplication of the recording is, however, possible and the recordings have definite life.

The mechanical method includes the well-known gramophone record and other methods of embossing or indenting the base material. Fairly rapid track and stylus wear leading to increased noise and falling off in frequency response are the chief disadvantages of this medium.

The magnetic systems employ ferromagnetic oxide powder mixed with some binding substance as a coating for a suitable base material. Paper or plastic tapes and discs are coated with a thin layer of this material. The magnetic oxide coating is, however, somewhat abrasive and causes wear of the reproducing devices requiring their replacement from time to time. The paper or plastic backing materials are also subject to damage or distortion. Modern magnetic tapes have, however, good recording properties and can cover a very wide frequency range with a low noise value, at suitable speeds.

In contrast with the optical and mechanical methods, the recordings can be readily erased and recorded again.

A later version of this principle which is finding increasing application where a wide range of recorded frequencies is not required, and where a very large number of repetitions is required, uses a relatively thick (about ⅛") base of rubber, neoprene or chlorosulphonated polyethylene impregnated during manufacture with magnetic oxide in a finely-divided form. This material is eminently suitable for telephone purposes since it has adequate frequency response at relatively low speeds, has long life, and creates extremely small wear on the recording and reproducing devices, even after very many months of continuous operation. Manufacturing limitations on the degree of impregnation that can be achieved with this material place some restriction on the frequency range and output level as compared with good recording tape, but both are well within the requirements of the telephone system.

APPLICATION

The application of recorded announcement devices to automatic telephony can do much to give subscribers an improved service while relieving telephonists of much routine and ofttimes tedious duty in

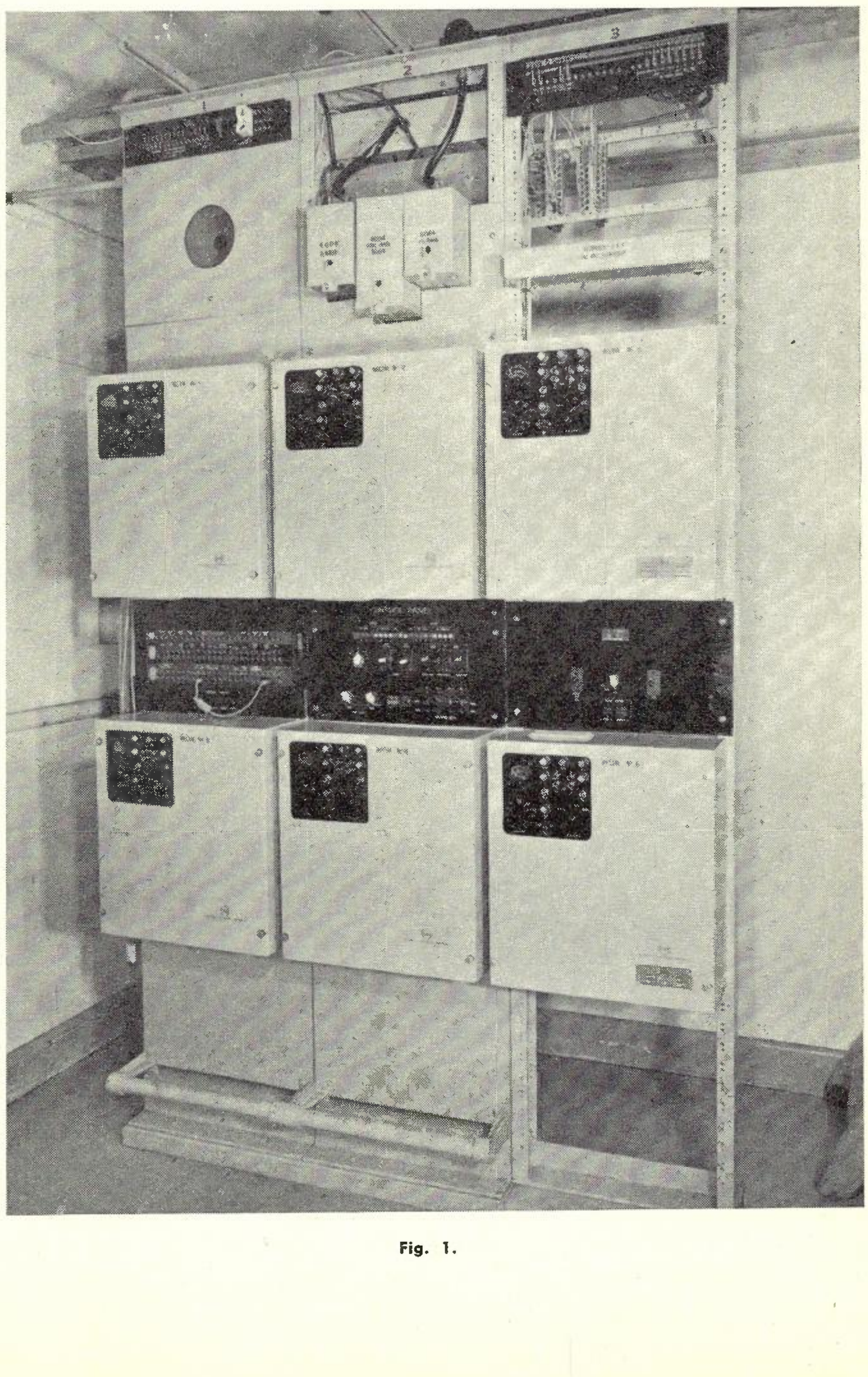


Fig. 1.

* See page 379.

repeating information to subscribers. Some of these applications, such as Time of Day, Weather Information and the like, can be useful revenue earners apart from the excellent service they give. Others, while not directly revenue earning, can be easily justified by the savings in telephonist's or other staff time and, in many cases, by giving subscribers an improved service on a 24-hour basis.

There are, of course, a number of instances where, as yet, there is no alternative to the human element but it is not unlikely that as time goes on the recorded voice will encroach further into this field.

Many overseas telephone administrations provide a variety of information services by this means, including such information as news bulletins, sports fixtures, racing results, cinema and theatre programmes, train services, and even cooking recipes and biblical texts for the day. So far as this country is concerned the automatic information services are at present restricted to Time of Day, Weather Forecast and occasional Topical Events such as Test Match Cricket Scores. These latter services have been catered for in all capital cities in Australia and are also in use in many of the large telephone centres in the World.

For Australian conditions equipment using the magnetic type of recording medium with impregnated neoprene bands has been chosen mainly by reason of its long life and low maintenance costs. Fig. 1 shows six machines of this type working in pairs (one working and one standby) to cater for the general information services mentioned and installed in a large centre in Melbourne. The recording is carried out by selected telephonists elsewhere in the building and the machines are remotely controlled from the recording booth by the telephonist making the recording.

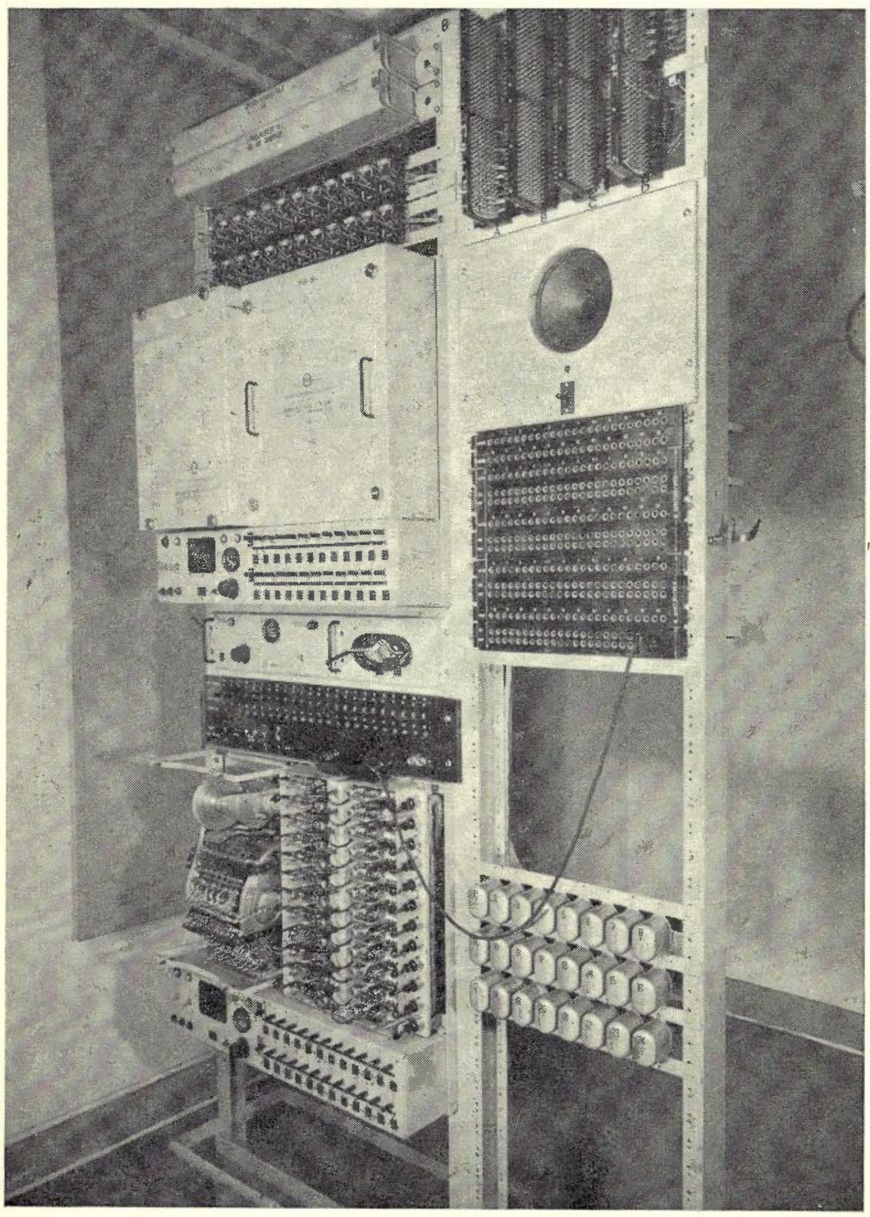


Fig. 2.

There are, of course, many other directions in which the recorded voice can play a useful part in telephony in providing improved service and often serving to reduce traffic congestion on equipment and on important routes. These uses include such services as:—

(a) Trunk congestion and delay period announcements.
(b) Subscribers' interception service for number changes, call diversions, etc.
(c) Temporary withdrawals of service.
(d) Spare lines, spare levels and faulty service announcements (replacing the present N.U. Tone).
(e) Trunk call progress advices.
(f) Emergency announcements, etc.

Special applications include announcements for automatic testing devices, automatic alarm systems at remote exchanges and similar telemetering requirements.

Indeed, any service that requires a repetitive verbal advice of a more or less routine character or one that requires to be changed from time to time or provided at short notice can be handled by this means with much advantage.

E.L.S.A. INTERCEPTION IN MELBOURNE

As an instance of the application of such means, for subscribers' interception purposes, the recent introduction in Australia of extended local service areas (E.L.S.A.) required the allotment of a number of telephonists and the routing of circuits to a suitable manual information centre in Melbourne to handle the necessary interception enquiries. The need was, however, met by the installation of multi-track automatic verbal announcement equipment providing up to 24 separate announcements of about 15 seconds' duration each. These were connected where required to points in the network to intercept calls to the original routes and to direct subscribers to the new routes. The success of this arrangement can be judged from the fact that the team of telephonists required was reduced to a few and even they did not find their duties too onerous. It is estimated that this equipment saved on the average about five telephonists over a period of some months on this service alone.

Fig. 2 shows this equipment installed in Melbourne. The installation was made largely to provide for interception on a major work and to demonstrate the effectiveness of this type of equipment in saving telephonists time and to obtain design data for machines of this type for exchange interception service generally.

Fig. 3 shows a close-up view of one of the machines. The magnetic drum together with the multiple erase and record'reproducing heads can be seen on the left, with the track amplifiers arranged in two banks of twelve on the right. The drum is fitted with a wide impregnated neoprene band and each head assembly traces out a complete and separate track on each revolution. Cam-operated switches at the side of the drum mark the start and finish of the track.

A three-stage transistor amplifier is associated with each track for reproducing. The power output is adjustable up to 30 milliwatts with not more than 3% TH distortion over a frequency range from 200 c/s to 4 kc/s. About 7 db of negative feedback is provided in the amplifier to improve response at the upper frequencies.

The full output of these amplifiers is, of course, more than is necessary for one subscriber and would suffice for some 20 simultaneous connections if required. In such cases a transformer with a 600 ohms primary and a very low impedance secondary (not exceeding 6 ohms) is required at the distribution point to reduce crosstalk between subscribers connected to the same service, and also to improve voltage regulation with varying load. This transformer is not, of course, required where only one subscriber can reach the announcement at any one time. The amplifiers are card mounted and slide into shelves on the unit and are connected by jacks and plugs. This type of construction is in line with modern practice and represents a considerable saving in space as well as contributing to ease of maintenance.

Each machine includes a control panel which provides facilities for recording and monitoring on each track by means of keys and jacks. A level meter and small loudspeaker are provided for checking. This panel can be seen at the bottom of Fig. 3. A recording unit is also provided and can be seen immediately below the control panel of machine No. 1 in Fig. 2. This unit generates erase and bias frequencies and includes a level meter for monitoring the recording. It has an interlock circuit which prevents its use without the special handset microphone provided. Thus recordings cannot be made nor existing recorded tracks erased or interfered with by unauthorised persons either deliberately or inadvertently. It is mounted separately from the machine.

Where an announcement is required to serve a large number of subscribers simultaneously and where the importance of the service warrants it, a "message fail" detector circuit can be provided. The majority of the E.L.S.A. announcements were considered sufficiently important for this facility to be provided and, also, to justify the provision of duplicate machines with automatic changeover on the failure of any message. On this equipment the message fail detectors are transistor units and in this case were mounted on the machine rack together with the changeover relays and can be seen above the machines in Fig. 2.

These machines (as well as those for the Information Services (Fig. 1) installed in all capital cities) were manufactured in this country to the Department's requirements by the Rola Company (Australia) Pty. Ltd., Magnetic Recording Division, Melbourne.

EXCHANGE INTERCEPTION MACHINES

The design of machines based on those supplied for the E.L.S.A. interception but having a maximum of 12 tracks only, to provide facilities for exchange interception purposes, has been undertaken. These machines are intended to cater generally for day to day number changes, cancellations, call diversions. directory errors and such similar short-term requirements affecting individual subscribers' services. They may also carry more permanent recordings of such facilities as unallotted lines, spare levels, temporarily disconnected services, etc., where these may be required. These announcements would in some cases replace the present N.U. Tone now used on these services.

There could be some benefit to the subscriber in this arrangement as, of the service tones now provided in automatic exchanges, the N.U. Tone is, perhaps, the one that subscribers find most difficulty in recognising and interpreting. Even when recognised it does not give the subscriber any indication of the cause of the failure of his call. The standard N.U. Tone circuits (CE.406 or similar) could be used directly for verbal announcement distribution but would require increased power from the amplifiers to offset the loss in the 3 coil-relay-type feeding circuits. Also a somewhat higher level is desirable for speech recognition as compared with a simple tone. Further, some of the N.U. Tone circuits are unbalanced and some modification of the present circuits to make them more suitable for use with verbal announcements would be desirable. Apart from the technical considerations, the substitution of a single verbal announcement for N.U. Tone could lead to confusion by being inappropriate in some instances. Separate announcements appropriate to each service are therefore to be preferred and would be of greater assistance to the subscriber.

The flexibility in the use of these machines for many purposes will depend to a large extent on the design of suitable relay sets for use on the particular application. For instance, where a message length greater than 15 seconds is required it could be accommodated on several tracks by arranging sequential switching in the relay set using pulses from the drum springs. Again, the announcement could request the subscriber to take some action such as dialling additional digits, to complete the connection via the appropriate relay set.

As normally the machines will only be carrying individual subscriber interception announcements it is not usually necessary to make duplicate provision of machines for standby purposes. In any event, a "machine fail" alarm is incorporated in each machine and can be connected to the station alarm system. Also, when used as a replacement for a service tone, the circuits can usually be arranged to revert to the original tone.

Where a track is used for a common announcement to a large number of subscribers, a "message fail" alarm should be provided in the amplifier at the distribution point to cover as much as possible of the common circuit. While a track on these machines could be used for such announcements, separate single track units provided in duplicate with an automatic changeover circuit are often to be preferred.

These latest multi-track machines have shown themselves to be very reliable in service and to require little maintenance since the number of mechanical parts has been reduced to a minimum. Cleaning and lubricating, very occasionally, are all that is normally required. The use of transistors in place of valves further reduces maintenance and permits of al-

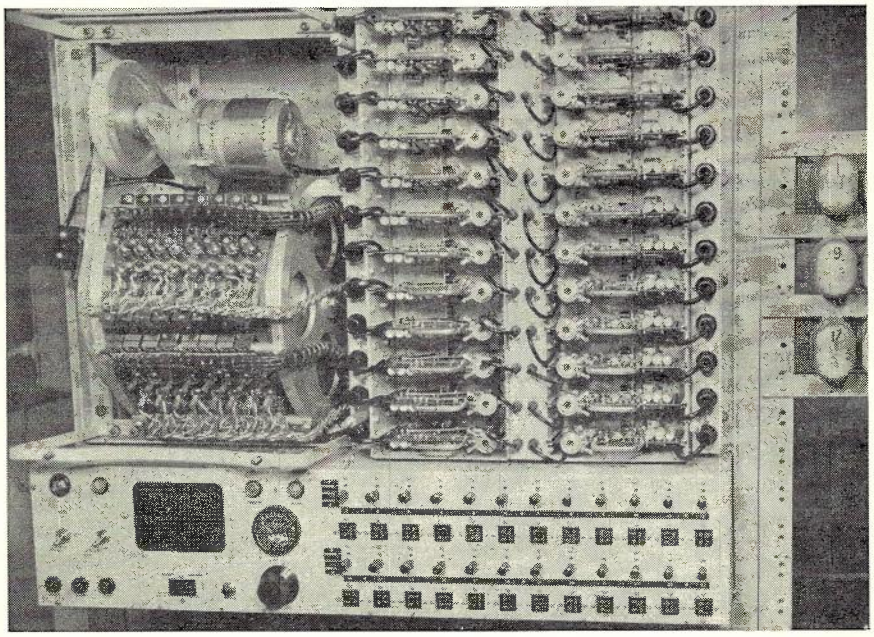


Fig. 3.

most complete operation from the exchange 50 volt D.C. supply. Later machines will probably be arranged for full D.C. operation thus making the machines completely independent of commercial mains supply.

It is hoped to be able to give a full technical description of these new exchange interception machines and to include references to new and interesting applications for devices of this type in later issues of this Journal.

CONCLUSION

It will be apparent from the foregoing survey of the position that electro-magnetic recording and announcing devices can provide the telephone design engineer with a useful tool in circuit design and the telephone administration with the means to improve service to the subscribers and, at the same time, effect savings in operating costs.

The author wishes to acknowledge the assistance given by the Rola Company, Melbourne, in the design, and also the Service Section of the Victorian Administration in setting up and testing the equipment used for the E.L.S.A. interception in Melbourne.

NOTES ON A NEW CABLING PRACTICE FOR USE WITH P.V.C. CABLE

T. F. REED, A.M.I.E.E.
L. C. HAIG

The standard slatted type runway has been used for many years on exchange installation and was quite satisfactory for use with textile braided switchboard cable, but with the general introduction of P.V.C. sheathed cable, which is normally much softer and more flexible than the braided type, a runway giving more continuous support to avoid sagging was needed.

Shallow troughing can be used and while it does of course afford the continuous support required for P.V.C. cable, it is difficult to keep free of dust unless provided with a cover, when it can become a home for rodents. Above all it can be expensive both in initial cost and erection.

Perforated steel runway, while not new to the electrical trade, having been used for power cable fixing in large buildings and for large ship's installations, appeared to offer advantages with P.V.C. cable. Enquiry of the trade showed that this material could be supplied in standard 8 foot lengths in widths from 6 inches to 36 inches. The runway consists of 16 S.W.G. sheet metal with holes of .8 x .312 inches punched in rows .6 inches apart. The edges of the sheet are turned at right angles providing a side member of approximately ¾ inch.

To test the suitability of this material and to gain some experience with it, the Victorian administration was asked to undertake an exchange installation using it in suitable widths and preferably with all P.V.C. cable. As the standard twine lacing was obviously unsuitable with this type of runway, plastic or metal straps and cable guide pins were suggested. This not only proved to be quite practicable, but resulted in an immediate saving in manhours and moreover relieved the installation staff of cable stitching which has always been considered an onerous task.

For this purpose soft aluminium rod of 3/16″ diameter, which is easily cut and bent, was purchased to form cable stirrups. The stirrups are held in place with a "Quicknut" which can be pressed on to the rod with the fingers and remains firmly in position against the underside of the runway. These fastenings are extensively used in the trimming of motor vehicle bodies, and the one used is only one of a number of such fasteners available. Figure 1 shows a stirrup being placed in position over a cable pack and figure 2 shows the completed cable run to the M.D.F.

The trial installation with this type of runway is being conducted at Glenroy Exchange, Victoria, which will be a 4,000 line branch exchange with SE.50 equipment on 2,000 type racks. Cabling is now 90% completed, and although final cost figures are not yet available, present indications are that this method of cable fixing will result in considerable savings in both material (the perforated type being approximately half the cost of the equivalent present standard runway) and labour of perhaps 50% to 60% as compared with standard lacing techniques.

This new practice appears to have considerable application for Departmental use both in the cabling of exchanges and subscribers premises (particularly large city buildings), although slight modifications to the runway as supplied would be desirable for future exchange use. It is hoped to give more details in a later issue of this Journal when final figures of costs are available, and details of suggested improvements will also be given.

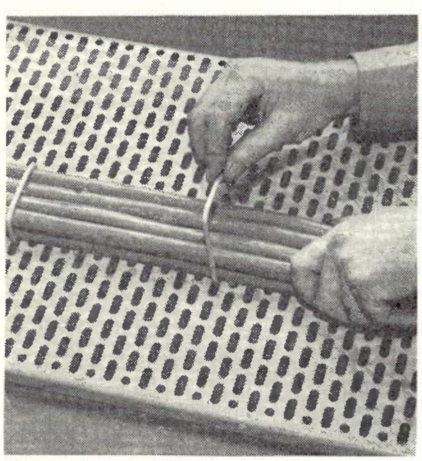


Fig. 1.—Metal Cable Stirrup being placed in position.

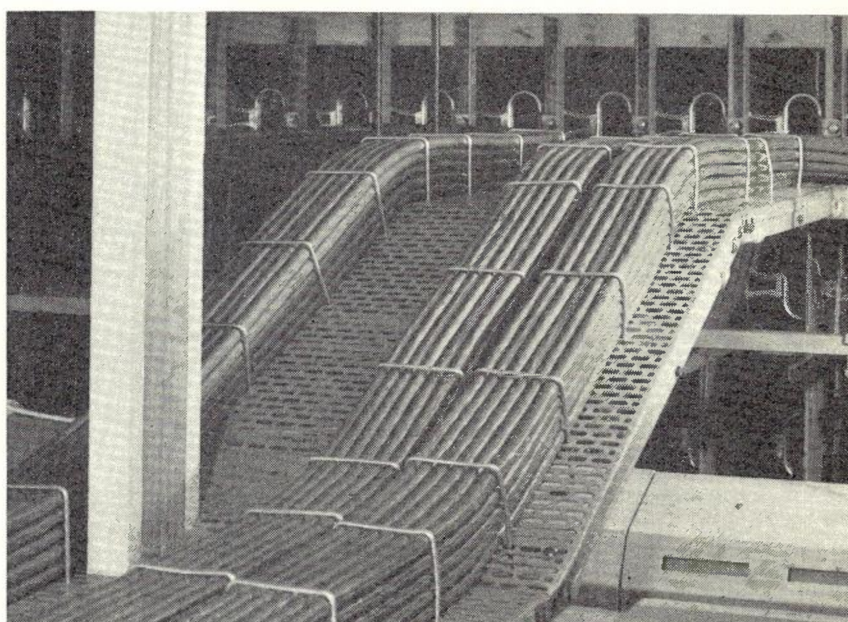


Fig. 2.—Completed cable run to M.D.F.

OUR CONTRIBUTORS

The Board of Editors has decided to adopt a reader's suggestion that in future we publish a photograph and short biographical note on each of our contributors. This follows the practice used in many other Journals and we expect that it will help to add interest to our own Journal.

J. C. WILSON

J. C. WILSON, author of the article "Pole Mounted Repeaters for Carrier Systems", joined the Department in Melbourne in 1937, as a Junior Mechanic. He transferred to Research Section in January, 1943 as Engineer, working mainly on Military Telephone Equipment and problems associated with local productions of telephone equipment in the early post-war years. From late 1947 he carried out special planning investigations for the Chief Engineer and later joined the newly-formed Technical Planning Section which was the first planning group in Central Office. After 12 months at Headquarters in the Telephone Equipment Section, Mr. Wilson joined the Research Section in 1955 where he has been Sectional Engineer in charge of the Line Communication Sub-Section.

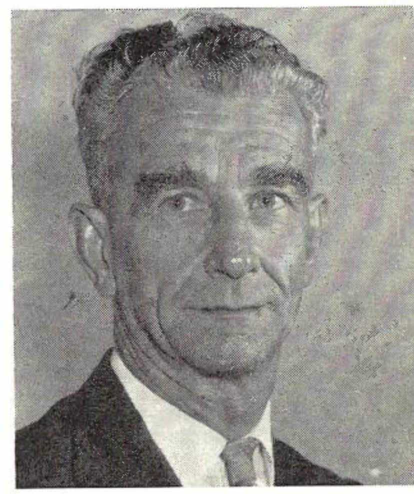
S. DOSSING, author of the article "Pulse Echo Tester for Open Wire Cable, and Composite Lines", received his M.Sc.E.E. Degree with Honours from the Technical University of Denmark in 1945. After a period as assistant to the Professor of Telecommunications, he joined the Engineering Sales Division of Philips, in Copenhagen, transferring later to Messrs. H. Buch and Co., Copenhagen, where he was responsible for Sales, Installation and Service of a wide range of Telecommunication Equipment, Radar Equipment and Scientific Instruments.

He joined the Australian Post Office in 1949, and is at present Divisional Engineer, Methods and Practices in the Long Line Equipment Section, Central Office. His duties include the inspection and evaluation of new Line Transmission Equipment and associated Testing Instruments and also cover special investigations in the field. He received an M.E.E. degree from the University of Melbourne in 1959.

Mr. Dossing has contributed a number of articles to Danish, English and Australian Journals, the present article being his sixth published in this Journal.

S. DOSSING

R. E. BOGNER, author of the article "Telephone Numbers and the User", joined the Department as a Cadet Engineer in 1953, subsequently gaining the degrees of B.E. and M.E. at the University of Adelaide. During his post-graduate work on speech bandwidth reduction, he transferred to the Research Laboratories where he now works as a Group Engineer in the Telephonometry and Acoustics Division. In his two years in this Division, his work has mainly been in the fields of electro-acoustic measurements and design, and speech studies.

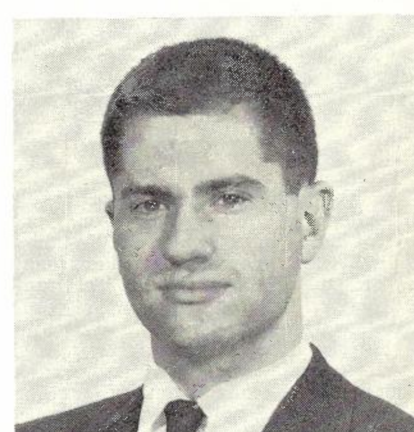


G. P. JOLLEY

G. P. JOLLEY, author of the article "Protection and Dust Proofing of Automatic Equipment", joined the Department in 1921.

His experience covers most phases of the activities of the Engineering Branch —both Maintenance and Installation. He spent several years on maintenance at Carlton Exchange, an exchange which was fitted with the early Strowger version of dustproofing. As he remembers, the handles of the doors were very efficient coat tearers.

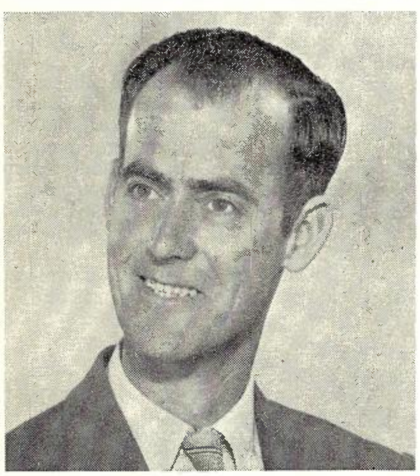
He is now Supervising Technician at the Civic Exchange in Melbourne.



R. E. BOGNER

R. W. KETT

R. W. KETT, author of the article "Acoustic Shock Absorbers", was educated at Caulfield Grammar School and obtained the Diploma of Communication Engineering from the Royal Melbourne Technical College in 1945, at which time he joined the Research Laboratories. He has since been chiefly concerned with Telephone Instrument Measurement Techniques and was also associated with the Bass Strait Cable Extension Project. His present position is that of Group Engineer in the Telephonometry Division of the Research Laboratories.



A. K. PIPER

A. K. PIPER, author of the article "Unbalance Fault Test Set for Open Wire Lines", was educated at Westmead and Ultimo Technical Schools and entered the Department as Telegraph Messenger at Botany in 1939. He became a Junior Mechanic-in-training in 1941, qualified as Technician in 1945 and passed the Senior Technician's examination in the same year.

Between 1946 and 1949 he was stationed at Nyngan as Senior Technician and in late 1949 was transferred to Coffs Harbour. In August 1960 he took up duty as Supervising Technician 2, at Newcastle Trunk Exchange.

K. A. McDONALD, author of the article "Work Study", joined the Department in 1940 as a Junior Mechanic. In 1948 he qualified as an Engineer and subsequently was employed as a Group Engineer in Long Line Equipment Installation, Country District Works and Metropolitan District Works Divisions in Victoria. He visited Europe in 1954 and spent a short time with the British Post Office studying divisional management in a Lines Division.

After one year as Divisional Engineer, Engineering Studies, Victoria, he transferred, in 1957, to the position of Divisional Engineer (Methods), Engineering Methods and Training Section, at Central Office. During that time he has led a team engaged on the conduct of Work and Method Studies in the Engineering Division.

Mr. McDonald is an Associate Member of the Institution of Engineers, Australia.

W. A. STIRLING

W. A. STIRLING, author of the article "Qualitative Maintenance in Manual Exchanges", commenced as Junior Mechanic in 1941 and was advanced as Technician in 1946. He was promoted Senior Technician in 19449, Supervising Technician Grade 1, Corowa in 1952 and Supervising Technician Grade 2, Albury Repeater Station in 1959. He has acted as Supervising Techician Grade 3, Albury Exchange since August, 1956.

Mr. Stirling has had considerable experience in the maintenance of magneto, C.B. R.A.X. and Automatic exchanges and associated subscribers services, and is familiar with most types of Long Line and Carrier Equipment.

Since taking charge of the Albury Exchange, Mr. Stirling has introduced qualitative maintenance and endeavoured to ascertain fault trends and determine preventative measures.

K. A. McDONALD

F. M. SHEPHERD, author of the article "Coaxial Cable Amplifiers", was born in Melbourne in 1922 and was educated at State Schools and Trinity Grammar School. During World War II he served with the A.I.F. in the Wireless Workshops of the Corps of Australian Electrical and Mechanical Engineers.

Mr. Shepherd then continued his studies in Engineering at Sydney University and graduated Bachelor of Engineering with honours in 1951. During this period he became a Cadet Engineer with the Department and on graduation began in the District Works Section in Sydney. He later was transferred to the Studios Division and took charge of Departmental responsibilities in the National Television Transmitting Station project at Gore Hill in 1956. He is now a Divisional Engineer in Transmission Planning, Sydney.

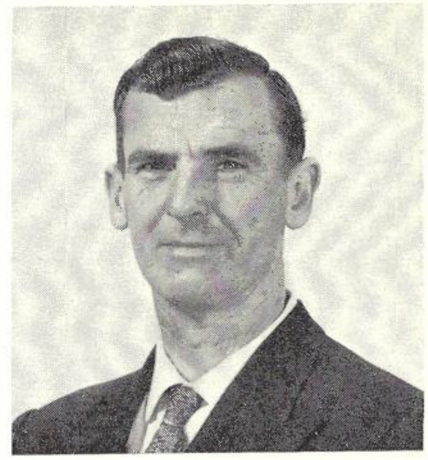
He is an Associate Member of the Institution of Engineers, Australia and a member of the Institution of Radio Engineers, Australia.

F. M. SHEPHERD

T. F. REED

T. F. REED, author of the article on "Recorded Voice Announcements in Modern Telephone Practice" has written previous articles in the Journal on allied subjects. Mr. Reed was educated in England and received his training in telecommunications in the Engineering Department of the British Post Office. He transferred to the Australian Post Office under a recruitment scheme for qualified engineers in 1949. He served as a Group Engineer in the Victorian Administration and was appointed to Divisional Engineer in the Telephone Equipment Section, Central Office in 1955. In this capacity he has been concerned with Exchange Installation methods and has been responsible for the development of new types of ringing equipment, batteries and recorded voice devices. He was concerned with the design and installation of the equipment for the A.P.O. Weather Information Service in 1957/58. He is an Associate Member of the Institution of Electrical Engineers, London.

H. J. LEWIS, author of the article "The Australian Aluminium Public Telephone Cabinet" is a Divisional Engineer in the Workshops Section at Headquarters. He joined the Department as Radio Technician in 1939 and worked at the Melbourne Broadcast Studios and Lyndhurst Radio until qualifying as Engineer. Mr. Lewis then served in the Outer Metropolitan Lines Division during 1946-47, and in the Melbourne Workshops as Engineer and Divisional Engineer, Design and Plant, for the following four years. Subsequently he has been in the Workshops Section at Headquarters in various duties of Planning and Production work, and recently on Plant and Workshops Practices. Mr. Lewis had practical experience in the manufacture, installation, and maintenance of Telephone Cabinets, whilst at the Workshops and has since served on the Committee which designed the present louvre-glazed wooden cabinet. During the recent illness of Mr. Edwards he acted as Chairman of the Committee which designed the new aluminium cabinet.



H. J. LEWIS

Contributions and Letters to the Editors

May be addressed to:

the State Secretaries or the General Secretary at the following addresses:—

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Box 246C, G.P.O. Hobart, Tas.

The General Secretary,
Telecommunication Society of Australia,
Box 4050, G.P.O. Melbourne,
Victoria, Australia.

"ANSWERS TO EXAMINATION QUESTIONS"

Examinations Nos. 4736, 4737, 4738 and 4739—4th July, 1959, and subsequent dates.

TO GAIN PART OF THE QUALIFICATIONS FOR PROMOTION OR TRANSFER AS SENIOR TECHNICIAN, TELEPHONE, RESEARCH, RADIO AND TELEGRAPHS, POSTMASTER - GENERAL'S DEPARTMENT.

TELECOMMUNICATION PRINCIPLES

Q.3.—An inductor and resistor, when connected in series across a 200 volt 50 c/s supply, draw a current of 4 amperes. With the inductor short-circuited the current drawn from the supply is 6 2/3 amperes.

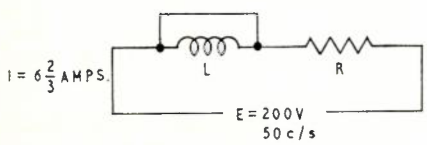
With the inductor and resistor in series across the 200 volt 50 c/s supply, calculate—

(i) the impedance of the circuit,
(ii) the power factor of the circuit,
(iii) the voltage drop across the resistor,
(iv) the voltage drop across the inductor,
(v) the power absorbed by the circuit

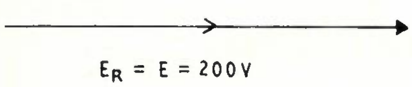
Illustrate your answer with vector diagrams.

ANSWER (R. C. COCKBURN)

Circuit condition with inductor short circuit



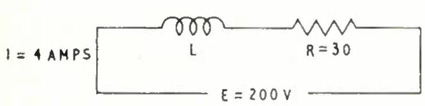
The vector diagram for this condition is as follows:—



$$\therefore \text{ Resistance} = \frac{E}{I}$$

$$= \frac{200}{6\frac{2}{3}} = 30 \text{ ohms.}$$

Normal circuit condition.



(i) ....

$$\text{Impedance} = \frac{E}{I}$$

$$= \frac{200}{4} = 50 \text{ ohms}$$

(ii) ....

$$\text{Power Factor} = \text{Cos } \phi = \frac{R}{Z}$$

$$= \frac{30}{50} = 0.6 \text{ lagging}$$

(iii) ....

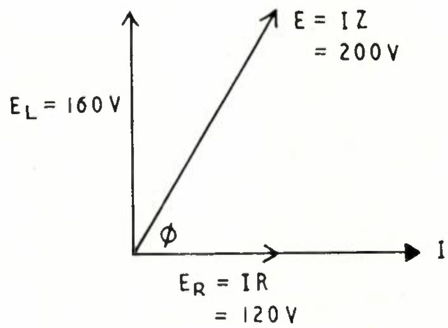
P.D. across resistor $= I \times R$

$= 4 \times 30 = 120$ volts

(iv) The voltage distribution in the circuit is as follows:—

P.D. across Inductor $= \sqrt{E^2 - E_R^2}$

$= \sqrt{200^2 - 120^2} = 160$ volts



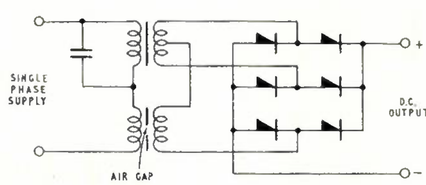
(v) ....

Power $= E \times I \times$ Power Factor

$= 2000 \times 4 \times 0.6 = 480$ watts

Answers: (i) 50 ohms; (ii) 0.6 lagging; (iii) 120 volts; (iv) 160 volts; (v) 480 watts.

Q.5.—The diagram shows the elementary circuit of a Rectifier.

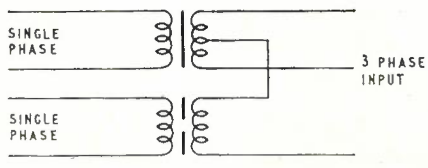


Explain briefly the operation of the circuit and how it safeguards against accidental overload.

ANSWER: (D. KENNER).

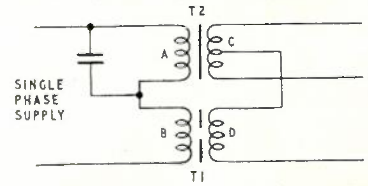
This rectifier, a "Westat" constant potential rectifier, provides a means of converting single phase A.C. to 3 phase, which is then passed through a 3 phase full wave rectifier bridge to give a D.C. output.

The "Westat" makes use of a reversed application of the "Scott connection" principle. The original Scott connection was used to derive two single phase outputs from a 3 phase supply, the output voltages being displaced by 90°.



Reversed Scott Principle

In the Westat, as only a single phase is available, a phase splitting scheme is used to obtain the equivalent of two single phase inputs displaced by 90°.



The values of capacity, inductance and resistance are arranged so that at the full rated load the voltage across "A" *lags* the supply current by 45°, while the voltage across "B" *leads* the same supply current by 45°.

This causes a voltage displacement of 90° between coils A and B. On the secondary side of the transformer there is also a 90° voltage displacement between C and D.

The transformer T_1 is provided with an air gap in the core so that its inductance will remain constant.

The inductance of T_2 will vary with variations in load current.

On no load the secondary output is single phase.

As the load is increased, the output tends towards 3 phase until at the full rated load the maximum 90° displacement is obtained and the output becomes 3 phase, providing compensation for voltage drops across transformers, rectifiers, etc.

If the rated maximum is exceeded, the 90° displacement no longer exists and the output tends towards single phase, resulting in a decreased output from the rectifier. This effect provides an automatic safeguard against overload so that protective circuit breakers or overload coils are not necessary.

Q.6.—(a) State the equivalent of Ohms Law for a magnetic circuit.

(b) Define the term reluctance as applied to a magnetic circuit and state the formula.

(c) A telephone relay has a magnetic circuit consisting of soft iron of mean length 16 cm. and cross sectional area 4 sq. cm. When released the air gap between the pole face and armature is 2.5 mm. The effective area of the pole face is 5 sq. cm. Find the ampere turns required to produce a flux of 30,000 maxwells in the gap. (The permeability of soft iron is 800.)

ANSWER: (E. CULPH).

(a) The total flux in a magnetic circuit ϕ is directly proportional to the magneto-motive force (F) and inversely proportional to the reluctance (S).

Therefore—

$$\phi = \frac{F}{S}$$

where ϕ = Magnetic flux in Maxwells
F = Magneto-motive force in Gilberts
S = Reluctance (no units))

(b) Reluctance is the opposition offered by a magnetic circuit to the establishment of lines of force.

$$S = \frac{l}{\mu\, a} \quad \text{where} \quad \begin{array}{l} s = \text{Reluctance} \\ l = \text{length of magnetic circuit} \\ \mu = \text{permeability} \\ a = \text{cross-sectional area of magnetic circuit} \end{array}$$

(c) $\phi = \frac{F}{S} \quad F = \frac{4\pi NI}{10} \quad S = \frac{l}{\mu\, a}$

The reluctance of this circuit consists of:—

(i) The reluctance or opposition of the iron (permeability of 800).

(ii) The reluctance or opposition of the air gap (permeability of air unity).

Therefore, the total reluctance of the circuit (S) is reluctance of iron (S_1) plus reluctance of air gap S_2), thus—

$$S = S_1 + S_2$$

$$S_1 = \frac{l_1}{\mu_1\, a_1} = \frac{16}{800 \times 4} = \frac{1}{200} \text{ or } .005$$

$$S_2 = \frac{l_2}{\mu_2\, a_2} = \frac{.25}{1 \times 5} = \frac{1}{20} \text{ or } .05$$

$$S = .005 + .05 = .055$$

$$\phi = \frac{F}{S} \therefore F = \phi \times S$$

$$\text{or } \frac{4\pi\, IN}{10} = \phi \times S$$

$$\therefore \text{Ampere turns (IN)} = \frac{\phi \times S \times 10}{4} =$$

$$\frac{30{,}000}{1} \times \frac{55}{1000} \times \frac{10}{1} \times \frac{1}{4} \times \frac{7}{22}$$

$= 1312$ Ampere turns.

Q.7.—(a) State three forms of electron emission which can occur in an electron tube.

(b) Explain how amplification of an a.c. signal can be achieved by using a triode valve. Illustrate your answer with sketches.

ANSWER: (K. NEILSON)

(a) Forms of electron emission which occur in electron tubes are—

(1) Thermionic
(2) Secondary
(3) Cold Cathode
(4) Photo Electric

(b) The triode valve amplifies an A.C. signal by converting small changes in input voltage to large voltage changes in the output circuit.

This can be seen by considering the simple circuit of a triode as an amplifier (Fig. 1) and the triode's characteristic curve (Fig. 2).

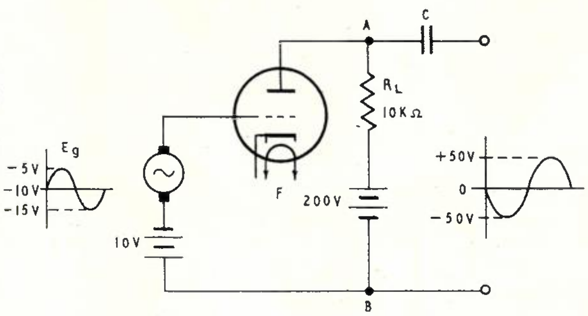


Fig. 1.

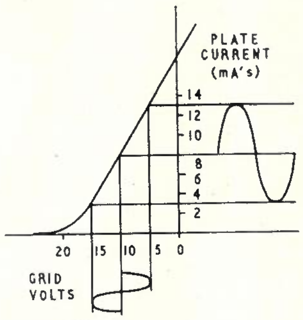


Fig. 2.

With the fixed bias at −10V, the normal anode current is 8 mA, and the voltage drop across the load resistor R_L is 80V. Point A is therefore at +120V with respect to point B.

Assuming that a sinusoidal alternating voltage of 5 volts is applied by the generator to the grid, the grid voltage varies between −5 and −15V, the plate current varies between 13mA and 3mA (Fig. 2), and the potential differences across the load resistor varies between 130V and 30V. The potential difference between points A and B therefore varies between 70 and 170 volts. The capacitor C in the output circuit separates the A.C. component from the D.C. component and an A.C. sinusoidal peak voltage of 50 volts appears across the output terminals.

Thus the input alternating voltage of 5 volts peak has been amplified to an A.C. voltage of 50 volts peak.

Q.10.—(a) Briefly explain what is meant by the term "modulation" as applied to a carrier telephone system.

(b) What is the main reason for suppressing the carrier frequency in a carrier telephone system modulator?

(c) Why is it necessary to limit the signal level applied to a metal rectifier type modulator? Explain briefly one way this can be done.

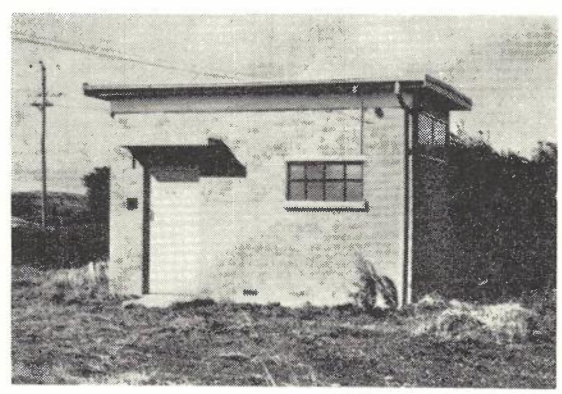
ANSWER: (S. GALE).

(a) Modulation is the process whereby the voice frequency input signals are "transferred" into a higher frequency range for transmission over the bearer circuit. For example, when audio frequencies in the range 0.3-2.6 kc/s are applied to a non-linear device (modulator) together with a carrier frequency of say, 10 kc/s, the process of amplitude modulation produces sum and difference products—the upper sideband 10.3 – 12.6 kc/s, and the lower sideband 7.4 – 9.7 kc/s. One of these sidebands is selected by a band-pass filter for transmission to the distant terminal.

(b) Suppression of the carrier frequency in the modulator permits a simpler and cheaper design of modulator band-pass filter. This filter passes the required sideband and attenuates the other—the sidebands are separated by about 600 c/s. If the band-pass filter were required to suppress the carrier also, it would need a much sharper cut-off to attenuate sufficiently the carrier frequency which is only about 300 c/s from, and at a higher power level than the required sideband.

(c) The characteristics of metal rectifiers used as modulators require that the voice input voltage is low compared with the applied carrier voltage. When the voice input voltage is too high, the modulator is unbalanced and carrier voltage appears in the output. Also, the modulator produces unwanted intermodulation products which distort the modulation envelope and impair intelligibility.

A special neon lamp may be connected across the input to the modulator to keep the voice input voltage from exceeding a pre-determined value. The neon lamp normally produces negligible loss in the speech circuit. When the speech voltage exceeds the permissible limit, the lamp "strikes" and produces a shunting effect across the modulator input, thus preventing overloading.

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