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The
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THE BRITISH POST OFFICE SPEAKING CLOCK MARK II

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Introduction

Telephone Subscribers in Melbourne and Sydney will shortly be able to dial a special code and hear time announcements from a speaking clock. The equipment used for these two installations has been designed by the British Post Office Engineering Department and made in England by the Telephone Manufacturing Company. It is an improved version of the original speaking clock apparatus which has provided a similar service in Great Britain since 1936.

Each speaking clock consists of an announcing machine (which produces the actual speech and time signals) together with auxiliary rack mounted apparatus for driving the machine at a constant speed, for amplifying its audio signals, and for correcting the time signals to conform with standard time as determined by an observatory. The original design of speaking clock was controlled by a pendulum, and required hourly correction in order to produce time signals accurate to within ± 0.1 second. This order of accuracy was insufficient for the requirements of the Australian Post Office because it was necessary to derive from each clock civil and marine time signals which would not deviate more than ± 20 mS from standard time. The requirement has been met by the British Speaking Clock Mark II in which a quartz crystal controlled oscillator is used for the drive, and which will give signals accurate to within ± 5 mS when corrected only once every 24 hours.

Each installation consists of two complete clocks plus common equipment and auxiliary power supply. Either of the two clocks of an installation may be used to supply announcements of time to the telephone subscribers. The second clock runs continuously as a standby (driven by the auxiliary power equipment) and is put into service automatically if a fault should occur in the first. Facilities are provided to enable the signals from the Melbourne installation to be used to maintain service at Sydney (or vice versa) in the event of a total breakdown of the local system. Intermediate centres can be fed with signals as desired.

After the initial setting-up procedure, the operation of an installation (including the daily time check) is entirely automatic, and skilled attention is required only for routine maintenance and for the clearing of faults if they should arise.

General Principles

Basically each clock consists of a phonic motor which is driven at a constant speed from the amplified output of a crystal oscillator. Upon the motor shaft are mounted discs carrying sound tracks from which the successive announcements are derived.

Fig. 1 shows the layout of an installation. Each clock is driven from a 100 kc/s crystal controlled oscillator, the output of which is fed into a frequency divider which produces the 50 c/s supply required by the announcing machine motor. A third oscillator is also provided for reasons which are discussed later. The 50 c/s supply passes first through a timing corrector circuit, which is used during the daily correction interval, and then via amplifiers to the phonic motor of the announcing machine.

The announcements and time signals produced by the announcing machine pass through a "Line Amplifier and Pilot Tone Alarm" panel (the function of which is described below) and are then fed into two local power amplifiers. One of these is connected to relay sets feeding the local telephone network, while the other acts as a reserve.

Superimposed upon the speech signals for each announcing machine is a pilot tone of 3200 c/s which is used to detect the presence or absence of any portion of the announcements. The detection occurs in the "Line Amplifier and Pilot Tone Alarm" panel, and the tone is removed before passing on the signals to the local network. Announcements with the tone included are sent out over lines to a distant centre, if required, to act as a reserve for the distant installation. Similarly incoming signals from the distant centre pass through "Line Amplifier and Pilot Tone Alarm" panels for the detection and removal of the pilot tone, and act as a reserve for the local installation.

Four sources of signals are thus available for distribution to the local subscribers. If a fault should occur, switching from one source to the next reserve is controlled by the Pilot Tone Alarm circuits and by other alarm circuits of the installation.

The above is a brief outline of the fundamental units of which a clock installation is composed. In the succeeding paragraphs these units are described in greater detail.

The Stable 50 c/s Supply

Three 100 kc/s bridge-stabilised crystal-controlled oscillators are provided for each installation. Two of these are normally linked to the clocks via a patching panel: the third is supplied to assist in fault detection, since by intercomparison the identification of a faulty oscillator can readily be made. An alarm is given whenever the frequency deviation between oscillators becomes excessive. In addition, meters are provided to show the difference in rate of the oscillators, and a log of the readings of these will provide an indication of long term drift.

The oscillators are connected to individual frequency dividers which give outputs of 50 c/s for driving the clock motors.

The Announcing Machine

Fig. 2† shows the Announcing Machine, the fundamental mechanism of a clock. Its main function is to produce, at ten second intervals, announcements of the type "At the third stroke it will be ten, twenty four, and forty seconds", followed by three pulses of 1000 c/s tone (called "pips") each 100 mS long and spaced at 1 second intervals. The commencement of the third pulse of tone marks the time stated in the preceding announcement. Normally the 12 hour system of denoting time is used (e.g. 1 o'clock in the afternoon is called

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†Figures 2 and 3 show the prototype announcing machine with all covers removed. Illustrations of the machines supplied to the Australian Post Office will appear in a later article dealing with the manufacture of the clock.

"one" and not "thirteen" hours) but the clock mechanism is so designed that it may easily be adapted for a 24 hour system if required.

Referring now to Fig 3†, the synchronous motor (4) drives at the constant speed of 30 r.p.m. a shaft upon which are mounted three glass discs (1, 2, 3). The announcements and the time signals are derived from variable-area circular sound tracks which have been recorded photographically upon these discs in the following manner:—

Disc 1: The minutes tracks "one" to "59" and "O'clock".

Disc 2: The words "At the third stroke . . . ." (called the "Phrase") and the hours tracks ("It will be one . . .", "It will be two . . ." etc.).

Disc 3: A synchronising signal, the seconds tracks (". . . and ten seconds", ". . . and twenty seconds", etc., and "precisely"), and a series of thirteen "pips" tracks.

Limitations of size restrict the number of complete tracks which can be accommodated on a disc to between 30 and 40. This number is adequate for disc 2 (13 tracks) and disc 3 (20 tracks), but not for disc 1 which requires 60 tracks. Fortunately, however, the "minutes" portion of the announcement is the shortest component (there are no additional words like "and . . . seconds" or "it will be" included) and so each minute track may be recorded on a half sector of the disc. Disc 1, therefore, has recorded upon it two sets of 30 half-length tracks, one half of the disc bearing the "odd" and the other the "even" minute numerals.

For each set of tracks there is provided a lamp and photocell unit, which is fixed for the phrase, the synchronising signal and the pips, and is moved on a carriage for selection of the hours, minutes, and seconds.

Disc 1 therefore has two moving photocell units (5, 6), disc 2 has one fixed and one moving (7, 8) and disc 3 has two fixed and one moving (9, 10, 11). The photocell outputs are connected to cathode followers (12) and thence to springsets (13) which are operated by cams on a 6 r.p.m. shaft of the main motor gearbox. This timing shaft rotates once in 10 seconds (the period of an announcement) and at the appropriate moments the successive parts of the announcement are switched in so that the complete sentence is built up. Thus the switching sequence is in the order:

Phrase: Disc 2 (fixed photocell).
Hours: Disc 2 (moving photocell).
Minutes: Disc 1 (moving photocell).
Seconds: Disc 3 (moving photocell).
Pips: Disc 3 (fixed photocell).

The announcement must of course be changed every ten seconds in order to state the correct time. This is achieved by moving the carriages carrying the photocells across the face of each disc in such a manner that the correct tracks are selected. The motive power for this operation (which obviously must take place between announcements) is derived from an auxiliary motor (14) via a subsidiary shaft which runs past the carriages and carries clutch operated pawls (15, 16, 17) which engage with ratchet wheels on small cam shafts associated with each moving carriage.

Once every ten seconds, the closing of contacts on the 6 r.p.m. shaft of the gear-box causes the clutch (17) of the "seconds" carriage to operate. Its pawl is engaged, the ratchet and cam are moved and the carriage advances one step to select the next track required for this portion of the announcement.

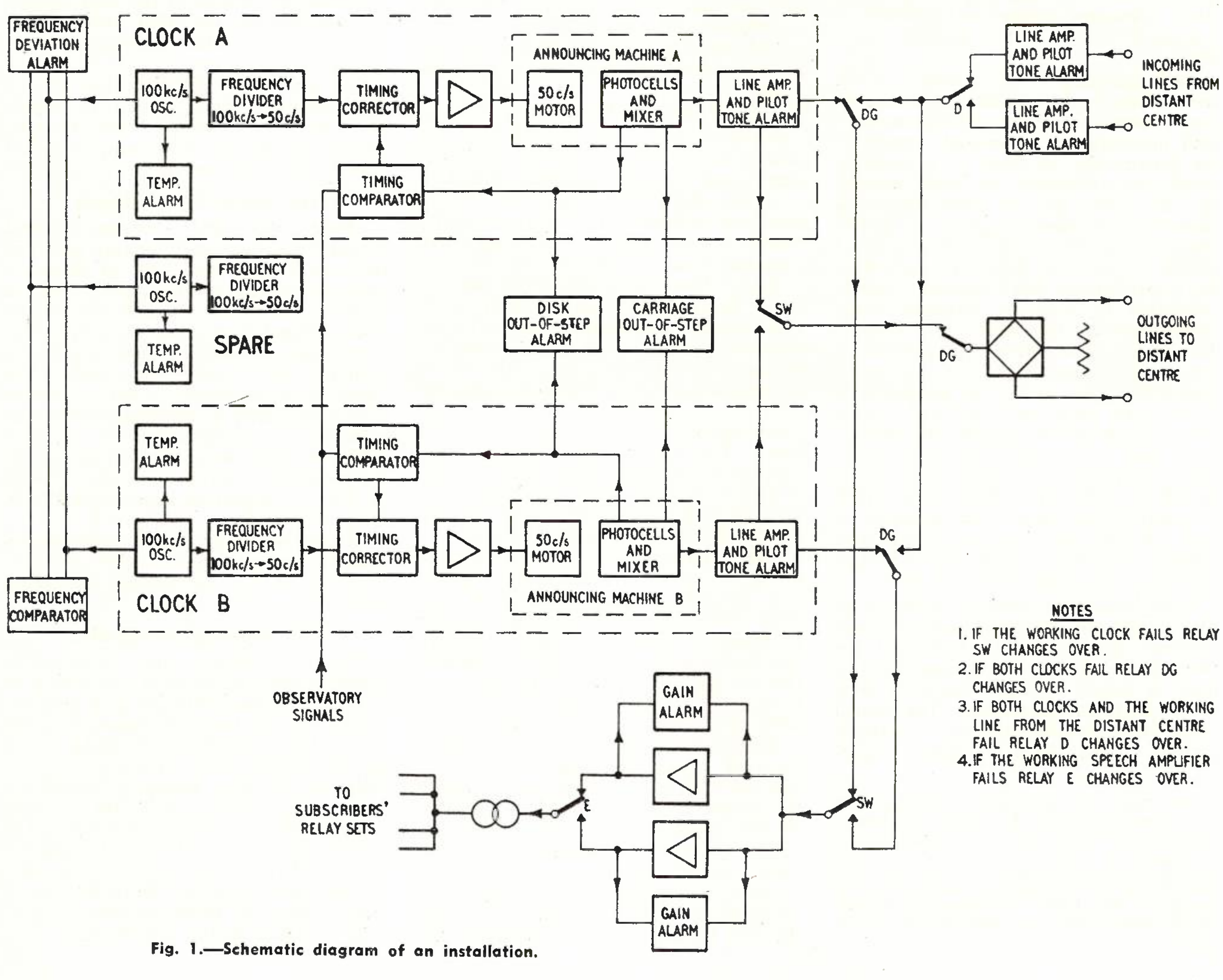


Fig. 1.—Schematic diagram of an installation.

As the carriage moves across the disc, alternate tracks are used for successive announcements until the limit of travel is reached. The carriage then returns in steps to its original position, selecting the remaining tracks as it goes. By using this interlaced system of recording of the tracks it is possible to reproduce the announcements in sequence without the discontinuity of a "carriage return" operation.

The seconds camshaft rotates once every two minutes in 12 discrete steps. Six of the positions correspond to "odd" minute announcements and the other six to "even" minutes. Now the "odd" and "even" minutes photocells must be switched after each "and 50 seconds" announcement, but the minutes carriage must be moved only once every two minutes—i.e., once per revolution of the seconds camshaft. This is achieved in the following way.

When the seconds carriage moves to the "odd minute - 50 seconds" position contacts associated with the seconds camshaft are closed and a circuit is thus prepared for the operation of the "minutes" carriage shaft. When the next impulse arrives from the timing shaft both the seconds and the minutes carriages move on together. As the seconds carriage thus moves into the "even minute - precisely" position an additional pair of contacts operate a relay which changes over the input to the announcement combining cams from the odd minute photocell to the even minute photocell. The six "even" minute announcements then follow. Then when the seconds carriage moves to the "odd minute - precisely" position the change-over relay releases, and the announcements are again taken from the odd minute photocell until the "odd minute - 50 seconds" position whereupon the cycle recommences. After each announcement ending in ". . . fifty-nine and fifty seconds" all three carriages move simultaneously and the hour track also is changed. The time taken for the carriage movements is not critical, provided that the operation is completed during the interval between announcements. It is thus permissible to drive the auxiliary motor (14) from the mains supply.

The final part of each announcement, the "pips", is derived from one of a series of 13 tracks recorded on disc 3. These are so disposed on the disc that the pips on successive tracks are displaced by the angular equivalent of 10 mS. By a suitable selection of the pip track, therefore, the timing of the pip signal can be adjusted in steps of 10 mS. This facility is useful for compensating for the delay times of the observatory line and the distribution network: the most suitable pip track is chosen when the equipment is installed, and thereafter the pip optical system remains fixed.

Mounted on the announcing machine bedplate is a small chassis (12). This carries cathode followers and a mixer stage for combining the outputs of the various photocells.

An associated paper by Mr. Forty, in this number of the Journal, deals with the "Photographic Technique of Sound Recording on Glass Discs".

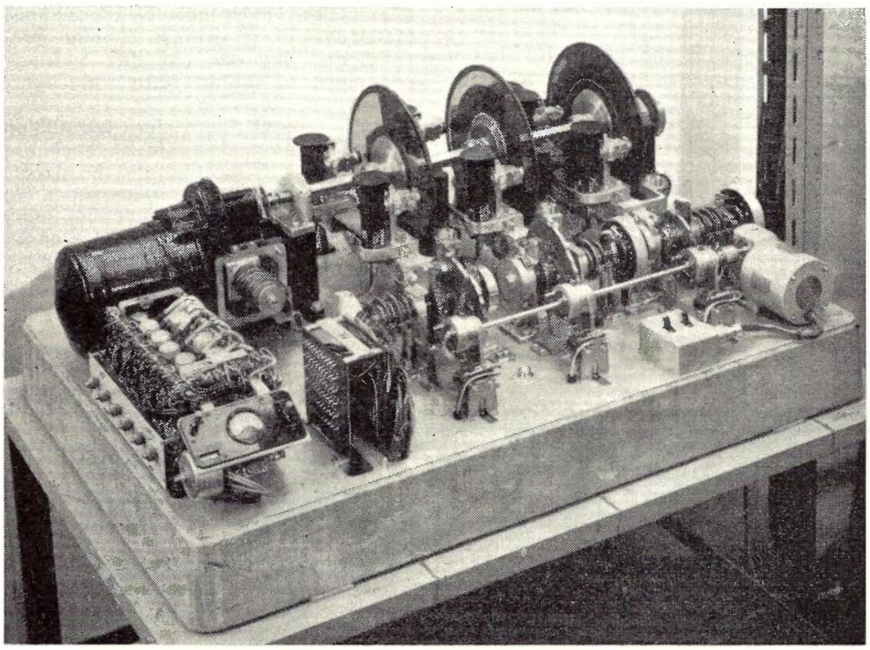


Fig. 2.—Announcing machine.

Time Correction

The system so far described will produce announcements of time at 10 seconds intervals. It is necessary, however, to make these announcements conform with standard time which is determined by the national observatory. The clock oscillator frequency may not be exact or may change with ageing of the crystal. Furthermore, standard time is subject to corrections which are applied by the observatory as a result of astronomical observations. Consequently it is essential to make a periodic comparison of the time declared by the clock with time signals obtained from the observatory, and to apply a correction to the clock if it should be required. A regular check is therefore made for this purpose once per day.

To simplify the error detection and the correcting equipment, the correction is applied in a series of discrete steps. At a prearranged time, therefore, signals derived at one second intervals from the clock (from the synchronising track on disc 3) are compared with similar signals received over a line from the observatory, and it is determined whether, at the instant of comparison of the first pair of pulses, the clock is fast or slow. If the clock is found to be fast, then it is retarded by an interval of 1 mS, or vice versa. This correction is performed automatically, and is completed before the next pair of pulses arrive for comparison.

The 1 millisecond corrections continue to be applied in this manner at one second intervals until it is found that the observatory signal and the clock signal differ by less than $\pm$ 1.5 mS, when the examination ceases until the next correction check on the following day.

Referring now to Fig. 1 it will be seen that the observatory line is connected to a panel called the Timing Comparator which also receives the signals from the synchronising track of the clock. Associated with this panel are three others called Timing Corrector Nos. 1, 2 and 3. These collectively form a control circuit in the 50 c/s supply from the oscillator to the clock motor, and contain a phase shifting device which may introduce a phase shift of either sign and of predetermined magnitude.

The sequence of operations which occurs when time correction is applied may now be described in greater detail. Shortly before the observatory transmits its time signals, a series of cam operated contacts associated with the photocell carriages of the announcing machine prepare the time correction apparatus for the check. When the first pulse arrives from the observatory, it passes through a circuit where its shape is modified and then into the Timing Comparator. At approximately the same time a similar signal is supplied by the clock. The two are compared, and if the clock is fast (or slow) by more than 1.5 mS, the "fast" (or "slow") relay of the Timing Comparator is operated and the information is passed to the phase shifting device of Timing Corrector No. 1. This device then retards or advances the phase of the 50 c/s supply to the clock motor by an amount which corresponds to a change of 1 mS in the clock time.

Towards the end of this phase shifting operation a rest signal is sent to the Timing Comparator to prepare it for the arrival of the next pair of pulses.

The whole of this detecting, correcting and resetting operation must of course take less than one second to complete. The process is repeated at one second intervals until the clock time is within ± 1.5 mS of standard time. When this condition occurs both the "fast" and the "slow" relays of the Timing Comparator are operated, no phase shift takes place in Timing Corrector No. 1 and no reset signal is returned. The correction circuit is thus shut down until the next check is initiated. The amount of correction applied to the check is displayed on the Timing Corrector No. 2 panel, and an alarm is given if a correction of more than 6 mS has been required.

Alarm Circuits and Standby Facilities

As described above there may be four sources of signals available for distribution to local telephone subscribers, i.e., two local clocks and two incoming lines from a distant installation. One of the local clocks is chosen as the working source: the other and the distant clocks are used as reserves. All four sources are linked by changeover contacts which will switch in a reserve source if the working source fails. This operation is controlled by the alarm circuits of the installation, and in particular by the pilot tone alarm system which will now be described.

During the recording of the announcing machine discs, a constant level tone of 3.2 kc/s has been superimposed on all the speech and "pip" tracks. Consequently if the machine is working correctly this tone should be present continuously in the output signals. A "line amplifier and pilot tone alarm" panel is inserted in the line from each source. On this panel a low pass filter suppresses the tone and transmits the speech signals to the local distribution amplifiers while a band pass filter rejects the speech frequencies and passes the tone to a detection alarm circuit. This system gives a complete safeguard against any fault which would cause the omission of part or all of an announcement (such as photocell, lamp, contact, or amplifier faults).

There remains the possibility that a clock may be making announcements which are complete but incorrect. This may happen if through a fault condition the motor drive frequency changes, or if a photocell carriage is not stepped forward at the correct moment.

It is unlikely that such faults would occur simultaneously on both the clocks of an installation and so a reliable detection of this type of fault may be made by comparison of the two.

The "disc out of step" alarm compares the timing of the synchronising tracks of Disc 3 of the machines and so determines differences of drive frequency, while the "carriage out of step" alarm gives an indication of differences of carriage position. Other alarm circuits are provided to give warning of failure or excessive frequency drift of the oscillators.

Distribution of Announcements

The speech and time signals of the working clock are fed into two power amplifiers, one of which supplies the public network and the other acts as a reserve. An alarm circuit, which detects change of gain, controls the changeover of the amplifiers if a fault should occur on the one connected for service. Since the amplifiers can be interchanged independently of the rest of the system, service can continue provided that any one amplifier and any one clock or distant source are functioning.

It is expected that a clock installation will be accommodated in an exchange building, but its location may be remote from the telephone apparatus room. To avoid loss of level in the junction, therefore, the designed load impedance of the power amplifier is 400 ohms, and a

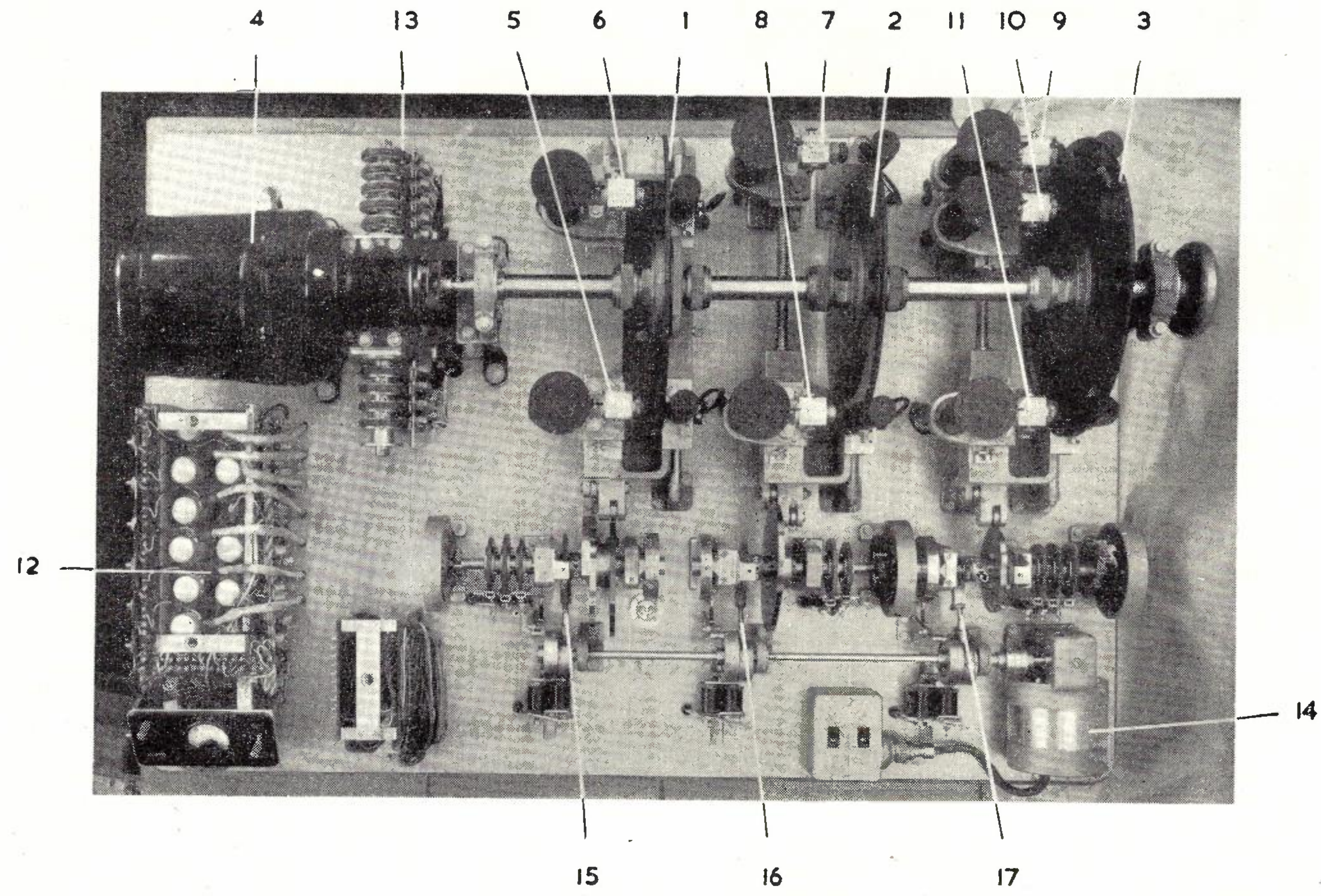


Fig. 3.—Plan view of announcing machine.

transformer is provided, to be installed in the apparatus room, to step down to a 4 ohms load resistor across which the subscriber's relay sets are connected in parallel (the low value of 4 ohms for the load being employed to avoid level changes with varying load and to prevent cross talk).

Time Signal Generators

Provided with each installation are two mechanisms (manufactured by Muirhead & Co. Ltd., England) for producing civil and marine time signals. Each machine consists of a small synchronous motor which drives a series of cams through suitable gearing. Contacts are closed by the cams at the correct intervals to control the signals transmitted. The machines are mounted on a single table between the clock announcing machines and are driven from the controlled 50 c/s supplies which feed the clocks. Consequently each time-signal generator will continue to function in step with observatory time as long as its parent clock is in operation.

Auxiliary Power Supply

An auxiliary 200/250 V AC 50 c/s power supply is provided to ensure that service is maintained in the event of a mains failure. The equipment comprises two generators, driven by 50 V DC motors, and a switchboard. The working clock is normally run from the main supply and the standby clock from the first generator. The second generator is normally idle. If the mains should fail the standby clock is automatically brought into service and an alarm is given. The second generator may then be started up and used to supply the first clock (which now becomes the standby and which will of course require to be synchronised with the second clock before it can be used). It is important that the supply to the 100 kc/s oscillators should not be interrupted since this would cause a sudden and unpredictable change in the rating of the crystals. Consequently arrangements are made to switch the oscillator supplies automatically from the mains to generator and vice versa if one of these supplies should be interrupted.

Accuracy

The ultimate accuracy of the time signals as received by a telephone subscriber depends upon the following factors:—

1. The precision of correction of the clock to conform with observatory time.
2. The short term stability of the phonic motor.
3. The stability of the drive oscillator.
4. The time delays in the distribution network and in the observatory line.

Each clock is normally corrected once per day and immediately after the correction interval the time announced will be within ± 1.5 mS of standard observatory time as received at the clock installation. The phonic motor driving the clock mechanism is subject to random angular variations arising from compliance in both the electrical and the mechanical couplings. These variations give rise to an error which varies from instant to instant but does not exceed $\pm$ 1 mS. Furthermore the drive oscillator frequency is likely to drift by an amount not exceeding 2 mS per day. Consequently the accuracy of the clock signals is of the order of $\pm$ 2.5 mS immediately after correction or $\pm$ 4.5 mS just before correction is applied.

Added to these errors is that due to the time delay in the distribution network. This may amount to several mS per 100 miles, and is of course always tending to make the signals slow with respect to standard time. Delay in the line from the observatory to the clock has a similar effect. If the distribution network is considered as a whole, it may be desirable to minimise the average error in time signals by sending them from the clock in advance of true time. If, for instance, the delay to the furthest point of the network is 20 mS and the signals are sent 10 mS fast, then the error due to line delay at any point in the system will not exceed $\pm$ 10 mS. To make this compromise possible a series of "pip" tracks is provided on the "seconds" disc as previously described.

Conclusion

Throughout the design of the new Speaking Clock system, the first consideration has been that of reliability of operation. It is confidently expected that these two installations will give the Australian Post Office the long and efficient service which their predecessors have rendered to Great Britain.

THE INFORMATION THEORY

FRANCIS BELLO

***Fortune's editors invite the reader to a venture into an exciting area of scientific thought. The accompanying article explains a new concept of information, pointing to communication systems of the future that will make present telephone and television circuits look primitive. While it is of immediate interest to engineers, the theory has profound implications for all who handle information—i.e., everyone.**

Great scientific theories, like great symphonies and great novels, are among man's proudest—and rarest—creations. What sets the scientific theory apart from and, in a sense, above the other creations is that it may profoundly and rapidly alter man's view of his world.

In this century man's views, not to say his life, have already been deeply altered by such scientific insights as relativity theory and quantum theory. Within the last five years a new theory has appeared that seems to bear some of the same hallmarks of greatness. The new theory, still almost unknown to the general public, goes under either of two names: communication theory or information theory. Whether or not it will ultimately rank with the enduring great is a question now being resolved in a score of major laboratories here and abroad.

The central teachings of the theory are directed at electrical engineers. It gives them, for the first time, a comprehensive understanding of their trade. It tells them how to measure the commodity they are called upon to transmit —the commodity called "information"— and how to measure the efficiency of their machinery for transmitting it. Thus the theory applies directly to telegraph, telephone, radio, television, and radar systems; to electronic computers and to automatic controls for factories as well as for weapons.

It may be no exaggeration to say that man's progress in peace, and security in war, depend more on fruitful applications of information theory than on physical demonstrations, either in bombs or in power plants, that Einstein's famous equation works. As might be expected, military applications are coming first. For example: The recently disclosed "Distant Early Warning Line" of automatic radar stations, stretching from Alaska to Greenland, almost certainly incorporates more of the lessons of information theory than any other communication system yet devised. The warning line was designed by the two organizations that should know more about the theory than anyone else: Massachusetts Institute of Technology (working through its Lincoln Laboratory) and Bell Telephone Laboratories.

The theory has an unusual joint origin. To M.I.T.'s eminent mathematician, Norbert Wiener, goes the major credit for discovering the new continent and grasping its dimensions; to Claude Shannon of Bell Laboratories goes the credit for mapping the new territory in detail and charting some breath-taking peaks. Wiener's basic contribution was to recognize that communication of information is a problem in statistics, a view he first stated clearly in a secret World War II document that dealt with the problem of shooting down airplanes. He followed this in 1948 with his now famous

*This paper has been reprinted from the December 1953 issue of "Fortune" by kind permission of the Editors of that Journal and Mr. Francis Bello. Acknowledgments are due also to Rolf Klep for the diagrams in Figs. 1 to 5, and to Max Gschwind for the diagram Fig. 7.

book "Cybernetics, or Control and Communication in the Animal and the Machine". The same year Shannon published his great work, "A Mathematical Theory of Communication", aimed specifically at the electrical engineer.

The fascination of the theory, as Cybernetics indicates, is that it insists on thrusting beyond the confines of electrical engineering. In particular it is Wiener's belief, shared by many others, that one of the lessons of cybernetics is "that any organism is held together by the possession of means for the acquisition, use, retention, and transmission of information." Naturally, therefore, attempts are being made to use information theory in a dozen fields from psychiatry to sociology. In a few fields, notably psychology, neurophysiology, and linguistics, the theory has already been applied with considerable success.

What Information Means

What the theory does for the first time is provide a precise unit of measure for the "amount of information" in various broad classes of messages. The class may be represented by a voice on the telephone, a picture on a television screen, the language of Shakespeare, or the music of Beethoven. When the engineer has used the theory to measure the information content, or information density, of such messages, he can tell how large his transmission channel must be to carry each.

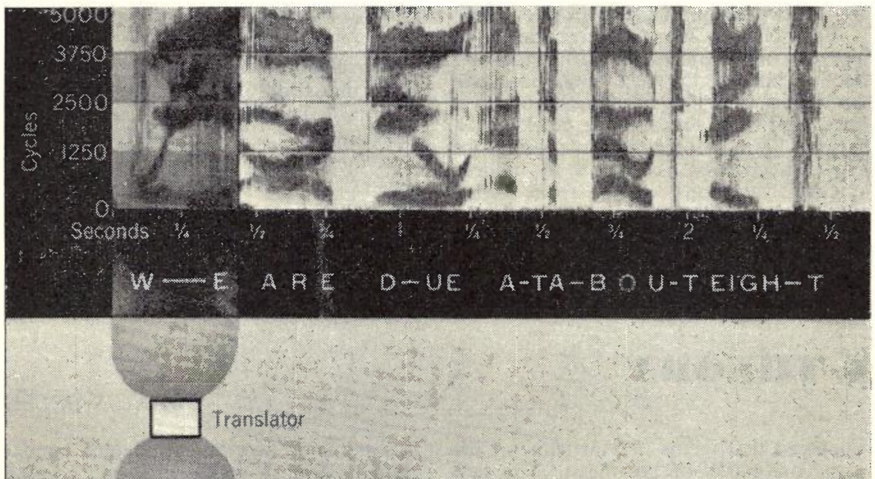
Information, as used in the theory, is very carefully defined and information theorists have trouble forcing people to stick with the definition. To Wiener and Shannon, information is contained, to great or less degree, in any message a communication engineer is asked to transmit. He is not interested in semantics or meaning; he must assume that even gibberish may have meaning if someone is willing to pay to have it transmitted. "You have to realize," says one student of the theory, "that this is a little like Alice in Wonderland. The word 'information' means exactly what we say it means."

Shannon once had to tell a group of prominent scientists who had become badly confused by his use of the word: "I think perhaps the word 'information' is causing more trouble . . . than it is worth, except that it is difficult to find another word that is anywhere near right. It should be kept solidly in mind that [information] is only a measure of the difficulty in transmitting the sequences [i.e., messages] produced by some information source".

If Samuel Morse had been listening he would have felt perfectly at home with the concept of transmission difficulty. And he would have been quick to appreciate that the way to measure difficulty is by statistical techniques. In setting up his dot-dash code, Morse made one of the first applications of statistics to a communication problem. On the basis of type counts made in a printing shop, Morse assigned a short code to the most frequent letters and longer codes to the less frequent. Thus he could transmit E, the most frequent, by simply sending a dot, but for V, one of the least frequent, he had to send dot-dot-dot-dash.

Thus Morse would expect to have more difficulty, i.e., expend more dots and dashes, transmitting 100 letters of gibberish, which might use V as frequently as E, than sensible English in which letters appeared with their familiar frequency. However, Morse might have been as astonished as anyone else to hear Shannon equate difficulty and information, because by this equation gibberish, to the extent that it is good random gibberish, will always contain more "information" than an equally long sequence of letters from, say, "Hamlet" or the "Britannica". Lest the reader, at this point, balk and say that Shannon and Wiener have no right to call gibberish "information", he must let them continue.

Most people will agree that any message communicates information only to the extent that it contains "news". If a message source generates an endless succession of A's, the engineer need not transmit it at all. He would simply



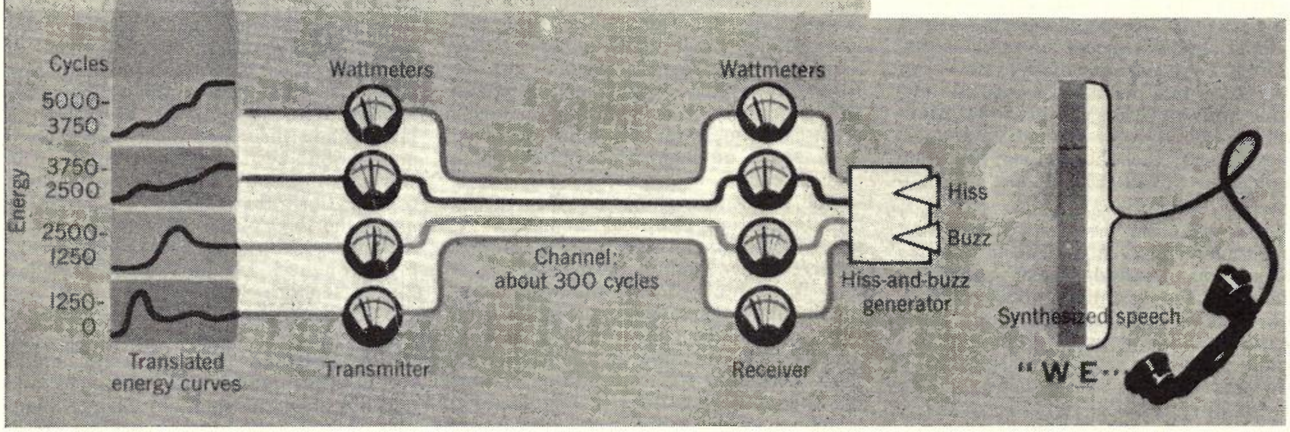


Fig. 1.—Speech and how to compress it.

To transmit a spoken message with reasonable fidelity, the telephone company now uses channels capable of carrying about 28,000 bits of information per second. The amount of information in ordinary speech, if converted simply into written English (e.g., into a telegram), is only about forty bits per second. Thus, even allowing for the valuable information in tone, inflections, etc., the present method of transmitting speech by telephone is highly inefficient.

One experimental device that will compress speech into about one-tenth the normal channel space is Bell's Vocoder, which takes advantage of the fact that speech energy (shaded areas in the speech spectogram, above) rises and falls quite slowly. Slow rate of change is synonymous with slow information rate. The Vocoder divides the spectrum into eight or more bands (the diagram shows only four) and what it transmits is a measure of the average energv in each. This information (reflected in the wattmeters) no longer resembles speech. To synthesize speech at the receiver, the Vocoder uses a hiss-and-buzz generator that produces a surprisingly lifelike re-creation of the voice at the other end of the line.

build a device for creating the message at the receiving end. The lesson in this for the engineer is that whatever part of a message he can predict, he need not transmit. In this light all existing communication systems—telephone, radio, television — are vastly overdesigned, hence vastly inefficient.

Wiener and Shannon show, with their statistical approach, that all ordinary messages—speech, music, pictures—are highly predictable. They are not composed of random sequences of sounds, notes, or light and dark areas. They contain familiar patterns. When the engineer has familiarized himself with all the possible patterns in his messages, he can start omitting redundancies and start transmitting only what is essential —that is, only the unpredictable.

The Value of the Theory

It is doubtful if many communication engineers, before Wiener and Shannon, grasped the essence of their job in quite this light, obvious as it may seem now. The theory, of course, does more than express a philosophy of communication, it provides universal measures. Before the theory, engineers knew that when "something"—it couldn't yet be called information—in a message changed rapidly, they had to provide bigger transmission "pipes", i.e., channels, to carry it. Thus music produced vibrations in air that had an upper frequency of about 15,000 cycles per second. To transmit these vibrations with "high fidelity" they knew they had to use a channel with a "bandwidth" of 15,000 cycles. Actually, in AM radio they settled for 5,000 cycles, and lower fidelity. Telephone engineers used a bandwidth of about 3,500 cycles for speech. Then came television, in which "something" changed very rapidly indeed. The engineer found that to paint a picture on a screen with a beam of electrons he had to be prepared to vary the intensity of every dot on every one of the 525 scanning lines thirty times a second. To do this required a bandwidth of some four million cycles, or nearly 1,000 times that required for ordinary radio. Shannon recalls that one of the questions motivating his early work was: could television be compressed into a smaller bandwidth, or couldn't it?

While information theory now shows that it can, no one has progressed much beyond paper plans, for the job is extremely tricky and takes a lot of hardware, as the Figs. 1 and 2 and captions suggest.

It is precisely here that the value and power of a good theory become difficult to describe. A theory builds no machinery. But inevitably, when good theories are enunciated, they make machinery easier to build. "Before we had the theory a lot of us were deeply troubled," says Jerome Wiesner, director of M.I.T.'s Research Laboratory of Electronics. "We had been dealing with a commodity that we could never see or really define. We were in the situation petroleum engineers would be in if they didn't have a measuring unit like the gallon. We had intuitive feelings about these matters, but we didn't have a clear understanding."

One "Bit" of Information

To provide a measure for information, which makes it possible to measure the "something" in different sorts of messages, information theory builds from the simplest of all bases. It considers two symbols, say A and B, and the way they may be combined into messages. We have already seen that an endless string of A's presents nothing that needs transmitting. Information begins with uncertainty—with the first B. As more B's are mixed in with the A's the engineer has to send out more signals. In the extreme case when there are as many B's as A's and they appear at random, i.e., unpredictably, the flow of signals—hence the flow of information—reaches a maximum. The simplest possible code for A and B is 0 and 1. If the engineer sends the 1 over a channel as one electric impulse, and the 0 as "no impulse", he has achieved all the economy possible.

Thus the engineer is working hardest, in the simplest case, when transmitting two symbols of equal probability. This suggested to Wiener and Shannon that the unit of information be defined as that which makes a decision between two equally probable events. This unit was baptized the "bit" because the symbols 0 and 1 are technically known as

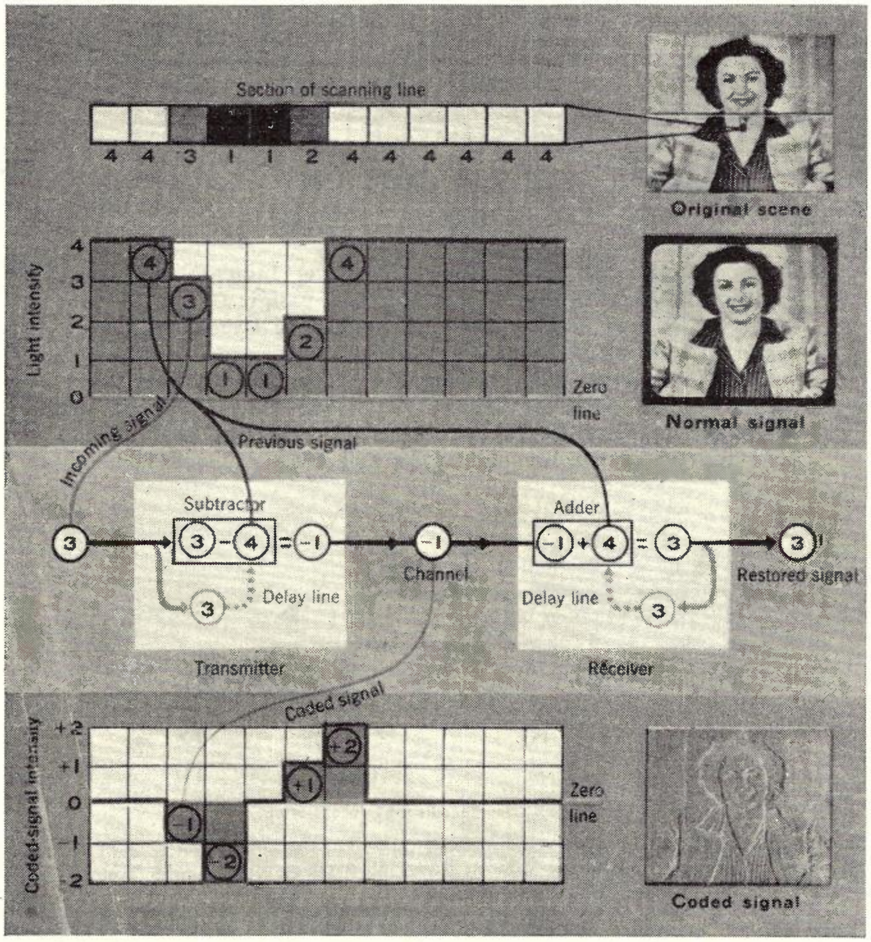


Fig. 2.—Television is predictable.

To transmit television the engineer now uses many times as much channel space as might be required with better encoding. The experimental Bell Labs system, above, demonstrates, as a first step toward compression, that television is highly predictable. So far, however, the system saves only power.
In ordinary television the scanning line, (top) is encoded into a signal (directly below), in which amplitude varies with light intensity, here scaled from 0 to 4. (The area shaded in the light intensity diagram represents signal power.) The better coding system works on the assumption that the upcoming signal (3, in the example) will be the same as the last (i.e., 4). If it is not, the transmitter subtracts the old signal (a copy of which it has cycled through a delay line) from the new one, and transmits the difference (here, -1). At the receiver an "adder" adds this difference to the previous signal (of which it also has a copy) and arrives at the correct signal (here, 3). The graph at the bottom indicates how a power saving is achieved, since most of the time the transmitter is sending "no change". (In which case the receiver keeps repeating the last signal.) The photograph, lower right, shows how the coded signal might look if intercepted.
The method achieves no bandwidth compression, however, because it is still prepared to alter every dot in the picture as rapidly as in the standard system. Compression requires an "elastic" transmitting system that can collapse long stretches of "no change" into a brief code (exactly as in the facsimile example, shown in Fig. 5), leaving more time to transmit the few signals representing change. The system will then be designed to transport the average volume of information instead of the peak.

"binary digits", which someone had previously abbreviated to "bits". Thus to transmit a random string of A's and B's the engineer has to transmit one full bit of information, either 0 or 1, every time the message source utters one letter or the other.

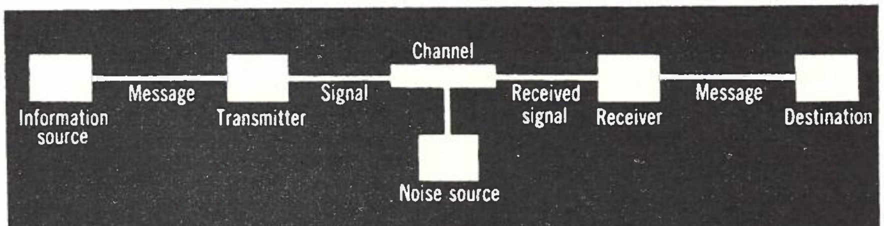
By stringing together code groups composed of bits—just as Morse used dots and dashes—it is possible to code the entire alphabet of twenty-six letters, of "alphabets" of any desired length. A code group two bits long provides four combinations, 00, 01, 10, 11, hence can be used to encode a four-letter "alphabet" say, A. B. C. D. A three-bit code can be arranged in eight possible combinations: 000, 001, 010, 011, 100, 101, 110, 111, hence will specify an eight-letter alphabet. Note that as the code lengthens by one bit, the number of combinations doubles. Thus an eight-bit code provides 256 combinations starting with 00000000 and ending with 11111111.

Information theory tells the engineer that his codes are efficient only when each 0 and 1, i.e., each bit, is working just as hard as it can. When this is achieved, says the theory, the engineer can count up the number of bits he has used, and this will tell him the net amount of information in the original message.

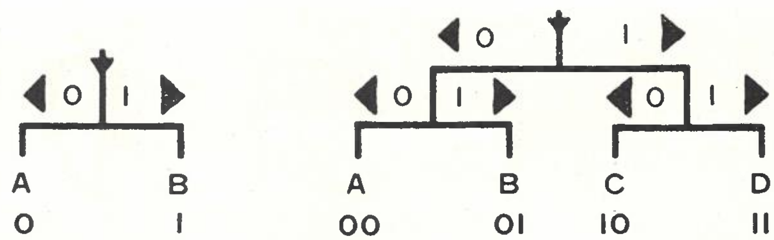
Since the engineer, obviously, cannot be expected to sit down and test every possible way of encoding a message into 0's and 1's, the theory provides him with an equation that gives, in bits, the amount of information per symbol in any message—be it speech, music, or pictures.* All the engineer has to put into the equation is the relative frequency with which each symbol appears in the message. This is not hard to do for a single message, but the answer obtained in this way is not very useful. What should go into the equation are frequencies with which groups of symbols are used in a large sample of messages.

This concept is easiest to follow if we consider written English. Morse dealt only with frequencies for each letter. However, he might have counted the frequencies of letter pairs, of which there are 676 possibilities from AA to ZZ. These he could have ranked in decreasing order of frequency, assigning a longer code to each as he went down the list. (Had he done this, of course, telegraphers would have given up in despair.) If letter pairs were coded into binary digits, with no regard to frequencies, the average code length would be about 9.4 bits. Such a code could be devised by drawing up a "code mobile" similar to that shown for the twenty-six-letter alphabet in Figs. 3

*In written messages the symbols are the letters of the alphabet; in spoken messages the symbols are the various phonetic sounds, of which there are about forty; in pictures the symbols are the number of distinguishable tones from white to black of which each "dot" of the picture is composed. In played music, the number of possible symbols may be obtained by "quantizing" the complex sound wave of the music into a succession of numerical values. How this may be done is illustrated in Fig. 7.



Communication theory deals with the generalized communication system shown above. The key to efficient communication is maximum compression (i.e., proper encoding) of the message at the transmitter. A number of encoding systems are described on these pages.



The symmetrical "code mobiles," above, indicate the basic method for establishing an efficient binary-digit (0 and 1) code for two or four letters, provided the letters appear in a message with equal frequency. The code is determined by the "0" and "1" signposts that are passed en route to each letter. The asymmetrical "mobile," below, yields an efficient code if the engineer is trying to transmit messages composed half of A's, one-quarter of B's, one-eighth C's and D's.

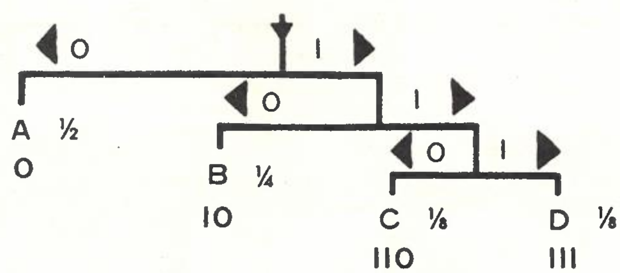


Fig. 3.—The Encoding of Information.

To transmit information—words, music, pictures—the communication engineer must encode it. A central teaching of the Wiener-Shannon theory of communication is that encoding should take advantage of the statistical nature of messages.

One code system of great value uses only two symbols, 0 and 1, which are called binary digits, or "bits" for short. The diagrams show how ordinary letters can be coded into bits. If two letters, A and B, appear in a message at random (hence with equal probability), an efficient code (centre diagram) will let A = 0, B = 1 (or vice versa). Similarly, each letter in a four-letter "alphabet", A, B, C, D, will require a two-bit code, provided, again, that one letter is as probable as another.

Suppose, however, an information source has an A-B-C-D alphabet but uses some letters more frequently than others. Then, says the theory, each letter does not carry a full two bit's worth of information, hence does not deserve a two-bit code. If a source creates messages that contain, on the average, half A's, one-quarter B's, and one-eighth C's and D's, it can be shown that an efficient code lets A = 0, B = 10 ("one-zero," not "ten"), C = 110, and D = 111. With this code a typical message BDAAABCA becomes: 10111000101100. So coded the total message contains only fourteen bits, or $1\frac{3}{4}$ bits per letter—not two bits.

The basic method for creating an efficient code is shown in lower diagram. The symbols are hung on an asymmetrical "mobile" so that the first decision point (marked 0 or 1) divides the symbols into two equally probable groups. (Here, A is as probable as B, C, and D combined.) The next decision point again divides the remaining symbols into two equally probable groups, and so on. The "mobile" is rigged correctly if random trips through it will generate messages that have the same letter frequencies as those composed by the information source itself.

Information theorists say that it is possible to make a similar, but gigantic, "code mobile" that would provide a coding of maximum efficiency for ordinary literary English. As the diagram, Fig. 4, indicates, an ordinary (equal-probability) mobile for the alphabet calls for between four and five bits per letter (4.7, to be exact). Shannon's surprising conclusion is that sensible English carries, on the average, only about one bit of information per letter.

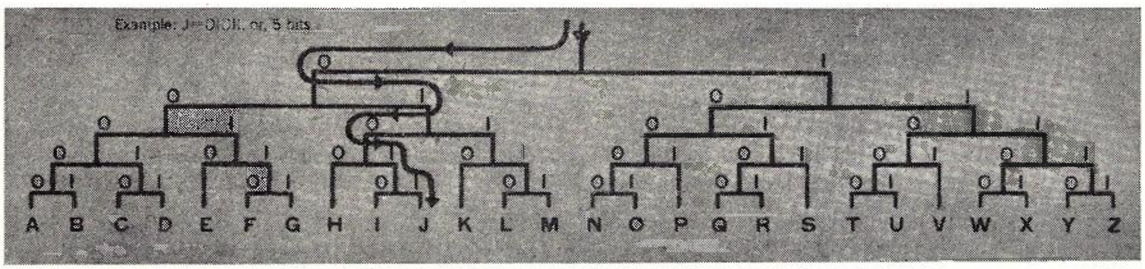


Fig. 4.—The alphabet in 4.7 bits per letter.

and 4. If the mobile were extended to support 676 symbols (i.e., 676 letter pairs), the number of bits needed to specify each would usually be nine, though some symbols would require ten.

If, however, the 676 symbols were hung, according to frequency, on what Figs. 3 and 4 describe as an asymmetrical "mobile", some commonplace letter pairs (for example, TH and IE) would be assigned codes only two or three bits long, while the least frequent pairs would carry codes sixteen or seventeen bits long. If ordinary English were translated into such a code, a count would show that, on the average, only 7.1 instead of 9.4 bits had been used to encode each pair of letters. This works out to 3.56 bits per letter as against the 4.7 bits required when the code is assigned without any reference to frequencies.

The question that fascinated Shannon was how little information does ordinary English really contain. If he could determine this he would know how tightly English might theoretically be encoded. With existing frequency tables he could go only one step beyond two-letter frequencies, to three-letter frequencies (calculated as an aid to cryptographers). These, in Shannon's equation, reduced the code requirement to 3.3 bits per letter.

It is easy to see why no one ever carried the frequency tables beyond three-letter groups: there are 17,576 possible ways to arrange twenty-six letters into groups of three, and nearly half a million combinations of four-letter groups, from AAAA to ZZZZ. Shannon, however, was determined to press further, so he reasoned that any average speaker of English ought to have a tremendous "built-in" knowledge of English statistics. To tap this knowledge, Shannon resorted to ingenious guessing games.

The Guessing Game

In one game he would pick a passage at random, from a book, and ask someone to guess the letters, one by one. He would tell the subject only if he were wrong, and the subject would continue until he finally guessed the right letter (or space). Shannon quickly discovered that the average person requires substantially fewer than 3.3 guesses to identify the correct letter in ordinary text. The relation between guesses and bits of information should become clearer in what follows.*

One of Shannon's favorite passages for this type of game was "There is no reverse on a motorcycle a friend of mine found this out rather dramatically the other day." In this passage there are 102 letters and spaces, including a final space after "day". Going through the passage letter by letter, one of Shannon's subjects guessed right on his first guess 79 times, and correctly identified all 102 letters and spaces with only 198 guesses, or less than two guesses per letter or space.

In Joyce, a Compression?

After mathematical analysis of many such experiments Shannon concluded that in ordinary literary English the long-range statistical effects reduce the information content to about one bit per letter. That is to say, if one sees the first 50 or 100 letters of a message, he can be reasonably certain, on the average, that the next following letter (which he hasn't seen) will be one of only two equally probable letters. To remove this much uncertainty requires, by definition, only one bit of information.

Naturally, the amount of uncertainty, hence amount of information, varies among different samples of English. In his basic paper on communication theory, Shannon writes: "Two [opposite] extremes of redundancy in English prose are represented by Basic English and by James Joyce's book, "Finnegans Wake". The Basic English vocabulary is limited to 850 words and the redundancy is very high. This is reflected in the expansion that occurs when a passage is translated into Basic English. Joyce on the other hand enlarges the vocabulary and is alleged to achieve a compression of semantic content."

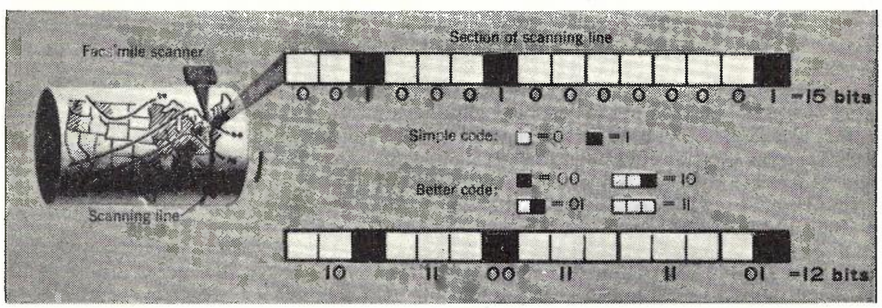


Fig. 5.—The weather map, bit by bit.

To transmit a weather map, facsimile uses, in effect, a binary code. As the scanner traverses the map it sends a pulse, or 1, at each unit of black space, and "no pulse" or 0, at each unit of white. The trouble with this simple system is that it spends so much time sending nothing (i.e., white space). Recently the Microwave Research Institute (Polytechnic Institute of Brooklyn) demonstrated a more efficient system for transmitting maps. The system uses a code similar to the "better code" shown above. The object is to transmit long stretches of white space quickly, i.e., in short code, at the penalty of sending infrequent black units in a code longer than the present simple code.

Shannon's calculation that the average letter of English (in a long passage) contains only one bit of information has this surprising implication. It says that with proper encoding it should be possible to translate any page of ordinary English into a succession of binary digits, 0 and 1, so that there are no more digits than there were letters in the original text. In other words, twenty-four of the twenty-six letters of the alphabet are superfluous. So far as printed English is concerned, this is the goal that information theory establishes for the communication engineer.†

*Information theorists view the game Twenty Questions as an exercise in their theory. If the game were played perfectly, they say, each yes or no should provide the contestant with one bit of information. In this view, twenty bits would suffice to identify 2^{20}, or one out of a million-plus, possible objects. This indicates why the twenty-first question would frequently be so helpful; with twenty-one questions it should be possible to identify one of 2^{21}, or over two million objects.

†However, the theory recognizes that redundancy often has value. It is English's high redundancy, for example, that makes typographical errors fairly easy to catch. By using a few extra binary digits, it is possible to design error-checking and error-correcting codes.

To help engineers visualize how English might be tightly encoded, Shannon asks them to imagine a communication system in which the transmitting device "guesses" upcoming letters in the way his subject guesses the letters in "There is no reverse on a motorcycle". The numbers under each of the following letters (and spaces) indicate the number of guesses the human subject required for the first words:

T H E R E   I S   N O
1 1 1 5 1 1 2 1 1 2 1 1
R E V E R S E
15 1 17 1 1 1 2

In theory, one could build a transmitter or encoding device that would approach this performance by providing it with a suitable set of operating instructions or programme. It might, for example, be programmed to guess T to start every message. After T it might always guess H, then E. After E, however, its programmed sequence of guesses, in order, might be space, S, I, Y, and R. Presumably the human subject ran through some such sequence before guessing R. Like the human, the machine finds that its programme of first and second choices works fine until it reaches the R and V in REVERSE.

With such a transmitter, the symbols that go over the channel are not the letters in the message but the numbers (in binary code) corresponding to the transmitter's guesses. (Naturally, strings of 1's would be coded into more economical form.) The receiver at the other end is an "identical twin" of the transmitter, hence it "knows", for example, that its own fifth guess after T-H-E would be R, and so on.

To reach the goal of two bits per letter—let alone the theoretical one bit—such a transmitter should not even start to guess until it had inspected at least the first ten letters of the message. Once it starts guessing it should make every guess on the basis of probabilities established by the preceding ten letters. This means that to programme such a transmitter someone would have to establish these probabilities by tabulating all combinations of eleven letters in a fair sample of all the English ever written. Since there are nearly four million billion ways to arrange twenty-six letters in groups of eleven, the task is all but unthinkable. Even so it might be done electronically if anyone thought the project worth while.

The Speaking Machine

Meanwhile, communication engineers will concentrate their efforts on fatter targets. Two of the fattest are present-day telephone and television systems, which, as one Bell Labs engineer phrases it, "ignore the past and pretend each [message] sample is a complete surprise".

Long before information theory, Bell Labs perceived that speech involved great redundancies of its own, independent of the redundancies existing in language itself. The Vocoder, described and diagrammed in Fig. 1, represents an early and continuing effort to code speech into more economical form for transmission.

So far, however, there are no plans to use the Vocoder in the telephone system—in part because one technical problem is still unsolved, that of establishing pitch with 100 per cent. accuracy. Meanwhile, Bell Labs has worked out another speech-compression system called Vobanc, which makes a bandwidth saving of only 50 per cent., but does it with equipment which is simpler than the Vocoder's, and without remaking speech from hisses and buzzes.

Fig. 6.

Supercompression of speech is achieved by this experimental Bell Laboratories machine known as AUDREY. Originally just an "automatic digit recogniser," AUDREY now can recognise sixteen of the principal phonetic sounds, which she translates into a four-bit code. So coded, about 100 conversations could be sent over the telephone channel that now carries only one. Like the Vocoder (see Fig. 1), AUDREY requires a hiss-and-buzz generator at the receiver to synthesize speech from its coded form. In the photograph, the machine's co-designer, K. H. Davis, is observing AUDREY'S acknowledgment—in lights, top panel—that she has recognised the sounds in the word "four".

An Ear for Speech

For the distant future, Bell researchers are experimenting with systems that promise to compress speech even more tightly than the Vocoder. One, now in early development, involves a machine that will recognize spoken sounds. This machine, called AUDREY, can be seen in Fig. 6. Originally just an "automatic digit recognizer", AUDREY has now been equipped to recognize sixteen of the most important phonetic sounds. When AUDREY recognizes a phonetic sound she signals a hiss-buzz generator (like the Vocoder's) to reproduce it. The result, while not yet equal to the Vocoder product, is surprisingly good. When AUDREY was expected only to recognize digits she frequently had trouble with digits spoken by anyone but her two inventors. Now, however, she can surmount this difficulty. Whereas she may still be unable to recognize a poorly spoken digit, she can signal the hiss-buzz generator to reproduce it accurately enough so it can be recognized as a poorly spoken digit.

If hooked into a phone system, the only signal AUDREY would send over the line would be a four-bit code identifying, in sequence, the particular phonetic sounds uttered by the speaker. Since an average speaker produces about ten of these per second, the channel need have a capacity of only about forty bits per second. This happens to be very close to the capacity needed to send the same message at the same rate by ordinary telegraphy.

Television is Predictable

In television the room for improvement is about as great, and the incentive to do something about it is possibly greater. It is much easier to visualize the redundancy in pictures on a TV screen than in a telephone conversation. As in a sequence of movie frames, there is usually very little difference in the successive pictures beamed onto a TV screen. Bell scientists estimate that frequently the redundancy in TV runs as high as 99 per cent. When this happens, the signal, in theory, could be transmitted on a 40,000-cycle, instead of four-million-cycle, channel.

Since the Bell System has almost sole responsibility for piping network television around the country, it is more eager than anyone else to slice away at the redundancy. With a compression of perhaps 100-to-1 it might be possible to send television signals across the ocean in one hop as is now done with short-wave radio. Bell Labs is designing experimental equipment that may achieve the first practical compression of a TV signal. As a first step Bell has already demonstrated that there are several ways to code a TV signal to reduce power consumption. One of these methods is illustrated in Fig. 2.

The Battle Against Noise

The communication art changes rapidly, however, and it is conceivable that ten or twenty years from now channel capacity will be much cheaper than it is today, and the Bell System may no longer feel any urgency about compressing television signals. Reason: Bell has in the laboratory new types of signal-carrying systems that will accommodate—in a single "pipe" called a wave guide—hundreds of standard TV channels. Nothing, however, is gained without cost. In the new "pipes" high capacity is achieved by speeding up the signalling process. This makes the signal more vulnerable to imperfections in transmission, which cause what the communication engineer calls noise. The term "noise" covers a host of electric disturbances that degrade a signal. The ultimate unavoidable source of noise is the "thermal" motion of electrons (the hum) in the electronic equipment itself.

Noise, basically a random phenomenon, is another fundamental problem to which information theory has applied the powerful tools of statistics. The theory tells the engineer how to establish the accuracy with which a message may be transmitted through a noisy channel. As Wiener points out, if there were no noise, the engineer could, in theory, transmit a perfectly measured voltage and thereby transmit an infinity of information. Thus a voltage measured precisely out to the billionth decimal place could represent a coded message a billion digits long.

If the engineer finds he must pass a TV signal through a wide but noisy channel he will probably turn to a relatively new coding system called "pulse code modulation", or PCM, which minimizes the effects of noise. PCM (as explained in Fig. 7) can be used to encode music, pictures, or any other type of message into the pulse-and-no-pulse of a binary code. PCM is effective in combating noise because it is extremely difficult for noise to give rise to a spurious pulse, or to blur out an existing pulse. The checkered wheel in Fig. 8 is designed to code information into PCM's nearly blur-proof form. (Photo transistors lined up along the radius of the wheel transmit pulses when they are behind white (clear) segments of the wheel, "no pulses" if black segments come between them and a light source.)

While the first U.S. patent on PCM was isued in 1942, there is reason to believe that PCM's virtues would have gone largely unappreciated if it had not been for information theory. Shannon showed for the first time precisely how the capacity of a channel in bits is related to the bandwidth, the signal power, and the noise. His equation showed that noise could be combated either by raising the signal power, by increasing the bandwidth, or by changing the signalling method. The theory also suggests that signalling methods even better than PCM remain to be discovered.

How Perfect?

It is the mark of a great theory that, beginning with certain intuitive concepts, it erects a series of relationships, which, rigorously extended, lead to propositions that are not at all self-evident. Thus the intuitive basis of relativity theory would have seemed reasonable to Aristotle, but its conclusion that energy and mass are exchangeable would not.

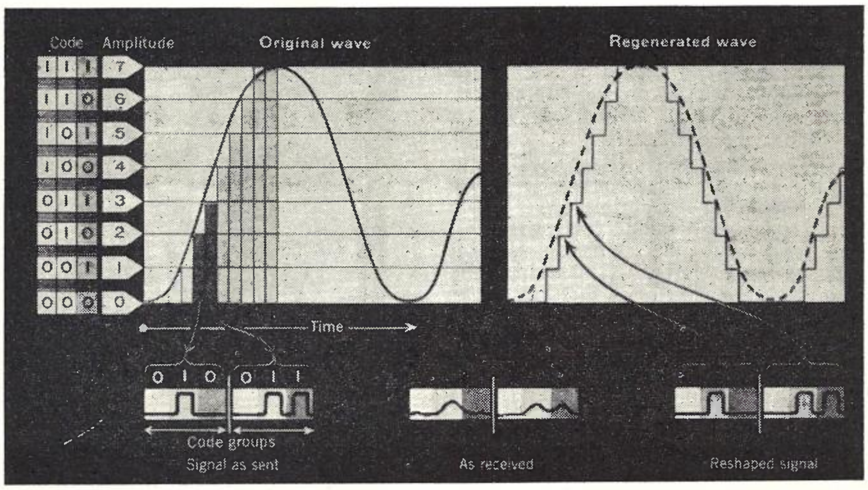


Fig. 7.

Superreliability of transmission is achieved by "pulse code modulation," or PCM, a new signaling method that, as evaluated by information theory, is more efficient than the familiar AM and FM of radio and television. To transmit speech and music, AM radio uses a continuous signal that varies in amplitude with the amplitude of the signal source. This is the undulating wave at the top left. In PCM this wave is "sliced up," and each slice is given a numerical value (here 0 to 7). These values are translated into a binary code. The lower diagrams show how binary's 1's and 0's, transmitted as pulses and "no pulses," can survive a great deal of "noise" distortion. It is extremely difficult for noise to give rise to a spurious pulse or to obliterate an existing one. At the receiver the pulses are converted to the continuous-wave form of the original signal.

While information theory does not contain anything so dramatic as $E = mc^2$, it does contain one conclusion of great subtlety that continues to astonish its most diligent students. It is a conclusion that, by extension, has great significance for designers of computers and automatic factories, on the one hand, and neurophysiologists on the other. And there are those who believe it may one day have significance in the everyday (i.e., non-electronic) affairs of men.

The striking conclusion is this: After setting up the relationship between channel capacity, bandwidth, power and noise, Shannon goes on to prove that if an information source produces information at a rate that does not exceed the channel capacity, there exists a method for putting the information through the channel and recovering it at the other side with negligibly small error. Simply stated, this means that a channel, no matter how noisy, can give, as a limit, ideal performance—in short, perfection from imperfection. "This to me," says M.I.T.'s Robert Fano, who teaches information theory, "is still a very astonishing thing. It has been definitely proved, but, except for trivial cases, we don't know how to do it."

Evidence is accumulating that living organisms long ago acquired the secret for obtaining near-perfect performance from relatively imperfect apparatus. For example, generations of physiologists have puzzled over the ability of the ear, which seems quite grossly designed, to distinguish two tones almost identical in pitch. Recently, W. H. Huggins obtained his doctorate at M.I.T. with a brilliant theory of hearing that seems to explain the mystery. What the ear employs, evidently, is an extremely clever encoding system. While Huggins made no direct use of information theory, his work is generally included in information theory's fast growing body of literature, for it speaks of an information-handling mechanism.

Man as Communicator.

Some of the most interesting applications of information theory, outside of electrical engineering, are being made in experimental psychology. To the psychologist, man may be considered as a message source or as a channel, but not very readily as a transmitter or a receiver. If you try to measure his abilities purely as a transmitter or receiver, you find you are really using him as a channel. Thus there seems to be no good way to ascertain the rate at which the eye or ear may receive information except by measuring the amount that is remembered or otherwise played back.

In tests run at M.I.T., subjects were asked to point to numbered squares as fast as they could read numbers flashed in random sequence. The test was run with two numbers and two squares, four numbers and four squares, and so on up to 4,096 numbers and 4,096 squares. As might be expected, the subject can hit quite a few squares per second when he has only a few to choose from, but when he has 1,024 (each worth ten bits) he does well to average 1.5 per second. In terms of information theory, it turns out that the average person can handle about fifteen bits per second.

The highest human channel capacity that M.I.T. psychologists have measured is forty-five bits per second, determined by a variant of the experiment just described. The world's fastest typist, in typing 149 words per minute, is handling just about twenty-five bits per second, if each letter be given a value of two bits. (This seems fair since she probably cannot grasp the long-range clues that, according to Shannon, reduce the information to one bit per letter.) The world's shorthand record is 282 words per minute, which, on the same basis, works out to about forty-seven bits per second.

These figures provide an upper limit for the amount of information a person may handle in a lifetime. The upper limit: roughly 50 billion bits.* One can now appreciate the immense channel capacity used to transmit television. The information handled in the most diligently spent lifetime could, if suitably encoded, be transmitted over a television channel in about sixteen minutes. The information handled in an **average** lifetime could hardly keep a TV channel occupied more than ten seconds.

There are dangers, of course, in overworking any concept, no matter how helpful. Some psychologists who originally encouraged their colleagues to study information theory and to apply it in their experiments now feel that the theory is frequently misapplied by psychologists—and almost inevitably misapplied by sociologists.

Inside the Nerve.

As Norbert Wiener perceived with his characteristic great enthusiasm, the concepts of information theory apply directly to neurophysiology. Largely as a result of his inspiration, M.I.T. has become one of the leading centres for the study of the central nervous system. The work, which comes under the Research Laboratory of Electronics, not only has high significance in its own right, but since biological reflexes are the most economical known, it may suggest ways to improve man-made systems.

To learn more of fundamental nerve circuitry, the M.I.T. investigators insert dozens of ultra-tiny electrodes into the spinal cords of anesthetized animals to chart the detailed flow of nerve messages. In the old technique for recording nerve impulses, a relatively large electrode was clamped outside a bundle of nerve fibres. This method, explains one M.I.T. scientist, was about as helpful as trying to analyse the communication network of the entire U.S. using only the signals picked up by ships stationed off the coast. The new electrode-insertion method requires complex electronic recording gear that is available only at a relatively few places like M.I.T., and the work goes slowly.

Information and Life.

So far no mention has been made of a word that appears in information theory with great frequency. The word is "entropy", and Shannon uses it as synonymous with "amount of information". When Shannon had derived his equation for calculating "amount of information", he found it was precisely the same equation that physicists use to calculate the quantity known as "entropy" in thermodynamics. What the physicist means by "entropy" has stumped freshman physics students for well over seventy-five years, but it is really not too difficult a concept. In thermodynamics, entropy measures the degree of randomness, or disorder, in atomic and molecular systems. The more disorder, the higher the entropy. The famous second law of thermodynamics states that in an isolated system, entropy may stay constant or increase, but never decrease. For an analogy, consider a shoebox into which one puts a handful of white beads at one end and a handful of black beads at the other. If the box is never touched the beads will stay in their respective ends, i.e., entropy (disorder) will stay constant. However, the moment the box is disturbed the beads will begin to mix, and disorder, i.e., entropy, will increase.

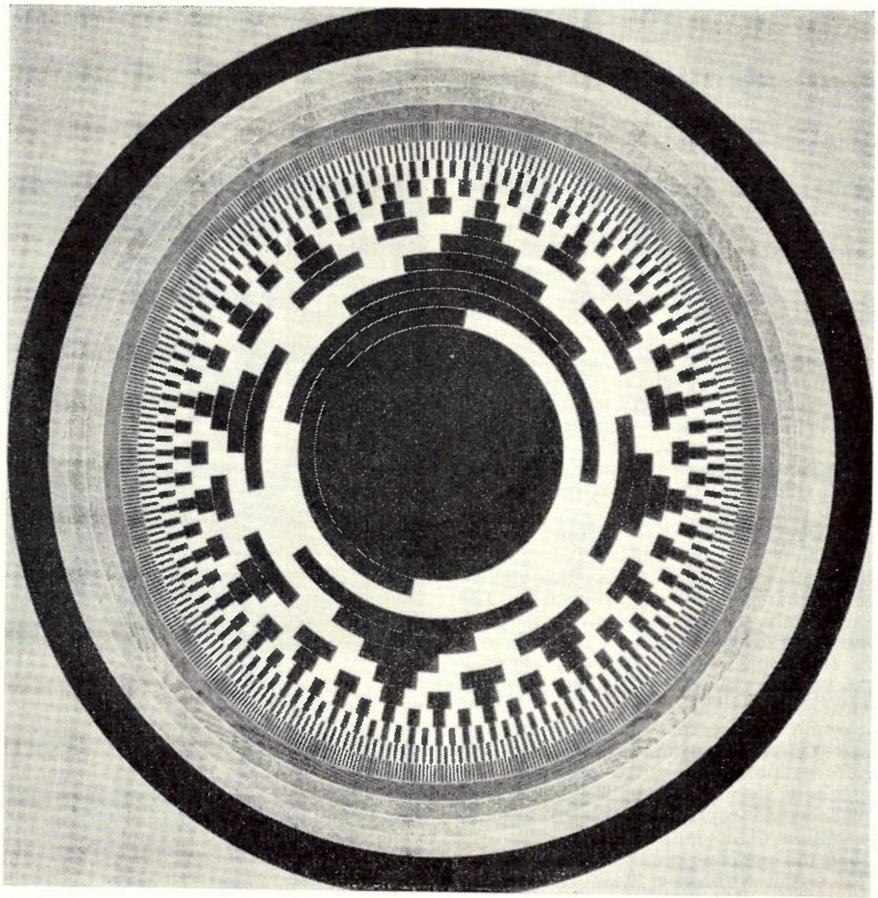


Fig. 8.—This checkered wheel is at the heart of experimental communication systems of high reliability being studied by the U.S. Army Signal Corps. As explained in this article, it converts information into a starkly simple code symbolic of communication's new era.

In Shannon's view, entropy (or amount of information) reaches a maximum when all the symbols in a message appear independently with equal probability, i.e., in random order.† Shannon does not suggest that there is any real identity between his entropy and thermodynamic entropy. Other scientists, however, have speculated that some deep, underlying identity may exist.

The identity seems tantalisingly real when one considers the nature of life. Life appears to refute the second law of thermodynamics, until one considers that life cannot continue in a closed system.

*Fifty bits per second, twelve hours a day for sixty years.

† Some information theorists, including Wiener, prefer to view information as equivalent to negative entropy—seemingly because information, to them, represents **order** not disorder. It is doubtful, however, if this reflects anything more than a bookkeeping difference.

In his book, "What Is Life?" Erwin Schrodinger, the Austrian-born physicist, stated a view that has gained popularity when he observed that life feeds on high-grade energy or negative entropy, that is, on substances with highly ordered structures. But the question remains: How does a simple leaf utilise solar energy to erect the primary ordered structures (e.g., sugar, starch, proteins)? It does this, Wiener and others suspect, because photosynthesis employs catalysts that somehow have the power to suspend the second law of thermodynamics, locally and temporarily. Such sorting agents, first proposed by Clerk Maxwell, have been called "Maxwell Demons". For the demon (catalyst) to operate it has to obtain information about the particles it is sorting. If life is thus viewed as a manipulation of energy and information, Wiener and others consider it fitting that both carry "entropy" as a common measure.

Information and Meaning.

While some extremely gifted minds have tried to use information theory as the foundation for a new theory of meaning, they have not been too successful, or at least they have not convinced their colleagues of their success. Yet even many of the unconvinced continue to hope that a foundation exists. One of the most hopeful is Warren Weaver, president-elect of the American Association for the Advancement of Science. Soon after Shannon's work appeared, Weaver wrote: "The theory . . . has so penetratingly cleared the air that one is now perhaps for the first time ready for a real theory of meaning . . . One has the vague feeling . . . that information and meaning may be subject to some joint restriction that compels the sacrifice of one if you insist on having much of the other."

Until Warren Weaver's hope is fulfilled, perhaps the hardest thing for the average person to keep steadily in mind is that information theory says nothing whatever about meaning. It is content to tell the engineer that a surprisingly large part of any English sentence (or of any other ordinary message) is predictable. But with all its quaint redundancies the English sentence is still, in Churchill's phrase, "a noble thing". The mind cannot conceive its all but infinite variety. In a billion years even television's capacious channel could not transmit more than a subsubmicroscopic fraction of the ways Churchill might have written a single speech.

The power of the theory lies in its ability to cope with messages of any nature. It will, for example, help the neurologist analyse communication networks that transmit apparently meaningless strings of coded symbols. Indeed, neurologists have already discovered that the signals that transmit information from the eye to the brain appear to be wholly random. However, to the brain, which knows the code, the signals are not meaningless; their apparent randomness simply reflects a high degree—conceivably the optimum degree—of compression. It is this same compression that information theory invites the communication engineer to achieve.

It is hard to see how information theory can fail to rank with the enduring great. For it goes to the heart of what appears to be life's most essential feature—the ability to communicate information.

ENGINEERING ECONOMICS AND ITS APPLICATION TO TELEPHONE PLANT DESIGN

N. M. MACDONALD, B.Sc., A.M.I.E.Aust.

Introduction

In many instances where new plant is necessary, alternative methods of providing the facilities required are available, and costs are an important factor in the selection between alternatives. The initial "capital" costs are not the only ones which should be taken into account. The scheme with the least first cost could, for example, require a larger expenditure on maintenance than the others, or the plant life could be shorter so that additional money would be necessary to replace it earlier than otherwise. Some of the schemes could also involve additions at frequent intervals while in other cases the facilities provided initially would meet requirements for a long period. In order to compare the costs of alternatives properly, it is necessary to combine all initial and future costs associated with each into a single figure, and the method of doing this is known as "engineering economics".

When costs are being compared it is necessary to ensure that the required facilities and performance are given by each alternative. It must also be remembered that uncertainties are involved in many of the costs, due for example to the impossibility of predicting exactly future development, the life of any item of plant, or material prices and wages at some future date. The longer costs are deferred, the greater is the uncertainty, and this makes it inadvisable to give too much weight to costs which will be incurred in the distant future. There are also some intangible factors, such as reliability and flexibility which cannot be expressed in terms of money. For such reasons, a cost comparison based on engineering economics cannot be the only factor in determining the method of providing a facility, especially in cases where the total costs do not differ greatly, and judgment based on experience must still play an important part in the choice.

Engineering economics is useful not only in the direct comparison of the costs of two or more specific methods of providing a facility. It can also be used to give valuable information on other general problems where a number of variable factors are involved, and it is desired to determine the best values for a minimum overall cost. Many general problems of this type are encountered in telephone plant design, and some examples will be given later in this article.

Principles of Engineering Economics

Annual Charges (1): Many of the costs associated with a work may be expressed directly as annual charges. For example the annual maintenance cost for an item of equipment can be evaluated readily from the time spent on routines and fault clearance, together with the cost of parts replaced and power consumed. Annual operating costs, such as those of a manual exchange, can be calculated similarly.

Although it is not so apparent, it is possible to represent capital costs in terms of annual charges, and at the same time make allowance for differences in plant lives. The simplest way of appreciating this is to suppose that the work is financed by a loan issued at a fixed rate of interest and repayable at the end of the plant life. This method of finance is actually used for many public works and similar methods are used by public companies, for example by the issue of shares. In order to make easy provision for the repayment of the loan, it is usual in most organisations to set aside each year an amount to allow for depreciation. There are a number of methods of determining the depreciation allowance (2), but the method generally favoured is the "sinking fund" method.

With this method, equal sums are invested each year to earn compound interest, and the sums are chosen so that the total amount which will have accumulated at the end of the expected plant life, will exactly repay the original loan. If the plant will have a realisable value at the end of its life, allowance is made for this by deducting from the amount which it is necessary to accumulate by annual sinking fund payments. The amount to be invested each year can be calculated readily for different lives and interest rates. Thus if £S is set aside at the end of each year for t years, at the end of the t th year the first year's investment will have amounted to £S $(1 + r)^{t-1}$, where r is the interest rate, or say the amount of interest earned by £1 in a year. The second payment will have amounted to £S $(1 + r)^{t-2}$, etc., and the last payment, which will not have earned interest, will remain unchanged at £S. The total will be

$$£S\ [1 + (1 + r) + \ldots\ldots\ldots + (1 + r)^{t-1}]$$

$$= £S \left[\frac{(1 + r)^t - 1}{(1 + r) - 1}\right]$$

$$= £S \frac{(1 + r)^t - 1}{r}$$

This should equal the capital cost less the residual value, if any, at the end of the plant life. The amount to be invested each year for each £1 required to repay the capital less residual value at the expiration of the loan is therefore the factor $\frac{r}{(1 + r)^t - 1}$ times the (capital cost less residual value). Tables are available for various values of r and t, and Fig. 1 gives an indication of the values. It should be remembered that allowances made in this way depend on the life of the plant being exactly as expected and this is not often the case. Where a number of units are provided at the same time, for example poles on a

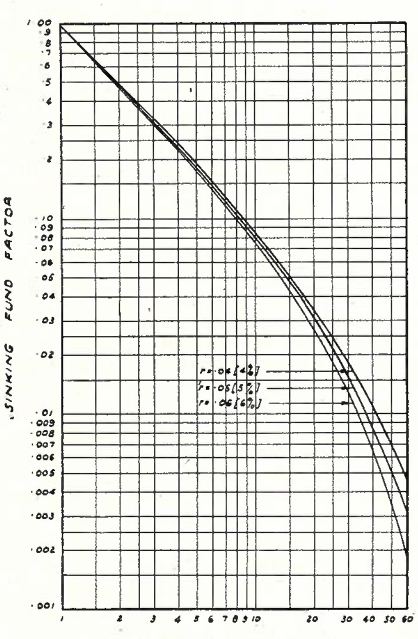


Fig. 1.—Sinking fund factors for various plant lives.

new aerial route, all do not need replacement at the same time, and statistics are often available for the average life and the deviation from the average. In such cases it is possible to make a sinking fund provision which is more accurate than when a single unit is involved (1).

When a work is financed by a loan, the organisation concerned does not spend any capital on the work, but merely pays the interest each year and invests the sinking fund allowance so that the loan may be repaid in due course. Thus the capital cost should not be regarded as part of the total cost of the work if the interest and sinking fund payments are so regarded; in fact, the capital cost is exactly equivalent to annual interest and sinking fund payments for the life of the plant.

The annual payment of a sum consisting of the maintenance and operating costs, together with interest and sinking fund payments will, therefore, allow a facility to be provided and to continue for the life of the plant. If it is desired to retain the facility then, another loan would be obtained and the annual charges would continue for another period. If all subsequent replacement costs were the same as the original cost, and the maintenance costs, interest rate, etc., did not vary, the facility could be provided and maintained for any required period by the expenditure of the annual charges. Under these conditions the total annual charges can be, and are, used directly to compare the costs of alternatives.

Departmental works are not financed directly by public loans, but by a new works vote from the Treasury, and an annual vote from the same source is used to defray maintenance costs and to replace worn out plant when no new facilities are provided at the same time. Sinking fund payments as such are not made, all revenue being paid back into Treasury. However, the application of the loan analogy to Departmental plant remains valid if it is considered that the capital is obtained as a loan from the Treasury, and that the same body invests part of the revenue received in other revenue producing works in order to replace Departmental plant which has reached the end of its life.

Plant Additions: The annual charge method of comparing costs is of value only when the costs of each alternative remain the same from year to year over the period under consideration. In most practical cases this condition does not apply. A simple example is one encountered when the provision of new subscribers' lines is necessary. One scheme would be to lay an underground cable to meet development for say 20 years or, alternatively, an aerial route could be provided to meet initial requirements only, with additional wires added from time to time as necessary. The annual charges for the cable would remain reasonably constant, but those for the aerial route would increase each time further wires were added. Thus no single cost would be associated with each alternative to enable the schemes to be compared directly. In other cases later plant additions may not be involved, but maintenance charges could increase from year to year as a result of wage increases.

In order to enable a comparison in such cases, each annual charge can be converted to a "present value", which is the sum of money which would have to be invested now at compound interest to pay the annual charge when it occurs. Thus, if an amount of £W is invested now at an interest factor of r, defined earlier, it will amount to £W $(1 + r)^t$ at the end of t years. Alternatively, the amount to be invested now to amount to £X at the end of t years would be £X/$(1 + r)^t$. The factor $1/(1 + r)^t$ is the present value factor, and Fig. 2 shows values for different values of r and t. By summing the present values of all annual charges occurring over the period under consideration, single costs will be obtained which will enable comparisons to be made.

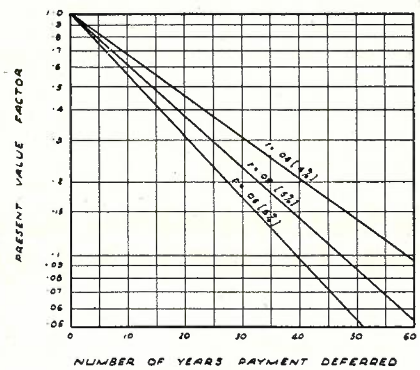


Fig. 2.—Present value factors for different values of r and t

Costing Period: The period over which costs are totalled is known as the costing period. For strict accuracy, the annual charges would have to be known accurately for each future year, and the total present value obtained by adding the present values of each annual charge until such time as the annual charges become the same for each alternative concerned. In most cases, however, the alternative adopted initially will influence the annual charges for ever, so that the sum would have to be taken for an infinite period. This is known as a perpetuity calculation. Provided that the annual charges increase from year to year at a rate less than that of the interest rate used, that is, the value for one year is less than k. $(1 + r)$ times the value for the previous year, k being a constant, it can be shown that the total sum for the infinite period will have a finite value, or the series will be convergent. If the annual charges increase at a greater rate an infinite sum will be obtained.

However, within this limitation, perpetuity calculations have the advantage of correctness and simplify the calculations in cases where annual charges are assumed to remain constant for each capital addition. This results from the fact that an amount Y invested will produce an annual interest payment of rY for an infinite period, so that the present value of a constant payment of Z, commencing in 1 year and continuing for perpetuity is Z/r. The present value of a constant annual charge of (capital cost x r + maintenance cost + sinking fund payment) will then be equal to (capital cost + maintenance cost /r + sinking fund payment /r). The present value of the cost of a later plant addition will be equal to the same cost multiplied by the present value factor applying to the time the addition is made.

The main disadvantage of the perpetuity method arises from the impossibility of predicting future annual charges accurately. This is due not only to the uncertainty of future prices and wages, and future requirements to meet development, but technical progress may result in the original method of provision becoming obsolete, and at the end of its life being replaced by an entirely different method with consequent changes in costs. As perpetuity calculations in effect give equal weight to costs whether they are certain or not, they can be misleading, and definite period calculations are often used. These terminate the costs at such time as the inaccuracy in predicting development becomes appreciable.

The costing period chosen depends largely on circumstances. For example, a period of 50 or 60 years is quoted in reference (3) which is concerned with electric power practice in the U.S.A. However, in this case, use is made of a special organisation to predict future economic trends, prices and development. A period of 20 years is used by the British Post Office and this agrees with Departmental experience in forecasting development, 20 years being the usual maximum planning period.

The termination of annual charges at the end of a definite period can reduce the total present value appreciably compared with the value for an infinite period, especially if the period is short and the interest rate low. Fig. 3 shows the effect for plant installed at the beginning of the first year and annual charges remaining constant thereafter. Thus, for a 20 year period and 5% interest rate the present value would be only .62 times that for an infinite period. The ratio would be reduced further if other annual charges were added later, the amount depending on the amount of the annual charge compared with the original. If the period is increased to say 50 years, the definite period present value would not differ from the infinite period value by more than about 10%. However, the appreciable reduction in the present values when the definite period comparison is made does not mean that the relativity between the costs of alternative schemes is affected to the same extent. For example, if the annual charges remain constant for all schemes, the present values for a perpetuity comparison would be the annual charges multiplied by the factor 1/r, while for a definite period comparison they would be multiplied by a lesser factor, but this would be the same for each alternative. The relativity between costs of alternatives would therefore not be altered in any way. When later extensions are made, and particularly when these differ between alternatives, the relativity can be altered by amounts depending on the costing period, and it is possible in some cases for a scheme which is the cheapest under a perpetuity comparison, to be the dearest under a definite period comparison. Nevertheless, in most practical cases the relativity is not affected to any marked extent.

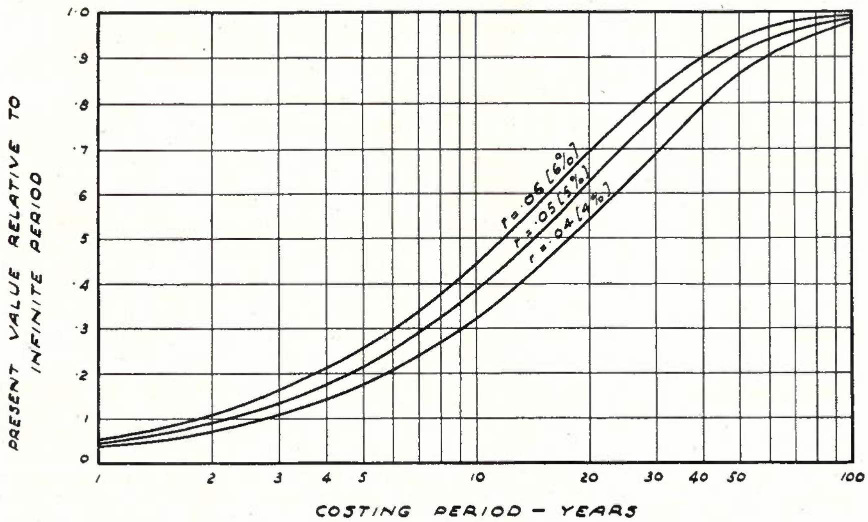


Fig. 3.—Present values of equal payments each year over different costing periods relative to that of same payments for an infinite period.

The main disadvantage of definite period comparisons is that they disregard anything that happens after the end of the period, in effect, assuming that the same means of providing facilities will be used then, irrespective of the means used initially.

Apart from the definite period and perpetuity methods, there is another method which has been in use in the Department for many years (5). This is a perpetuity method modified to take account of plant provided during a 20 year planning period only. Although this is inconsistent, it is a practical compromise method with the advantage of simplicity and without the disadvantage of placing weight on future extension costs. The effect on the relativity of costs between alternatives compared with the perpetuity methods is less than that of the definite period method.

Replacement of Plant before the end of its Life: In many instances when alternative methods of providing new facilities are being considered, it is found that one or more of the schemes involve the replacement of existing plant before the end of its useful life. A familiar example is that where an aerial route is to be replaced by an underground cable when it is necessary to provide a large number of new subscribers' services. In these cases, it can be seen from a consideration of the loan method of finance that interest and sinking fund payments must continue on the plant replaced until the end of its life in order to repay the loan, unless, of course, the plant can be recovered readily and cheaply for use elsewhere. In the latter case the annual payments would cease at the time of dismantling. Maintenance charges must, of course, cease in either case when the plant is dismantled.

It should be mentioned that the continuation of sinking fund payments is at variance with the common belief when perpetuity comparisons are used that sinking fund payments are necessary to replace plant at the end of its useful life. Thus, in the example referred to above, if this belief were correct, sinking fund payments on the aerial route would not be made, as the facility would not be replaced.

Interest Rates: Interest rates used in Departmental comparisons are based largely on the interest rate applicable to current Commonwealth loans, and a rate of 4% has been used since about 1948 but this is now due for revision to 5%. The rate is low compared with that used by private telephone operating companies in other countries, 6, 7 or 8% being common for these concerns. The higher rate is usually justified by private companies for the risks taken which do not apply in the case of Government ownership.

Application to the Direct Comparison of Costs in Particular Cases.

Scope of Application: Engineering economics should be used to compare costs of any alternatives where different lives, maintenance or operating costs are involved, or where plant is extended at intervals. Examples range from the provision of new trunk line facilities on a particular route by underground cable or aerial construction, or by radio link, the provision of switching facilities at a particular exchange by manual or automatic equipment, to the provision of reserve power at a particular station by means of batteries or an automatic start engine-generator set. In any case however, the procedure in comparing costs is similar.

Preliminary Work: The facilities required initially and in the future must first be set down, and each of the alternative schemes of providing them outlined in sufficient detail to enable costs to be computed. Care must be taken to ensure that every item of plant necessary to provide the facilities is taken into account, unless common to all alternatives. Each alternative scheme should be considered independently from the viewpoint of how the scheme would be engineered if that alternative were actually adopted. It is usually found that a number of assumptions are involved in this preliminary work, and judgment is necessary with these if the final result is to be reasonably accurate.

Calculation of Costs: Capital costs are first calculated for the plant required initially and for each future extension, taking into account, if possible, future price variations. The capital costs are then converted to annual interest payments to which are added sinking fund allowances and estimated maintenance and operating costs to give the total annual charges involved in each future year. It is then possible to determine the total present values by adding directly the present values of each annual charge over the period concerned, using factors obtained from tables or curves similar to Fig. 2. For a definite period comparison this is probably the most simple procedure if the annual charges vary from year to year, but if a perpetuity calculation is used, the additions must continue indefinitely until the effect of payments in the distant future on each total present value is negligible.

If the annual charges for any capital provision are expected to remain constant, the calculations may be simplified by the use of other factors. The most useful one is the total present value of yearly payments of £1 each for a period of t years, which is equal to

$$£\ [(1 + r)^t - 1]/[r.(1 + r)^t].$$

Fig. 4, which is a modification of Fig. 3, shows values of this factor for different values of r and t. The annual charge associated with the initial provision is merely multiplied by this factor to give its present value. If a further addition is made to the plant say t_1 years after the initial provision, the total value for the associated annual charges, if constant at the time of provision, can be obtained for the costing period t years by the use of the factor for $t - t_1$ years, the number of payments involved. The total value at that time can in turn be converted to the present value by multiplying by the additional factor given in Fig. 2. This procedure is illustrated more clearly by the following example:

New subscribers' aerial route.

Costing period—20 years. Interest 5% per year.

Initial provision:

Capital cost £1000.
Maintenance charge—£35 per year.
Sinking fund allowance—£40 per year.

Additions at end of 10 years:

Capital cost £200.
Maintenance charge £10 per year.
Sinking fund allowance £8 per year.

Cost of initial provision:

Annual charges:—

Interest	£50
Maintenance	£35
Sinking fund	£40
Total	£125

Present value of 20 payments to end of costing period:—

£125 x 12.5 (from Fig. 4) = £1563

Cost of additions:

Annual charges:—

Interest	£10
Maintenance	£10
Sinking fund	£8
Total	£28

Value at end of 10th year of 10 payments to end of costing period:

£28 x 7.7 (from Fig. 4) = £216

Present value of these payments:

£216 x .61 (from Fig. 2) = £132

Total present value:

Initial provision	£1563
Additions	£132
Total	£1,695

Tables are also available to enable the conversion directly from the annual charge to the present value in the case of later additions, without the intermediate step of converting first to the value at the time of extension and then to the present value.

If perpetuity calculations are used and the cost of renewing plant at the end of its useful life is the same as the original capital cost, the procedure may be simplified further, in that it is not necessary to convert capital costs to interest payments and then back again to present values. This follows since the present value of a number of equal interest payments for an infinite period is equal to the capital cost. The other annual charges associated with the proposal would, however, still require conversion to a present value in the manner outlined previously.

Selection of alternative to be adopted: After the total present value has been calculated for each alternative, a selection is made to determine the scheme to be adopted. This must take into account the approximate nature of the costs which is due to some extent to the assumptions made in setting up the alternatives, but mainly due to the impossibility of predicting accurately future events, including requirements, costs and obsolescence. For this reason, differences in costs of the order of 10 per cent. of the total present values cannot be regarded as very significant, especially if the comparison is a simplified one which neglects future price increases. The economic comparison should be disregarded in such cases as a factor in deciding the scheme to be adopted.

In any comparison of alternatives, other considerations must also be taken into account. These include reliability and the adaptability of any scheme to give additional facilities in the event of unforeseen future developments. These factors cannot be assessed in terms of money. Another most important factor is the initial capital costs of the alternatives. Due to difficulties experienced by most organisations in obtaining unlimited

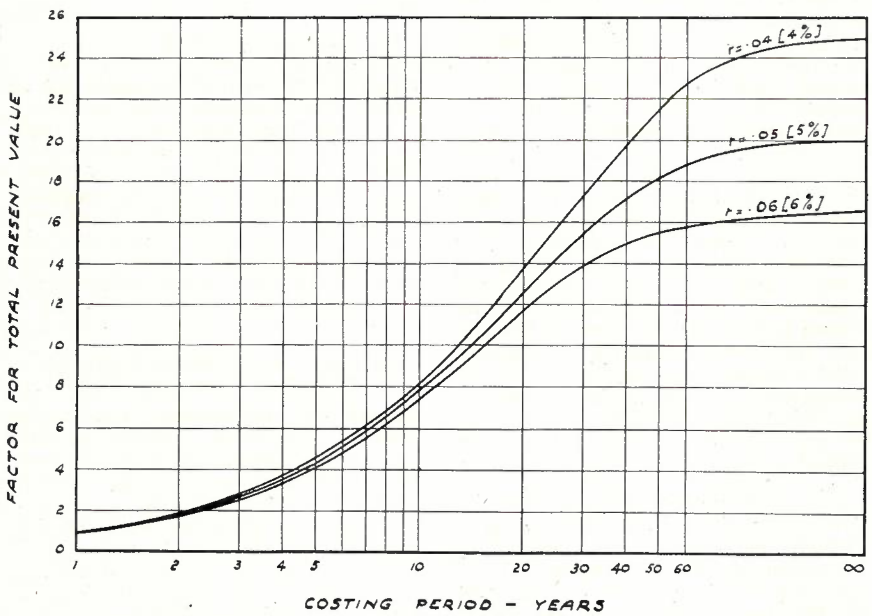


Fig. 4.—Present value factors for equal payments each year over different costing period.

finance for new works, any scheme with a relatively low initial cost is at an advantage compared with the others from the finance aspect. Unfortunately, if present values are approximately equal, a scheme with a lower first cost must have larger future costs than the other alternatives, and the trend over many years has been for prices to increase steadily, even though slight recessions occur at times. Unless these increases have been allowed for, an organisation can thus be involved in a much larger expenditure over a period of years by choosing an alternative because of its lower first cost. In each particular case, therefore, judgement is necessary in deciding the weight to be given to the intangible factors and the finance aspects.

Application to General Design Problems

Introduction of Variable Factors: The overall planning of trunk or exchange networks involves the consideration of the best means of providing service in many separate areas. The cheapest method for each sub-area may be determined by making a detailed economic study of all the possible alternatives in the manner outlined in the previous paragraphs. In practice, however, it is found that conditions in many of the sub-areas are similar, and it is often useful to use guiding rules obtained from general economic studies rather than to make repeated calculations for each specific case. The general studies may be made using a number of variable factors such as development rate, calling rate, subscriber density or any other factor which may vary between the sub-areas. The results may usually be expressed in the form of a set of graphs or a nomogram, from which the cheapest method for any particular area may be obtained.

In order to make the general studies reasonably straightforward, approximations are usually necessary in respect to

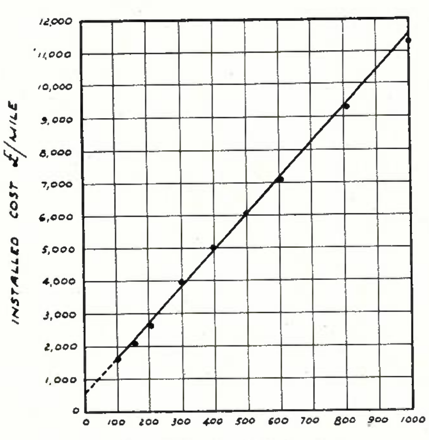


Fig. 5.—Installed cost per mile of 10 lb. local type cable, excluding duct cost.

each variable factor. For example, the costs of providing a mile of 10 lb. underground cable of various sizes in existing ducts are shown graphically in Fig. 5. The cost for x pairs may be expressed as an approximation, in the form $a + bx$ where a and b are constants. In many cases also, the inclusion of every variable factor which might influence the result would make the calculations extremely complicated, and some of the factors may be neglected for this reason. General studies are, therefore, less accurate than a detailed study for any particular case, even though the latter is also only approximate. For these reasons in important cases or ones where large expenditures may be involved, a separate detailed study is usually made, even if general information is available. Nevertheless, the general information is sufficiently accurate for use in many cases, and also is of great value in enabling the influence of the various factors on the total costs to be appreciated readily.

The following examples illustrate the application of general economic methods to a few of the many problems encountered in network design.

Methods of Trunk Cable Provision: So far, in Australia, new trunk cables have been mainly of the voice frequency loaded type with four wire amplified circuits, or of the 12 quad paper insulated carrier type with superimposed 12 or 17 channel systems. The relative fields of application of the two types depend mainly on the cable length, the numbers of circuits required initially and the development rate, the signalling arrangements, the proportion of circuits extended at the distant end by 12 channel open wire systems, the method of laying, that is, whether the cables are laid directly in the ground or whether ducts are required, and also on the facilities to be included for stations intermediate between the terminal stations.

If it is assumed that the cables are laid directly in the ground, which is the case over the major part of most of the longer distance routes in this country, the cost per mile of providing two "Go" and "Return" voice-frequency loaded cables may be represented fairly accurately by an expression of the form $a + bx$ as was the case for the local type cables shown in Fig. 5. The sinking fund allowance, being proportional to the capital cost, and the maintenance charges follow a similar type of law, so that the total present value of charges for a mile of cable can be expressed in the form $A + BN$, where N is the number of circuits required at the end of the 20 year planning period. If intermediate facilities are not required, the total present value for cable is $L(A + BN)$ where L is the route length.

Equipment costs may also be represented in a similar manner. The total present value of terminal amplifiers, associated power plant and other common terminal equipment may be expressed in the form $C + DN$ for any given development rate, and intermediate repeater costs in the form $(E + FN)L$. Thus, providing the cable is uniform throughout the length, the total present value of all costs of a voice-frequency cable scheme may be represented approximately, at a given development rate, by $V_1 + V_2N + V_3L + V_4NL$ where V_1, V_2, V_3 and V_4 are constants.

It may be shown similarly that the cost of two 24 pair 40 lb. carrier type cables with 12 or 24 channel terminal equipment and repeaters may be represented under the same conditions by $C_1 + C_2N + C_3L + C_4NL$. From these two expressions, a curve may be constructed as in Fig. 6, showing the values

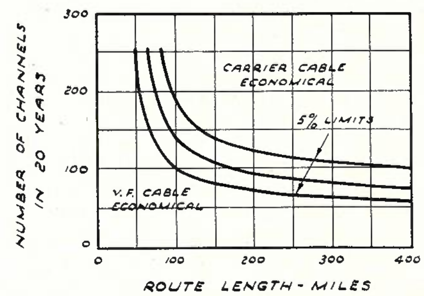


Fig. 6.—Comparison of relative applications of V.F. trunk cables and 12-channel cable carrier ducts and signalling neglected.

of N and L for which the total cost of construction, by either voice frequency or carrier type cable, would be equal, that is $(V_1 - C_1) + (V_2 - C_2)N + (V_3 - C_3)L + (V_4 - C_4)NL = O$ or $N = [(C_1 - V_1) + (C_3 - V_3)L]/[(V_2 - C_2) + (V_4 - C_4)L]$. For values of N and L less than those on the curve, voice-frequency cables are economical, while for greater values, carrier cables are economical.

Fig. 6 was prepared in 1950 using cable and equipment costs current at that time, and the modified perpetuity method of engineering economics, in which plant additions are not taken into account beyond the 20 year planning period. No allowance was made for future price increases, and it was also assumed that 2VF signalling would be used on either type of cable. Later developments in signalling have produced a cheaper D.C. signalling method for voice-frequency cables, and this could affect the results. In order to give an indication of the effect of price variations on the boundary curve, Fig. 6 also shows the curves which would result if the voice-frequency cable scheme cost were increased by 5% while the carrier scheme was decreased by the same amount, and vice versa. Although this study was simplified by neglecting some of the factors, additional variables may be introduced if further accuracy is desired. For example, variables could be added to cover the percentage of circuits group connected to 12-channel open wire systems at one end, differing development rates, or a tapering of facilities along the cable as a result of intermediate offices.

General design curves similar to those shown in Fig. 6, may be obtained in the same way to show the fields of application of coaxial cable carrier systems or short-haul cable carrier systems. Similar methods may also be used to give a guide to the relative applications for open wire carrier systems and physical construction, or to many other problems including, for example, the relative costs of cable or aerial subscriber's line construction with the initial number of subscribers and development rate as variable factors.

Economic Stages of Plant Extension: When the demand for certain facilities increases each year, it is necessary in planning to know the period of development to be provided for by each plant extension. The shorter the period, the greater will be the saving made due to the deferment of expenditure, but, on the other hand, frequent extensions usually require greater installation and other "fixed" costs than if plant were provided initially to meet development for a long period. There is, therefore, usually a definite period, given by a compromise between these two factors, for which it is economical to provide for development.

This problem is dealt with fully in reference (6), which also gives many other excellent examples of the use which may be made of general economic studies in exchange network design. In that article, to simplify the calculations, the following assumptions are made.

(i) the demand is linear with time and is given by $n = n_o + n_1 t$ where n_o is the number of units required initially and n_1 the additional number required each year.

(ii) the capital cost of an extension of x units is $a + bx$ where a and b are constants.

(iii) the lives of the different stages of extension are equally long and are all t_a years.

(iv) annual maintenance costs are directly proportional to the plant capital costs, the ratio being u.

(v) the different components of the plant are kept in operation throughout their lives, after which they are replaced by a new plant of the same capacity as the original one.

(vi) All stages of extension are of equal size after the initial installation, which has also to provide for the initial demand n_o.

If t_x is the economic period to be provided for by each extension, the capital cost of the initial provision is $a + b(n_o + n_1 t_x)$, and that for each extension is $a + bn_1 t_x$.

The present value over an infinite period of the costs associated with the initial provision will therefore be:

$$(a + b(n_o + n_1 t_x)) \cdot \left(1 + \frac{1 - S}{(1+r)^{t_a} - 1} + \frac{u}{r}\right),$$

and the total value at the time of extension for all charges associated with each extension over an infinite period, will be:

$$(a + bn_1 t_x) \cdot \left(1 + \frac{1 - S}{(1+r)^{t_a} - 1} + \frac{u}{r}\right), \ S$$

being the ratio of plant residual value to capital cost.

The total present value over an infinite period is then:

$$\left(1 + \frac{1 - S}{(1+r)^{t_a} - 1} + \frac{u}{r}\right) \cdot$$

$$\left(bn_o + \left(1 + \frac{1}{(1+r)^{t_a} - 1}\right)(a + bn_1 t_x)\right)$$

This may be found to be a minimum when:

$$t_x = \frac{(1+r)^{t_x} - 1}{\log_e (1+r)} - \frac{a}{bn_1}$$

The relation between t_x, the economic period of extension, and a/bn_1 is shown for different interest rates in Fig. 7.

For practical use, other curves may be prepared from Fig. 7. For example, lead covered local type 10 lb. cables installed in existing ducts, have values of a and b per mile of approximately £600 and £11 respectively, between 100 and 1200 pairs. If the number of pairs per mile required initially is n_o and the development rate is linear at 6 per cent. per annum, the economic period for each extension as a function of n_o will be as shown in Fig. 8 for interest rates of 4 and 5 per cent.

It is also of interest in practical applications to know whether the total present value has a sharply defined minimum at the economic period, or whether the minimum is fairly broad so that a certain amount of latitude may be permitted in its use. This information may be obtained by consideration of the factor

$$bn_o + \left(1 + \frac{1}{(1+r)^{t_x} - 1}\right) \cdot$$

$(a + bn_1 t_x)$ in the present value expression. The values of this expression

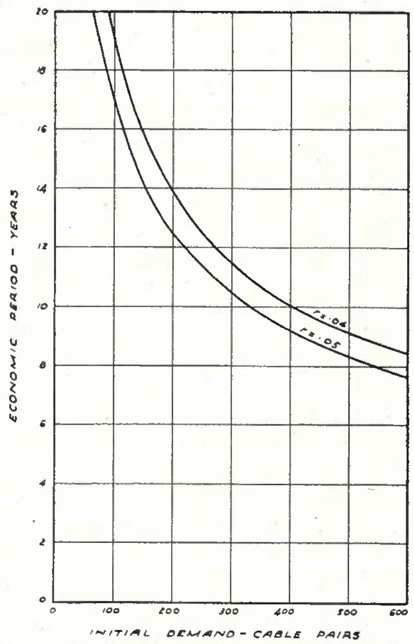


Fig. 8.—Economic period for providing 10 lb. local type cable in existing ducts—development rate 6%.

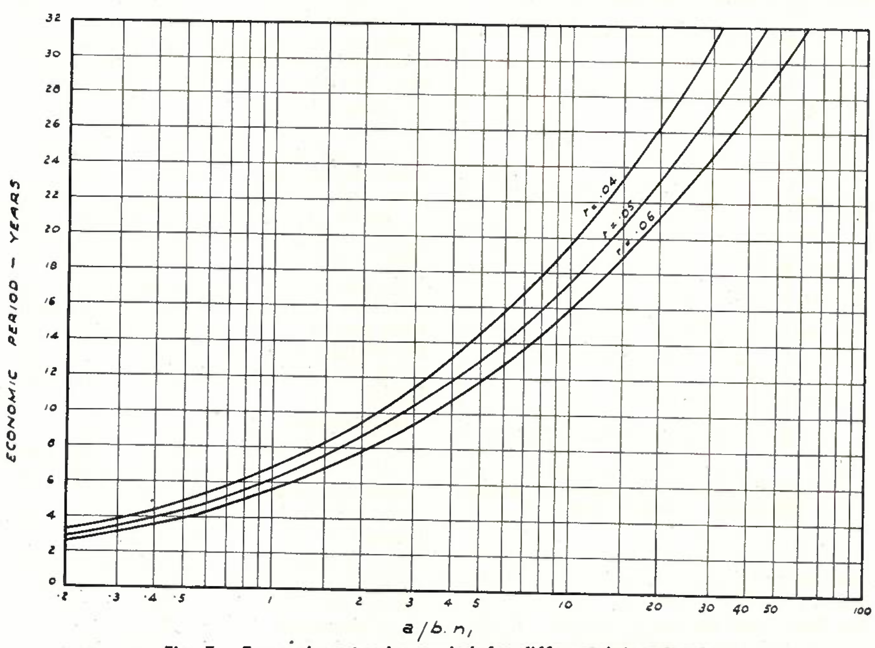


Fig. 7.—Economic extension period for different interest rates.

relative to the minimum are plotted in Fig. 9 for values of n_0 of 100 and 400 pairs, the other variables having the values used for Fig. 8.

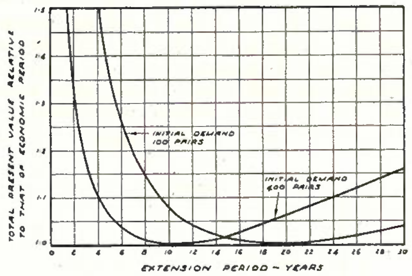


Fig. 9.—Total present value of providing 10 lb. cables in existing ducts to meet development for different periods, relative to value for economic period—interest rate 4% and growth 6% per annum.

It will be seen from Fig. 9 that the minima are fairly broad. Thus for the 400 pair initial demand, the total cost will be within 5 per cent. of the minimum if facilities are provided for a period anywhere between 5 and 19 years and in the 100 pair case between 11 and 31 years.

Curves similar to Figs. 8 and 9 may be obtained for other types of cables laid in ducts, for cables laid directly in the ground or for equipment extensions to automatic exchanges. Similar studies may also be made to cover cases where the original assumpton (v) does not apply, but the plant is recovered and replaced by a larger unit before the end of its life, as occurs for example in some power rectifier installations.

Economic Size of Rural Exchange Areas

The cost of providing subscribers' services in a multi-exchange network includes both line plant and equipment costs. The larger the individual exchange areas, the less will be the cost of exchange switching equipment per subscriber, as exchange costs include common costs for items such as buildings, power plant, and testing equipment. Trunk or junction line costs per subscriber also tend to decrease with larger areas. On the other hand, in larger areas, greater line costs per subscriber result due to both the greater average length of line and heavier gauge of wire required to give satisfactory transmission and signalling. For any particular case there will be an optimum size of exchange area, which will depend on the density of subscribers, the exchange plant existing, the arrangement of roads or streets in the area, and the cost of trunk or junction lines.

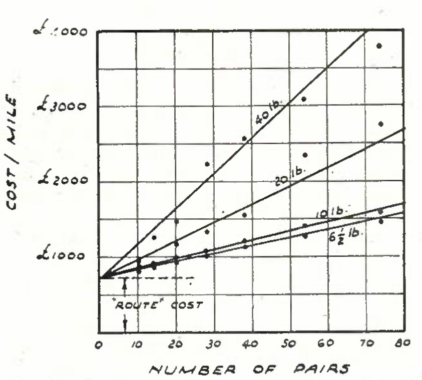
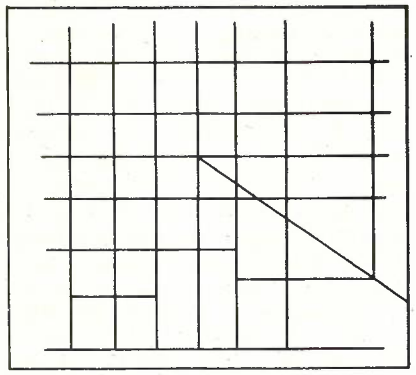
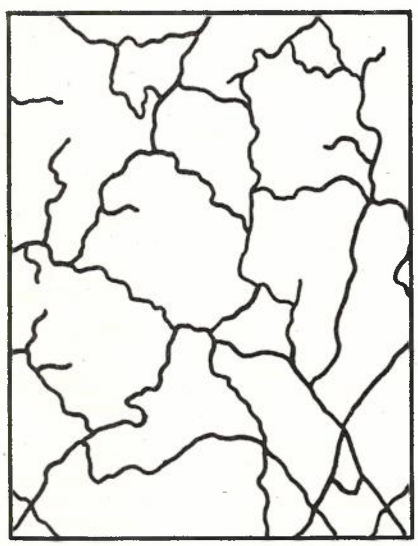


Fig. 10.—Approximate cost per mile of local type unarmoured cable laid by mole plough.

A general analysis for metropolitan areas is fairly complicated, but has been undertaken in reference (6), the results being given in summarised form in reference (7). A simpler analysis is possible for rural areas, especially areas where the subscriber density is sufficient to justify the use of cable for distribution. In such areas cables will be necessary along almost every road. From Fig. 10 it may be seen that the cable cost per mile consists approximately of a fixed "route" cost, together with a cost depending on the number of pairs and the conductor weight, which is termed the pair mileage cost. The "route" cost for a large area will be approximately the same irrespective of the way the area is subdivided into exchange areas, and the pair mileage costs will therefore be the only cable costs affecting the size of the exchange areas.



(a) Flat country.



(b) Hilly country.

Fig. 11.—Typical road layouts in country areas.

Typical road configurations for rural areas are shown in Fig. 11. In most areas, the ratio of the actual route distance from a central point to the radial distance, K_1, is approximately constant for the type of area. If the subscriber density per square mile is δ, constant throughout the area, it may be shown that the total pair mileage for a circular area of radius R about the exchange is $2\ \pi\ K_1\ \delta\ R^3/3$ and the total number of subscribers in the area is $\pi\ \delta R^2$. It will be seen from Fig. 10 that the pair mileage constant may be expressed approximately by b_1W where W is the conductor weight and b_1 is a constant. The average pair mileage cost per subscriber may thus be expressed by $2K_1\ b_1W\ R/3$.

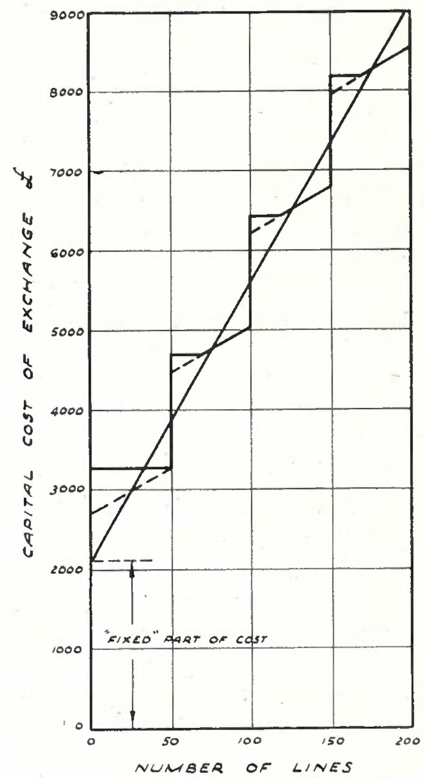


Fig. 12.—Capital cost of RAX building and equipment for various numbers of lines connected.

Fig. 12 shows the capital costs of rural automatic exchange equipment with different numbers of lines, the total consisting of a "fixed" part for building, power and other common equipment, and a variable cost per line provided. Only the "fixed" part C, will affect the size of the areas as the variable part will be involved for each subscriber no matter how the whole area is divided into exchanges. The cost per subscriber due to the part of the exchange equipment costs affecting the size of the exchange, will therefore be $C/\ \pi\ \delta R^2$. In practical cases, an additional charge must be added to C to cover trunk or junction line costs, as some additional cost usually results when an area is divided into a large number of small exchanges rather than a few large ones. The additional cost is often not as great as may be thought due to the number of trunk lines provided in small groups being approximately proportional to the number of subscribers. For simplicity, trunk lines costs will be neglected here although it is not difficult to introduce another factor to cover them.

The total average cost for the exchange area per subscriber for the relevant line and exchange equipment is therefore approximately $(2K_1\ b_1WR/3) + (C/\pi\ \delta R^2)$. For given values of K_1, b_1, W, C and δ, this expression will have a minimum value when $R^3 = 3C/\pi K_1\ \delta b_1 W$. It should be noted that C and b_1 represent present values of equipment and line charges over the period for which the facilities are planned. Fig. 13 shows economic values of R for different values of δ and W, K_1 being taken as 1.2, a typical value for hilly country, and b_1 and C as £1.75 and £2500 respectively for a 20 year period and 4% interest rate. The effect of neglecting trunk line costs is to make C smaller than the correct value, so that the values of R given by Fig. 13 are less than they would be in practice, and in effect represent minimum values. For comparison purposes a curve for 40 lb. cadmium copper aerial distribution has also been included in Fig. 13.

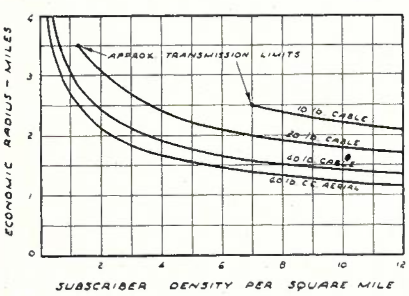


Fig. 13.—Economic radii of exchange areas for different subscriber densities and conductor weights.

Although the foregoing analysis is reasonably accurate for any area in which subscribers lines are provided by a specified type of cable, it does not indicate the gauge of conductor which would be most economical under different conditions. It is fairly obvious that when the subscriber density is greater than about 10 per square mile, which enables 10 lb. cable to be used economically within its transmission limit, there is no advantage in using larger gauge cables. However, the determination of the optimum gauge for lower densities requires further study.

One interesting method of approach is to introduce the transmission limits shown in Fig. 14 as an additional factor. If cables were obtainable with wires of any required gauge, and the same gauge were used throughout an area, the cheapest gauge would be that which would just meet the transmission limits at the exchange boundary. If the maximum route length from the exchange to any subscriber at a radial distance R from the exchange is K_2R, the gauge of cable would be given approximately either by $K_2R = .98W^{1/2}$ or $K_2R = 1.0 + .18W$, as may be seen from Fig. 14. The first expression is reasonably accurate for conductor weights up to 40 lb. per mile, although the second is more accurate if the weight is 20 lb. per mile or less. Using the weight $W = 1.04\ K_2^2R^2$, the combined average cost per subscriber for exchange and line plant is then given by $.7K_1\ K_2^2b_1R^3 + (C/\pi\delta R^2)$ which has a minimum value when $R^5 = .3C/K_1\ K_2^2b_1\delta$. Fig 15 shows the economic values of R and W for different subscriber densities δ, K_1 being taken as 1.2 and K_2 as 1.4. K_2 must be larger than K_1 for any given area and its value can be found in a similar manner to K_1 by inspection of maps of the type of country concerned. Isolated very large values of K_2 found by this method can be neglected without great loss of accuracy and service given by aerial extension from the cable transmission limit.

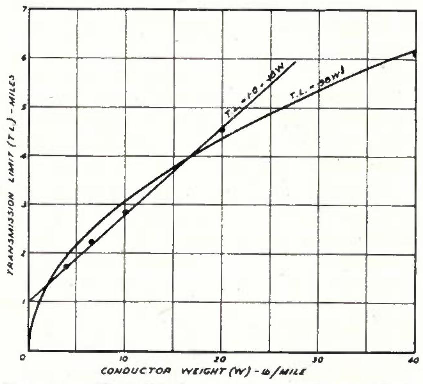


Fig. 14.—Transmission and signalling limits for local type subscribers' cables.

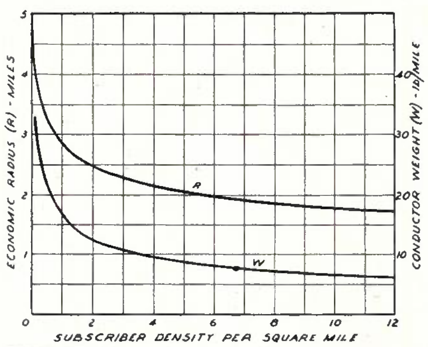


Fig. 15.—Economic radii of exchange areas and optimum cable conductor weights if any desired weight could be obtained.

Although Fig. 15 is interesting, it is of little use in practice due to cable gauges being limited to a few sizes for reasons of manufacturing economy. The information required for practical planning is obtained most readily from graphs similar to Fig. 16, which can be prepared simply from the formulae quoted previously. It will be seen from Fig. 16 that it is economical to use 20 lb. cable only when the subscriber density is under about 2 per square mile.

As an example of the use which can be made of this type of general economic study, Fig. 17 shows a section of the South Gippsland area in Victoria which was subdivided into RAX areas in 1946 using the principles outlined. At that time most of the services in the area were party lines on the Korumburra exchange, and in many cases were part privately erected, so that existing Departmental plant was negligible. However, there were approximately 5 farms per square mile over the whole area, and all of these were potential subscribers if a reasonable service could be given. Since that time RAXs have been provided in accordance with the plan throughout the whole area, 10 lb. cables being used largely for distribution.

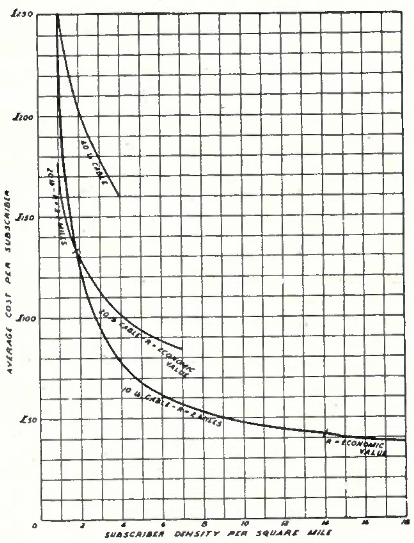


Fig. 16.—Present values of relevant average costs per subscriber for different subscriber densities and cable gauges.

General economic studies similar to that outlined for RAX areas can be made, using different variables, to give valuable information on other problems such as the optimum sizes of trunk switching areas.

Conclusion

A general outline of the application of engineering economics to telephone plant design problems has been given. Although the general methods in particular involve a number of approximations and require judgment in the interpretation of the results, they do give valuable information on a number of problems which can otherwise be resolved only by lengthy calculations, or when these became prohibitive, by arbitrary decision. Little application appears to have been made up to date of the general methods. This has been due in part to the approximations involved, and to practical cases introducing factors not allowed for in the general studies. However, it is possible in most cases to extend the general studies to cover the objections.

Bibliography

1. "Annual Carrying Charges in Economic Comparisons of Alternative Facilities"—Paul H. Jeynes; AIEE Transactions, Vol. 70, Part II, 1951, (page 1942).
2. "Cost and Production Handbook"—L. P. Alford; The Ronald Press Co., New York, 1942.
3. "Present Worth, or the Time Cost of Money, as a Factor in the Economic Comparison of Alternative Facilities"—Paul H. Jeynes; AIEE Transactions, Vol. 70, Part II, 1951 (page 1956).
4. British Post Office Engineering Instructions—Lines, General, B1001 to B1004.
5. Australian Post Office Engineering Instructions—Engineering Administrative Circular No. 8 and Addendum No. 1, and General, Works, PO100.
6. "The Economic Optimum in Urban Telephone Network Problems" — Y. Rapp; Ericsson Technics, No. 49, 1950.
7. "On the Planning of Networks for Telephone Plants"—Y. Rapp; Ericsson Review, No. 3, 1950 (page 84).

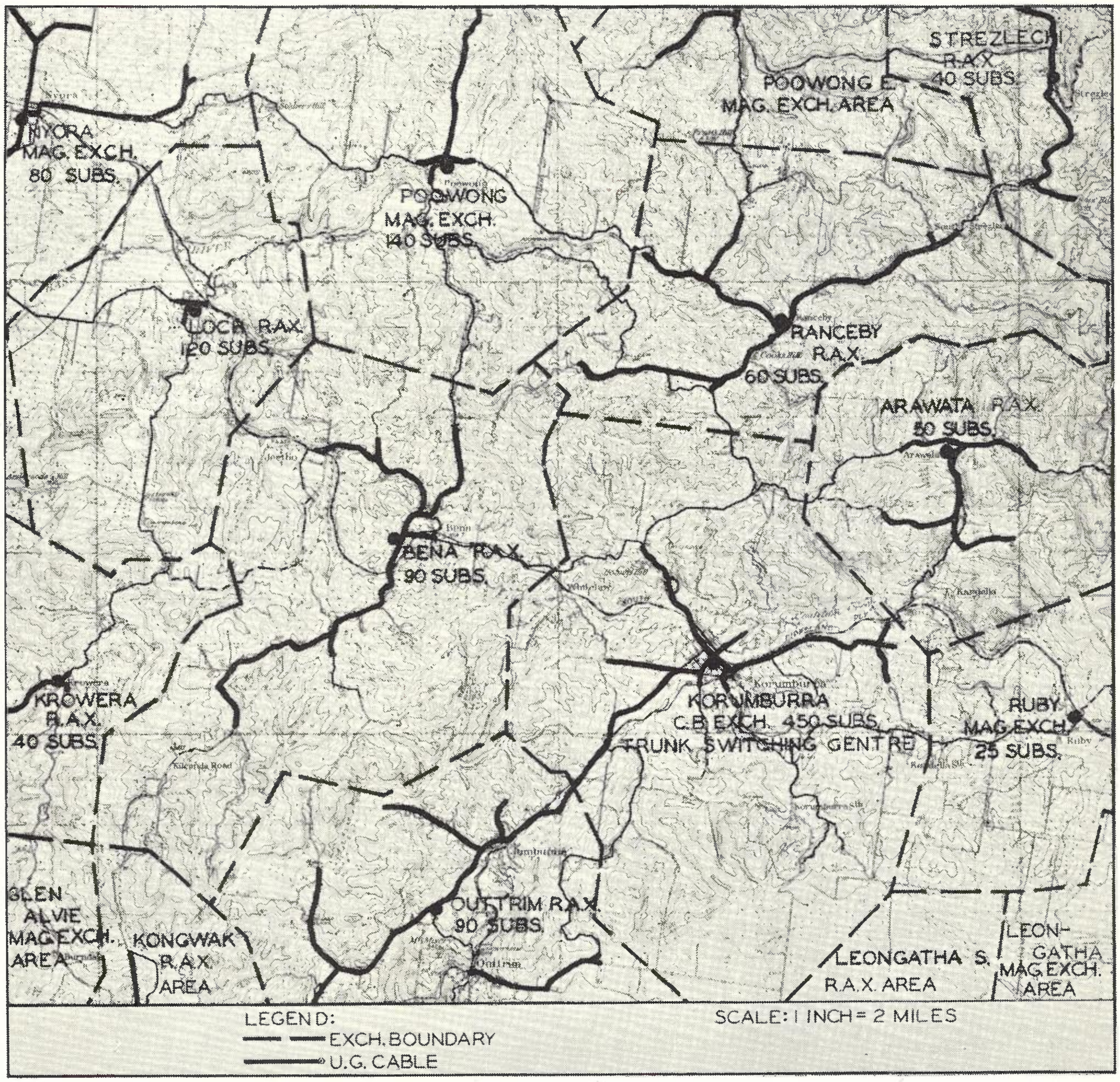


Fig. 17.—Example of Exchange Area Subdivision based on use of RAX's and 10 lb. cable.

A PHOTOGRAPHIC TECHNIQUE OF SOUND RECORDING ON GLASS DISCS

*A. J. FORTY, B.A., A.M.I.E.E.**

This article describes the basic process of the glass disc recording technique used by the British Post Office for making records suitable for use in announcing machines such as the Speaking Clock. An important advantage of the method described is that the records so produced have an exceptionally long life.

Introduction

Recordings on glass discs have been made and used by the British Post Office for the past 17 years. The field of application of the technique is restricted, but within a somewhat limited sphere the method has advantages which are unequalled by any other form of recording.

The recordings are made, by a photographic process, in the form of circular sound tracks on discs of plate glass 12in. in diameter coated with a suitable sensitive emulsion. From the negatives so obtained any number of positives (also on glass discs) may be made by a straightforward printing process. For reproduction of the sound a positive print is held by a central hub on a rotating shaft and the sound tracks are scanned optically.

The duration of the signal recorded on each track depends, of course, upon the rate of rotation for which the disc is designed; it is usually of the order of 1 to 2 sec. and rarely exceeds 5 sec. Consequently the main application of the process is for announcing machines which will reproduce short phrases of speech, or other signals, either singly or in combination and repeated at frequent intervals. It is particularly suited for this type of machine since there is no mechanical wear of the disc during use, and if certain precautions are taken to preserve the emulsion the life of the disc is virtually indefinite. The British Speaking Clock is an example of a machine employing this form of recording. The original discs fitted in 1936 were in continual use 24 hours per day until 1950, when they were replaced due to failure of the sealing of the cover glasses which protect the emulsion.

The Recording Process

Fig. 1 shows a typical disc negative. Dual sound tracks are recorded in bilateral variable area form (see later description) each 2 mm. wide and normally spaced 1 mm. apart. The circumferential length of each track and its orientation depend upon the purpose for which the disc is designed, and these quantities are adjustable at will during recording. It will be seen from Fig. 1 that the beginning and end of each sector of track are tapered to avoid the audible clicks which would arise in reproduction if the track terminated abruptly. Dense, unmodulated, full-width tracks are invariably recorded near the centre of each disc to aid in centring the prints on their hubs (for which a series of standard sizes has been adopted).

For most applications a series of tracks of speech wave-forms is required. These are recorded by means of a copying technique. The sound to be reproduced is first recorded on conventional 35 mm. sound film which is processed, edited and the required phrases or words accurately selected. The recordings on the glass disc negative are then made progressively, track by track, copying the sound track from each piece of film on to the disc by means of a special recording camera. This method of recording the disc has two major advantages. By adopting a copying technique the manifest difficulties of recording short phrases as spoken are largely avoided. Suitable lengths of film are selected before recording commences, and there is no chance of the disc being spoiled because one of the recorded phrases is badly enunciated. Furthermore the correct orientation of the track is a function of angular measurement rather than of time synchronisation.

Secondly, the speed at which the copies are made is entirely arbitrary. A relatively slow speed is normally used, to permit the use of slow, fine-grain, high-resolution plates with corresponding increase in frequency range and reduction in the background noise due to grain size and low contrast. Shutter operations, fades, and the general manipulation of the camera are simplified when the recording speed is low, but there is introduced the drawback that the frequency range of the recording is translated to a lower region of the spectrum, with the result that the amplifiers used must be designed for sub-audio frequency working.

The Recording Camera

General Description. The recording camera is shown in Fig. 2. Inside the light-tight box (1) a sensitive plate is carried in a plate holder which is attached to the shaft (2). This shaft is torsionally rigid, and can be turned at constant speed by a phonic motor via the gearbox (3). Fixed to the other end of the shaft is a drum (4) round the flange of which a piece of sound film (5) is wrapped and clamped in place by a retaining band so that the sound track projects beyond the edge. A scanning unit (6) consisting of a light source, optical system, photocell and cathode follower produces electrical signals from the film sound track as the camera shaft rotates. These signals pass through amplifiers (7) and are applied to a mirror galvanometer (8). The latter modulates a light beam which, by means of the optical system (9), records on the sensitive plate a faithful copy of the film sound track. A "fading" device enables the recorded length of each track to be varied, while the circumferential position of the track is set by slackening a universal joint in the main shaft and making suitable angular adjustment of the film drum.

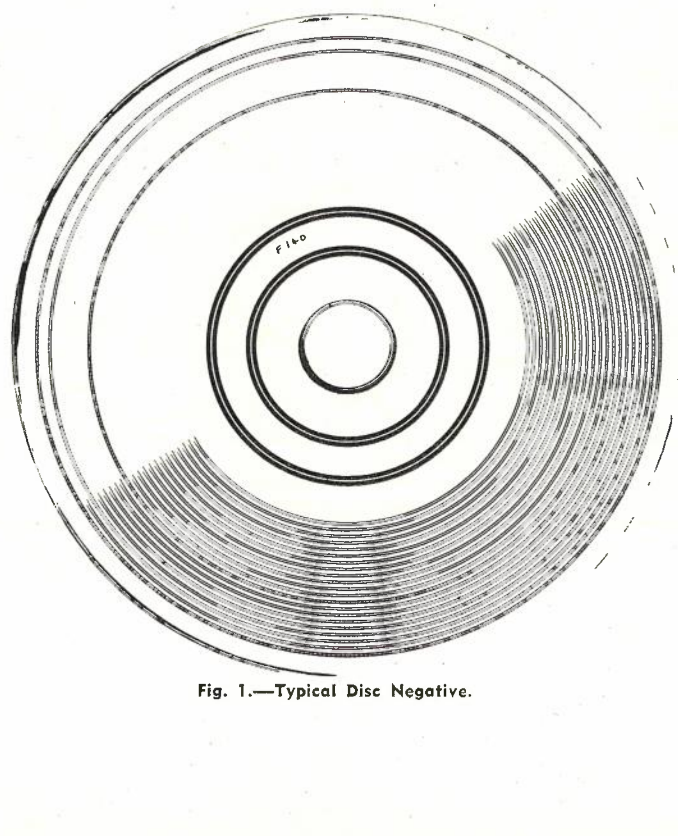


Fig. 1.—Typical Disc Negative.

*Mr. Forty is Senior Executive Engineer, British Post Office Research Station. This paper has been reprinted from the Post Office Electrical Engineers' Journal, Vol. 47, Part 1, April, 1954, by kind permission of the Editors of that Journal and Mr. A. J. Forty.

The radial position of the track on the plate is adjusted by raising or lowering the optical system by means of a lead-screw operated by the handle (10). A mechanical shutter is operated by means of contacts associated with the driving mechanism to ensure that complete circular tracks may be recorded without double exposure.

The phonic motor which drives the main shaft will run satisfactorily at any speed between 100 and 1,000 r.p.m., corresponding to shaft speeds varying from one revolution in 200 sec. to one revolution in 20 sec. The flexibility in the choice of speed is convenient for two reasons. Firstly it enables an adjustment to be made in exposure for plates of different sensitivity (the exposure is, of course, directly proportional to the shaft speed). Secondly, by relating the speed of drive to the frequency of a pure tone applied to the galvanometer it is possible to record accurately an integral number of cycles of a given frequency on a complete sound track.

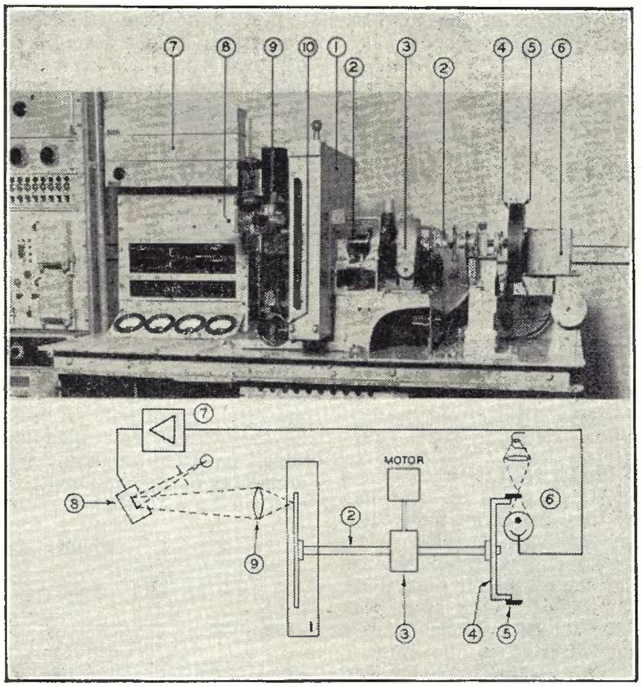


Fig. 2.—The Recording Camera.

The diameter of the drum used depends upon the rate of rotation for which the disc is designed. Suppose that d in. be the drum diameter and that the finished disc when used must rotate at an angular speed of x r.p.m. Then, since the normal sound film speed is 18 in. per sec. and the perimeter of the drum is πd in., the time of one revolution of the disc when played back must be $\pi d/18$ sec.

$$\text{Whence } \frac{\pi d}{18} = \frac{60}{x} \text{ and } d = \frac{1080}{\pi x} \text{ in.}$$

A series of drums is available varying in diameter from 1.7 in. to 28.6 in., corresponding to disc speeds varying from 200 to 12 r.p.m.

The scanning unit for the film drums uses a 75W lamp, with an optical system which projects upon the film a slit image which has a width of approximately 0.0005 in. This will scan standard 35 mm. sound film without appreciable loss of high frequency response up to 10 kc/s. Vacuum photocells are used for stability and freedom from distortion. A cathode follower is mounted in the same unit as the photocell. For certain applications (including copying) it may be necessary to mount a glass disc instead of a film drum on the camera shaft. A second scanning unit is available for reproduction from this type of source.

The scanning unit cathode follower feeds into a two-stage pre-amplifier of conventional design and this is followed by the galvanometer drive amplifier shown in Fig. 3. The latter uses a pentode in the anode feed of the output stage and has current feedback to the first stage. The output impedance is therefore high and the galvanometer is fed with substantially constant current, with a corresponding improvement in its frequency response.

The galvanometer is a moving-iron instrument with the armature and mirror carried on a stiff suspension of phosphor bronze giving a resonance frequency in the neighbourhood of 1,700 c/s. A copper ring has been deposited electrolytically upon the tip of the armature to give eddy current damping of the resonance peak. Large air gaps are provided in the A.C. flux path to improve the linearity.

A high pressure mercury vapour discharge lamp rated at 250W is used for recording. This lamp gives an intensely bright but compact source of light which enables slow plates to be given adequate exposure with practical camera speeds. The lamp is run from a D.C. supply through a dropping resistor, and the polarity of the electrodes is changed periodically to prolong the life.

Since with this type of source exposure cannot be controlled by variation of lamp brightness, neutral density filters are used for that purpose.

The Optical System. The optical system of the camera is shown in diagrammatic form in Fig. 4.

The condenser lens (2) produces an image of the arc (1) on the blades of the compensating shutter (5) immediately

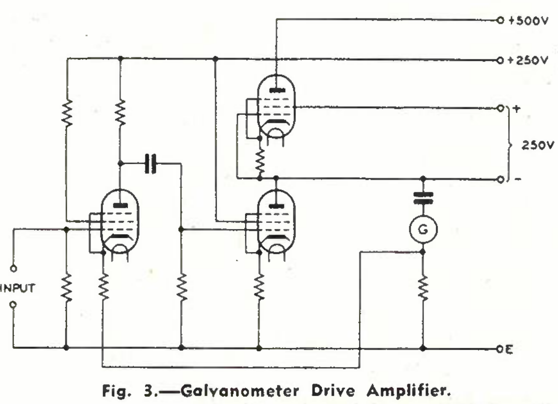


Fig. 3.—Galvanometer Drive Amplifier.

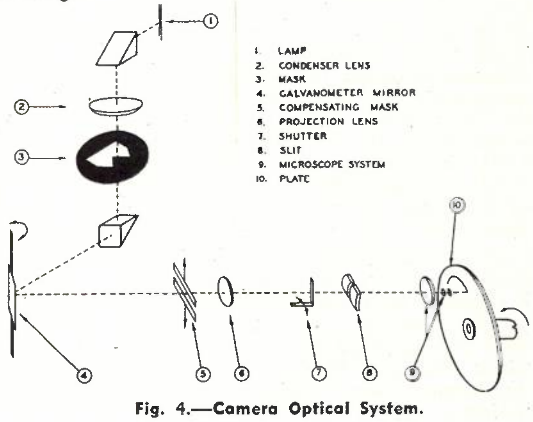


Fig. 4.—Camera Optical System.

in front of the projection lens (6). This compensating shutter is provided to control the amount of light which reaches the plate for tracks of different diameter. The effective exposure of a track is proportional to the amount of light, L, which passes through the optical system and inversely proportional to the velocity of the plate surface, i.e., to the diameter, D, of the track being recorded. The compensating shutter is controlled by the carriage upon which the optical system is mounted and is so arranged that the blades are fully open when the carriage is raised, i.e., when the outside track of the disc is being recorded. In this position the whole of the light from the arc passes through the projection lens. As the carriage is lowered for recording tracks of smaller diameter the compensating shutter blades gradually close in such a way that the ratio L/D is constant. In this way equally exposed tracks are automatically obtained. The projection lens throws an image of the mask (3) upon the slit (8), and the microscope system (9) forms an image of the slit upon the plate (10).

As the mirror (4) oscillates, therefore, so the image of the mask moves to and fro across the slit, and the intercepts of the wedges vary in amplitude in accordance with the magnitude of the signals fed to the galvanometer. The images on the plate of these two illuminated portions of the slit trace out two identical symmetrical waveforms, as shown diagrammatically in Fig. 5. The two waveforms collectively form a sound track of the type shown as "dual bilateral variable area". This type of track has the advantages that less distortion is introduced either by possible variation of illumination along the length of the reproducing slit, or by misalignment of the reproducing optical system. The actual size of the recording slit is about 0.0015 in., and the optical reduction is 3 : 1. Consequently the effective width of the image of the slit on the plate is about 0.0005 in.

The shutter blade (7) ensures that a complete circle of track is exposed. It is operated by a relay circuit controlled by two cams, one on the main camera shaft and the other on the gearbox shaft which rotates at 50 times the speed of the former, thus ensuring accuracy of timing.

Operation

Making the Negative. The plate holder, which holds the glass disc negative, can be rendered light-tight by the insertion of a dark slide and may be removed from the camera for loading in a dark room. The holder has been so designed that a photocell unit may be inserted in place of the disc and used in conjunction with a cathode-ray oscilloscope for checking depth of modulation and distortion when setting up. This device is also useful for determination of the correct position of the galvanometer for producing a balanced track.

The plate holder will also carry a small rectangular plate (4¼ in. x 3¼ in.). Plates of this size are available coated with the same emulsion as the glass discs, and are used to determine correct exposure, accuracy of shutter operations, etc. After preliminary tests have been made the plate holder is loaded with a glass disc and inserted in the camera. The piece of film required for the first track is fitted to the drum, the optical system is set to the correct track radius, the coupling between plate holder and drum is adjusted to give the correct orientation of track on the disc, the cams controlling the fading device are set and a neutral density filter is inserted in the optical path to give the correct exposure. Finally, the shaft is set in motion, the shutter key is operated, and the complete track is then automatically exposed. After all the tracks have been thus recorded the plate is removed and processed in the normal manner.

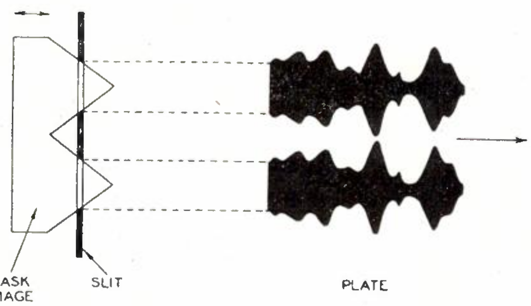


Fig. 5.—Formation of Sound Track (microscope system omitted).

Positive Prints. Contact prints are made from the glass disc negatives on similar glass discs which are to be used in the reproducing machines. Each positive is normally fitted with a cover glass which is sealed to the disc round the central hole. The cover glass gives protection to the emulsion from mechanical injury and also prevents deterioration which might occur if the disc should be used in conditions of high temperature or humidity.

For applications where the reproduction speed is high (in one case a speed of 1,500 r.p.m. has been used), accurate balancing of the disc and hub is required. A technique has therefore been evolved for grinding the edge of the finished print to render the periphery truly circular and concentric with the tracks.

Performance and Limitations

Frequency and Response. As mentioned earlier, the use of a slow speed for the copying process modifies the frequency range with which the camera has to deal. Of course, if a frequency f is present in the film recording, it should also occur in the finished sound track on the disc. During the recording process, however, the corresponding frequency which passes through the scanning unit, amplifiers and galvanometer of the camera will be a frequency f' where

$$f' = f \times \frac{\text{velocity of sound film when copying}}{\text{normal velocity of sound film}}$$

$$= f \times \frac{\pi d}{18t}$$

where d = drum diameter in inches, and t = time of one revolution of camera shaft in seconds.

In practice the ratio f'/f may be as small as 1/200.

To determine the frequency range which the camera must cover it is convenient to think in terms of cycles per revolution of disc rather than of absolute frequencies.

The high frequency response of the finished glass disc is restricted by the size of the shortest wavelength which it is possible to record satisfactorily upon the plate. With the present equipment this

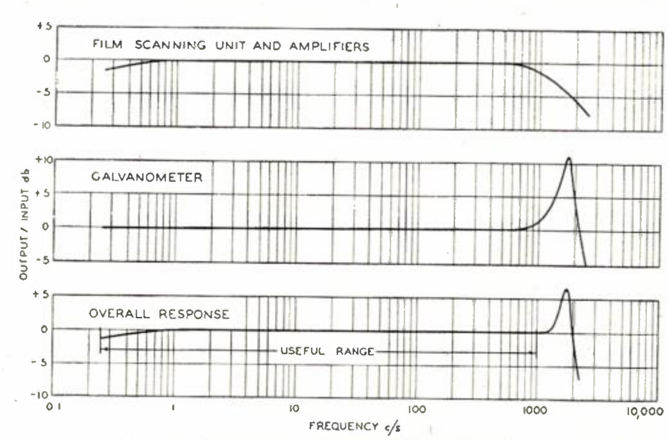


Fig. 6.—Frequency Response of Recording Camera.

is approximately 0.002 in. (the limiting factor in this connection being the optical system of the camera rather than the resolving power of the emulsion), giving a maximum number of 20,000 cycles which can be recorded on the outside track of a disc. The highest frequency to be dealt with by the camera is therefore that which is required to record 20,000 cycles per revolution at the fastest camera speed of 1 revolution in 20 sec., i.e., 1,000 c/s.

At the low frequency end of the spectrum the frequency response of a disc may be required to extend down to 50 c/s. For speech, disc playback speeds greater than 60 r.p.m. are seldom used because the phrase duration is impracticably small. So the lowest number of cycles per revolution of disc required is 50 (which reproduces at 50 c/s on a 60 r.p.m. disc). The lowest frequency with which the camera normally deals is therefore that required to record 50 cycles per revolution at the slowest camera speed of 1 revolution in 200 sec., i.e., 0.25 c/s.

The frequency response of the camera system must therefore extend from 0.25 c/s to 1,000 c/s, a range of 11 octaves.

The extent to which these requirements have been met is shown in Fig. 6.

Curve (a) shows the variation in current through the galvanometer for constant excitation of the film drum photocell, which was obtained by playing back pure-tone sound tracks at a variety of speeds.

Curve (b) shows the variation with frequency of the sensitivity of the galvanometer with constant current through the coil. For this curve the ordinate represents the depth of modulation of the recording light beam, which was measured by means of a photocell substituted for the sensitive plate.

Curve (c) is the sum of curves (a) and (b), and represents the overall frequency response characteristic of the camera system.

Most of the applications of glass discs are concerned with speech of telephone quality and require a frequency response which need not extend beyond 3,500 c/s. This can be achieved on the outside tracks of a disc with a disc speed as low as 12 r.p.m. and a phrase length of 5 sec. Under these limiting conditions flatness of disc is important, both when recording and when playing back, for serious loss of high frequency response may otherwise be caused by defocusing.

Distortion. Harmonic distortion may be present in the final print for a variety of reasons. If the original recording of speech has been made on magnetic tape and transferred to the sound film from which the disc tracks are copied then either of the first two media may introduce distortion.

The camera itself, including amplifiers, galvanometer and optical system, gives comparatively little distortion if properly adjusted. It is important that the galvanometer armature be accurately centred in its gap and that the illumination of the recording mask be uniform. If suitable precautions are taken it is possible to restrict the second harmonic introduced in the camera to less than 2 per cent. and the third also to less than 2 per cent.

Further distortion may arise in the processing of the negative and of the positive print, due to image growth or retraction.[1] This effect is illustrated in Fig. 7, where the waveform (a) is that which is obtained from an under-exposed or under-developed negative, (c) results from over-exposure or over-development, and (b) shows the correct condition. The presence of this form of distortion may readily be demonstrated by recording and playing back an amplitude modulated waveform of the type shown in Fig. 8. (For simplicity only one track envelope is shown.) If the correct exposure has been given then the mean amplitude of the recorded waveform (shown by the dotted line) is constant, and no low frequency is detected upon playback. If, however, over-exposure or under-exposure is present, then the low frequency can be measured. Since the image growth effect is most troublesome at high frequencies, 9,000 cycles per revolution are used for the carrier and the modulating frequency is chosen to give 400 cycles per revolution.

For reasons which will be discussed in the next section, the density of the final print is required to be high, a condition which would normally give rise to the distortion of Fig. 7 (c). It is, however, possible to correct for the over-exposure of the print by first producing a negative which also has a controlled amount of over-exposure. A normal print from such a negative would give distortion as in Fig. 7 (a), but the over-exposed print adds just sufficient image growth to give a final waveform which is correct. It is now normal practice to include on each glass disc negative a sound track of the type shown in Fig. 8. Test prints are made with varying exposure and processed in the normal way. The exposure which is found to give minimum distortion is then adopted for any further prints required.

Signal/Noise Ratio. Background noise is the most serious limitation of the present glass disc process. With good quality magnetic recording or with lacquer discs a signal/noise ratio of 60 db. can be obtained, with glass discs it is usually of the order of 30 db. The high noise level is due partly to the emulsion and partly to the base. The discs are coated by hand with an emulsion which is extremely thin; consequently the incidence of pinholes and dust particles is considerably greater than is the case with machine-produced sound film stock. Furthermore, the plate glass base has been found to carry minute inclusions of rouge which are left in the small craters which remain after the polishing process. These imperfections of the glass are not visible to the naked eye, but contribute largely to the elevated noise level when they occur in the clear portions of the soundtrack. It is possible by fine polishing to effect a considerable improvement (about 6 db.) in the signal noise ratio of the discs. Also, by obtaining final prints of high density, as described in the previous section, the noise due to pinholes in the dense portion of the sound track can be reduced (since then pinholes are filled in by the image growth effect).

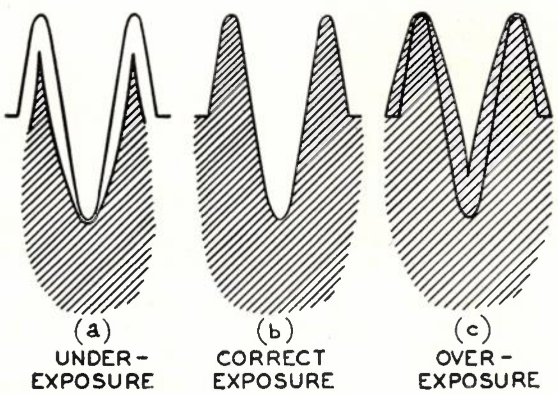


Fig. 7.—Image growth distortion.

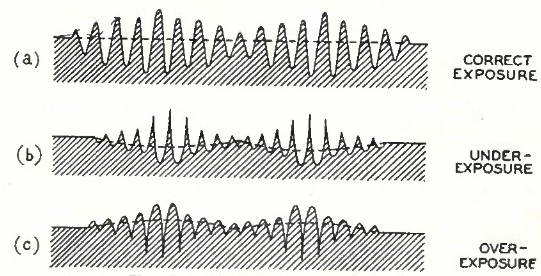


Fig. 8.—Distortion control track.

Drive Speed Flutter. When negatives are made by the copying process the plate is rigidly coupled to the film drum, and variations in the speed of rotation will not result in corresponding modulation of the sound tracks. Flutter in the drive is, however, undesirable because it gives rise to density modulation.

Normal sound tracks of full density do not show this modulation, but it is liable to contribute to the background noise by reason of its presence in the edge of the track where there is a fringing region of lower density owing to the finite size of the recording slit. "Wow" in the drive will also, of course, adversely affect tracks which are recorded direct from an oscillator instead of by copying from film or plate.

Considerable care has been taken to ensure that the speed of rotation of the camera shaft is as constant as possible by the insertion of suitable flexible couplings between the phonic motor and the high speed shaft of the gearbox, which is coupled to a large flywheel.

Methods of Application

No standard equipment exists for playing back glass disc records. Consequently a machine must be designed for each new requirement as it occurs. The machines so far made fall, broadly speaking, into two categories according to the method employed for scanning the sound tracks. The first class, to which the British Speaking Clock belongs, scans each track individually with a unit similar to that used on most sound film projectors, while the second scans a projected image of a group of tracks. The two types are described in the following sections.

Scanning by Unit Optical System. Fig. 9 illustrates a simple machine which has been designed to give congestion announcements (of the form "No lines at London") for use with automatic trunk working. The glass disc is mounted on a shaft which is driven through a gearbox by a synchronous motor. Several sound tracks of the type quoted above are recorded upon the disc: only one of these is used at each Group Centre where a machine is installed, but the number of different discs which must be recorded is thereby reduced. The machine has two scanning units consisting of lamp, optical system and cathode follower. The first of these reproduces the "No lines . . ." track required (its position can be adjusted accordingly) and the second is used to scan a track bearing the words "Test Call" used for routine testing. The disc also carries a distortion control track as described previously.

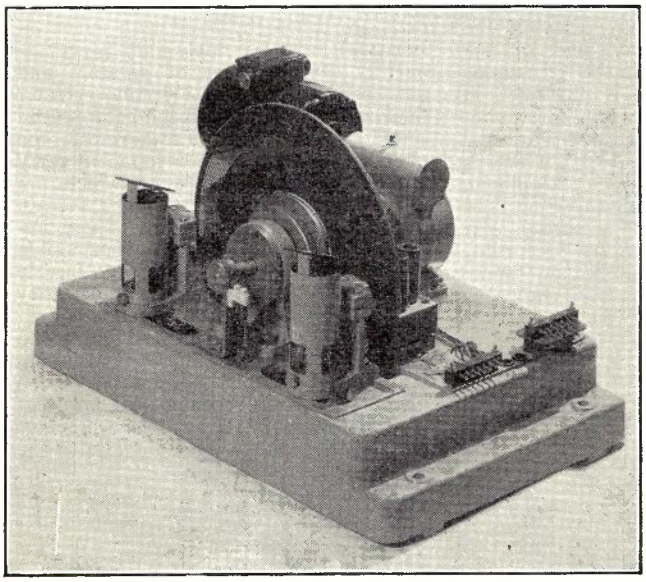


Fig. 9.—Simple announcing machine.

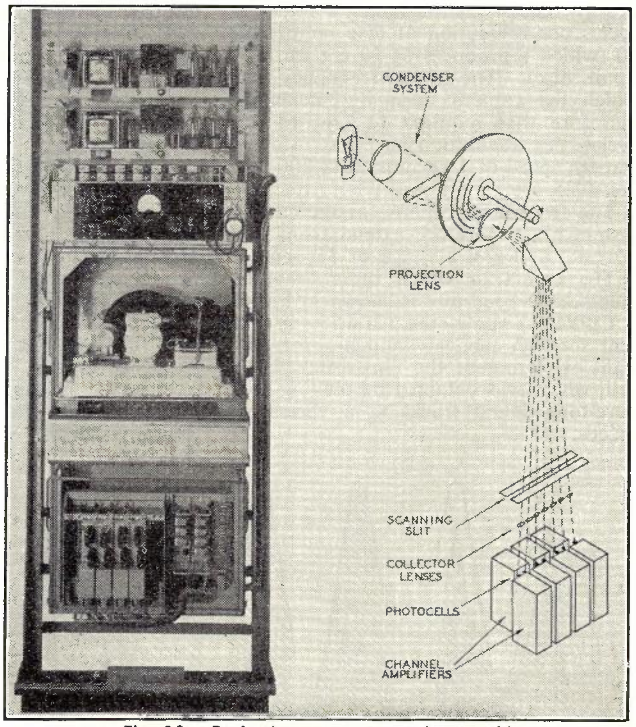


Fig. 10.—Projection-type announcing machine.

The Speaking Clock[2,3] is a more elaborate machine of this type with a controlled motor drive and facilities for changing the announcements to suit the time. The complete announcement is of the form "At the third stroke - it will be twelve - fifty nine-and ten seconds - pip, pip, pip". The hyphens indicate the way in which this announcement is subdivided for reproduction. Certain parts of the announcement ("At the third stroke" and the "pips") do not change, and are reproduced by fixed scanning units. The remaining components of the phrase are reproduced by scanning units which are mounted upon moving carriages, and a control mechanism alters the position of these to conform with correct time and selects the output of the relevant photocell when required. Auxiliary apparatus is provided which ensures accurate time-keeping, gives automatic correction of the clock at periodic intervals by comparing its signals with those from an observatory, and gives continuity of service by causing changeover to duplicate equipment in the event of failure or false operation of a component part of the system.

Projected Scanning. Fig. 10 shows a machine which is an elaboration of the Congestion Announcer described above. In addition to the "No Lines at London" announcement this equipment provides other phrases of the form "Delay half (or one, two, three) hour(s) at London", "Refer to Records" and "Test Call". All seven announcements are available continuously from one disc.

In the diagrammatic illustration a projection lens forms an image of a portion of the disc upon a slit, under which a row of photocells reproduce the series of enlarged sound tracks. For the simultaneous reproduction of several tracks this system shows considerable economy over the use of individual scanning units. Furthermore a comparatively large slit can be used for scanning since its effective size is reduced owing to the magnification of the projection system.

Conclusion

It has been possible in this paper to describe only the basic process of the glass disc recording technique. The method is flexible and lends itself to the manufacture of other types of record than speech sound tracks: for example discs bearing recordings of teleprinter test signals and "warble" tones have been made. There is little doubt many other such applications will arise in the future.

Acknowledgments

The thanks of the author are due to Dr. E. A. Speight who was responsible for the early development of this system of sound recording, to Mr. F. A. Milne who has done much of the later work, and to his other colleagues at the Research Station who have helped in the preparation of this article.

References

[1]"Modulated High Frequency Recording as a Means of Determining Conditions for Optimal Processing," J. V. Baker and D. H. Robinson, Journal of the Society of Motion Picture Engineers, Vol. 30, p. 3, January 1938.

[2]"The Post Office Speaking Clock," E. A. Speight and O. W. Gill, Journal of the Institution of Electrical Engineers, Vol. 80, p. 493, May 1937.

[3]"The Speaking Clock (Part 2: The Clock Mechanism)," E. A. Speight and O. W. Gill, P.O.E.E.J., Vol. 29, p. 263.

AN APPLICATION OF THE OXYGEN LANCE

D. B. SYNNOTT, B.Sc., Grad.I.E.Aust., Stud.I.E.E.

Introduction

Oxygen has been used for cutting operations for many years, its first appearance for cutting steel being in 1877. Practical means for combining the heating and cutting operations were not developed until 1901 and mechanical methods of operation a few years later. The process has great application in cutting large steel masses and, in the form of the oxygen lance, has many applications in piercing holes for various functions, for example, in forgings prior to machine cutting of holes and tapping blast furnaces. It will also pierce non-ferrous metals or non-metals but the function of the lance is slightly different in these instances.

The action of the lance in cutting ferrous metals is to produce sufficient heat by the process of oxidation of the metal to melt the metal in front of the lance. Advantage is taken of the capacity of oxygen to combine readily with iron that has been heated to kindling temperature. If iron or steel is heated to a temperature of approximately 1600 degrees F. and comes into contact with oxygen, it will immediately oxidise and burn rapidly—creating an effect similar to a Roman Candle—producing sparks and slag. The chemical reaction is:

$$3Fe + 2O_2 = Fe_3O_4 + \text{heat}$$

and if one pound of iron is used the heat liberated is 2900 B.Th.U. To combine with one pound of iron, 4.6 cubic feet of oxygen is required. In practice, however, less is normally required since some of the iron, which is molten due to the heat of the reaction, is swept away by the oxygen stream and some oxygen for the reaction is extracted from the atmosphere.

When cutting with the oxygen flame an oxyacetylene flame is normally used to supply the heat necessary to keep the oxidisation process going. With the lance, the flame is started by heating to the kindling temperature the end of the lance or the spot on the material where the cut is to start (if the material is a ferrous metal). The oxygen is then turned on and the lance feeds oxygen to the hot metal so that the reaction continues rapidly. When working in ferrous metals the lance is consumed during the operation, but the bulk of the heat required to keep the cut going is supplied by the material being cut, that is, the lance is principally a tool for conveying the oxygen to the point where the cutting action is taking place.

With non-ferrous metals, however, the combustion of the lance pipe supplies the entire amount of heat that is required for producing a fluid slag by reaction with the iron oxide. In these cases, the lance, which consists of a black iron pipe, is loaded with steel rods or wires to make the reaction more vigorous. (1, 2).

Work at the Central Exchange

At the Central automatic telephone exchange, Perth, an extension to the building has recently been completed. The MDF, which is located on the first floor, is also being extended into the new portion of the building. The room beneath the MDF extensions is used to house the air conditioning equipment. To avoid this equipment a special framework was designed to provide cable supports and runways, which enable the cable tails to be taken to the MDF uprights from the pothead joints which are located in the old building. This framework had to be supported by hangers from the floor beneath the MDF.

The floor is 7½ in. thick, comprised of 2½ in. of surface cement, 3½ in. of concrete with ¾ in. reinforcing rods at 4 in. spacing and 1½ in. of cement and plaster on the ceiling of the room below. 29 holes were required in an area 29 ft. 3 in. by 8 ft. 3 in.

Various methods of providing the holes were considered. Due to the proximity of the location of the holes to some of the automatic switching equipment, see Fig 1, the use of a pneumatic drill was barred because of the dust and vibration hazard, also the noise would have adversely affected the working of the exchange test desk, which is parallel to the MDF at the far end. In this connexion, although one was not available at the time, the use of a small jack hammer manufactured by Ingersoll Rand has possibilities. It is of only 14 pounds weight and will handle drills down to ¼ in. diameter.

Masonry drills of the Mason Master and Concrete Master type were considered and one of the latter, of ½ in. diameter, was bought. This is a circular trepanning tool, fitted with four tungsten carbide steel tips, with a hollow core and an ejector slot in the side. Operated in a heavy duty electric drill, at a nominal speed of 400 revolutions per minute, it was quite successful in drilling through the cement, progress of about one inch per minute being obtained. However, the drill made no impression on the granite aggregate and was of little value in this application.

The Burning Operation

The process of oxygen burning of the holes was then considered and it was decided to try the process to see what application it would have in this Department's operations. Commonwealth Industrial Gases Limited provided the operator, and line staff from the Primary Works Division was used for man-handling the gas cylinders and carrying out the fire precautions.

The lances used consisted of nine foot lengths of ⅜ in. internal diameter black iron pipe, packed with ⅛ in. mild steel rod—seven, eight or nine rods being used depending on variations in the pipes. Screwed pipe was necessary as

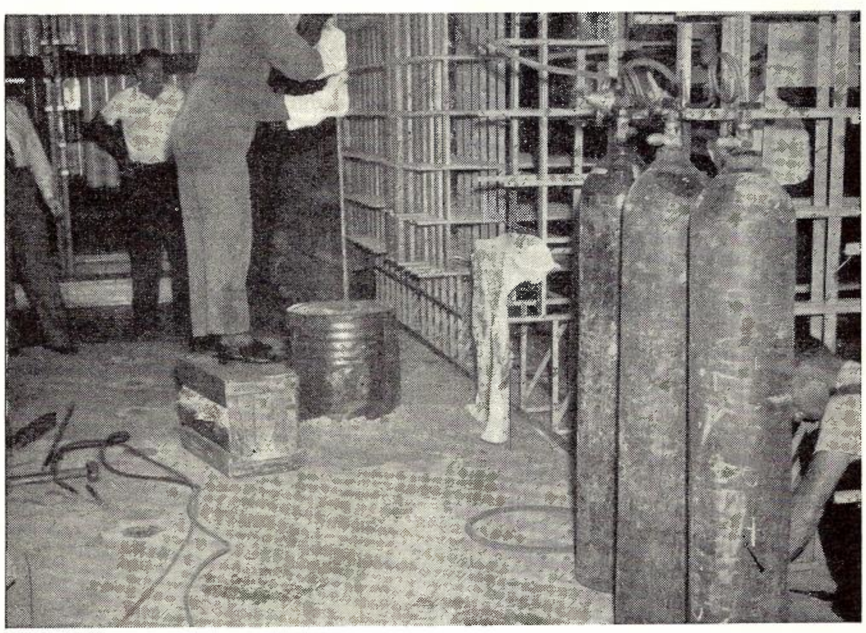


Fig 1. —The burning operation in progress. The operator wears welding glasses and asbestos gloves. The existing MDF and automatic switching equipment can be seen behind the operator.

the oxygen is fed to the lance through a screwed coupling: For safety, the whole assembly must be free of oil or grease as these may violently and spontaneously ignite in combination with the oxygen. To supply the required volume of oxygen three cylinders were coupled in parallel and connected through a regulator to a length of high pressure hose and thence to the lance. An oxyacetylene torch was used to heat the end of the lance to the kindling temperature. (2).

During the burning operation considerable spitting of molten slag takes place and a large volume of fumes is evolved. To mitigate against any danger or resultant damage, an open ended carbide drum was placed over the location of each hole and surrounded with sand and the lance was inserted through a hole in the top of the drum. As a further precaution, asbestos blankets were placed over any equipment near the location of the hole being burned and a man stood by with a pressured carbon tetrachloride fire extinguisher. The asbestos blankets were all that were necessary, mainly to protect the paintwork against blistering from the heat, because the drum becomes red hot. Fig. 1 shows the burning operation in progress. The fumes can be seen rising through the hole in the top of the drum. When each hole was burned these fumes filled the whole first floor of the exchange and made working conditions temporarily quite unpleasant.

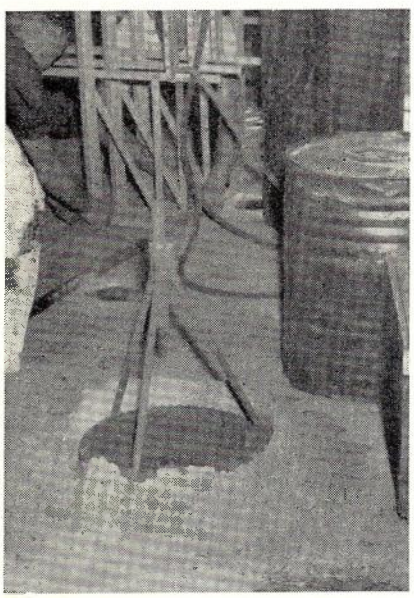


Fig. 2.—Arrangement of the guide, the drum and the sand during the burning operation.

To burn the hole, the lance was ignited and the oxygen turned on at low pressure. The tip of the lance was then located in a marking hole in the floor and the oxygen pressure increased to 120 pounds per square inch. To prevent the lance from freezing in the slag it was necessary to give it an oscillatory rotary movement. Under these conditions it took nearly four and a half minutes and approximately 4 ft. 6 in. of lance to burn each hole. A serious disadvantage of this procedure was that with the rotating motion and the softness of the tip of the lance due to the heat, the tip of the lance would wander once it struck the harder material comprising the aggregate. This resulted in the holes being up to six inches in diameter across the top and in some cases as much as four inches off the correct line.

An obvious refinement was the use of a guide for the lance, as shown in Fig. 2. It consisted of a length of ¾ in. G.I. pipe supported by a tripod to a ring gear from a bulldozer. This latter was used as a base since weight was needed to prevent movement of the guide as the lance was rotated to prevent freezing. The guide fitted under the carbide drum and in the photograph, which was taken after a hole had been completed and the drum had been lifted away, the arrangement of the drum, guide and sand can be seen.

The use of the guide resulted in marked improvement and economy. The time for burning each hole was reduced to approximately two minutes with similar saving in the length of lance used. The holes burned using the guide were straight and accurately located and the diameter across the top was about two inches. Fig. 3 shows one of these holes.

On the ground floor, sheets of metal covered with sand were used to catch the slag and protect the floor and the air conditioning equipment. Where miscellaneous items of equipment were likely to be sprayed by the slag when the lance burst through, asbestos blankets were used as cover, but these would not be of much use if much slag were caught as the heat of the slag burns through them. With the first holes, plaster was knocked down when the operator cleared slag from the holes. However, a little experience soon overcame this trouble. Two men were used initially in this room to maintain fire precautions and move the sand trays, etc., but experience showed that only one man was necessary.

Conclusion

To drill the holes with a hammer and star drill would have taken one man a full day, provided that none of the holes encountered a reinforcing rod, which would effectively stop the drilling process. Using the burning process it would take three men at least four hours including the time necessary to set up the gear and take it down when the job was completed. 1110 cubic feet of oxygen and 60 pounds of mild steel rod were used, representing an average of 30 cubic feet of oxygen and 2½ pounds of rod per hole, when using the guide.

A disadvantage of this process when applied to concrete is that the cement will decompose at temperatures greater than 300° F. In this instance, the cement in the immediate vicinity of each hole was decomposed to a friable material.

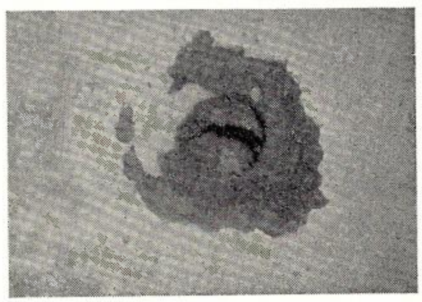


Fig. 3.—Holes made with the use of the guide.

It would appear that the main application of this process of burning holes in building structures would be in fairly special cases, such as holes through very thick material, e.g., the burning of a hole through a massive concrete wall; holes where metal such as girders, etc., will be encountered and in brick construction where a large number of holes is required.

Bibliography

1. Welding Handbook, 1942 Edition. Published by the American Welding Society.

2. The Oxygen Lance. A "Technical Talks" pamphlet published by Commonwealth Industrial Gases Ltd.

MR. T. E. S. COLLINS

In 1911, Mr. T. E. S. Collins joined the P.M.G.'s Department, Victoria, as a junior Assistant Engineer, and as Assistant Engineer and Engineer was closely associated with the late Mr. Ted Howson, Supervising Engineer, on the maintenance and installation of telephone equipment in the Melbourne metropolitan area.

During 1924, Mr. Collins was promoted to the position of Divisional Engineer, Ararat and virtually pioneered in Victoria the work of setting up a self-contained engineering organisation with headquarters outside the capital city. Following his return to Melbourne in 1934, he occupied the positions of Divisional Engineer, Equipment No. 2, Supervising Engineer, Country and Supervising Engineer, Workshops. In the later capacity, during the strenuous war years, he encountered and overcame many involved problems associated with the manufacture and assembly of vitally needed signal equipment for the Armed Services.

In 1947, Mr. Collins was promoted to the position of Supervising Engineer, General Works, Central Administration, and shortly afterwards, to that of Deputy Superintending Engineer, Victoria. During the five years immediately prior to his retirement, however, Mr. Collins became well known throughout the Commonwealth for his work in an acting capacity as Deputy Engineer-in-Chief, Central Administration.

During the whole of his Departmental career, Mr. Collins' outstanding characteristics were his kindly nature, courtesy and consideration for the feelings of others, together with a marked ability to get things done in a quiet and unobtrusive manner. He was always ready to give a helping hand to those who needed it and, in this regard, particularly, many members of the Department continue to remember him with affection and gratitude.

Mr. Collins was a keen and enthusiastic member of the Postal Electrical Society. During its early years he contributed in many ways to its subsequent development and presided over its activities in 1937.

Prior to his retirement, Mr. Collins was farewelled by a large gathering of his Departmental colleagues and friends, at which many fine tributes were paid to his personal characteristics and sterling service by Mr. G. T. Chippindall, C.B.E., Director-General, who was supported by the acting Assistant Director-General (Engineering Services), Mr. W. Engeman, and the Director, Victoria, Mr. N. W. Strange.

ANNUAL REPORT 1953/54

The lecture programme for the 1953/54 year enabled members of the Society to hear talks by Mr. R. R. Ashmole of Siemens Pty. Ltd. and by Messrs. E. J. Bulte, L. Garrioch, S. Mulhall, R. T. Fraser, P. R. Brett, and A. C. Wright. Through the courtesy of the Training Section, Engineer-in-Chief's Branch, the Society was able to show four films of general interest to Members at one meeting.

The Society has held its meetings in the Radio Theatre of the Melbourne Technical College, and our thanks are due to the Principal and officers of that organisation for this facility. In addition our thanks are due to Messrs. Permewan and Power of the College for their assistance in the preparation and screening of illustrations for the lectures.

The publication of the Telecommunication Journal of Australia has continued. The cost of this enterprise is still a problem and in an effort to assist in this regard, while not in any way detracting from the standard of our Journal, the editors and Committee have during the past year adopted the Times New Roman Type. A short explanation of the advantages of this action appeared in Volume 9 Number 3, the first issue to appear in the new form.

The Society's finances have been such that the continued publication of the Journal has only been possible with a subsidy of £198, which the Director-General has made available during the past year.

It has been necessary to accept with considerable regret the resignation of Mr. R. W. Turnbull, from the Board of Editors, on account of ill-health. His assistance has been very considerable and the Committee wishes him well. Mr. J. A. Harwood has consented to take Mr. Turnbull's place as an Editor.

It is the desire of the Committee to express its thanks to the authors of articles, members of the drafting staff who have prepared illustrations, members who have assisted in the collection of subscriptions, and to Miss Wright, who keeps our records of subscriptions to the Journal, for their work during the past year.

ANSWERS TO EXAMINATION PAPERS

The following answers generally give more detail than would be expected in the time available under examination conditions. The additional information should be helpful to students.

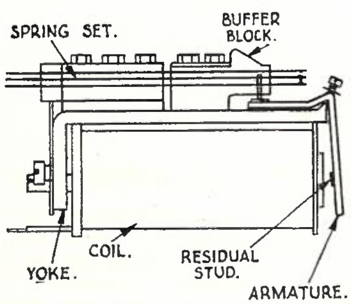
EXAMINATIONS Nos. 3819 and 3820. TECHNICIAN, TELEGRAPH MAINTENANCE

R. S. Butler.

Q.3.—Telephone relays are extensively used in Telegraph equipment today. Describe the construction and operation of one such modern relay.

A.—The drawing shows a standard 3000 Type Relay. It consists of a coil of wire wound over a soft iron core and insulated from it. The coil is held in place on the core by S.R.V.P. cheeks and the core extends through the cheeks at one end to facilitate its mounting in the yoke. The purpose of the coil and core is to provide the magnetic flux to operate the armature.

The yoke of the relay, which is made of soft iron, serves three main purposes. It provides a means of mounting the coil assembly, provides a low reluctance magnetic path from the coil to the armature, and serves as a means of mounting the relay contacts.



The armature is made of soft iron and is manufactured with an inverted "V" at the right angle bend which fits over a knife edge on the yoke. This arrangement acts as the relay armature pivot. The armature is held on to the knife edge by a spring-loaded screw passing through a slot in the armature pivot point and screwing into the knife edge.

Fitted through the armature opposite the core face is a non-ferrous residual stud. The purpose of this stud is to prevent the armature from "freezing" on to the core face after the magnetising current has been removed from the coil. A space is left between the residual stud and the core face, this constitutes the armature travel and is usually 31 mils in size.

The contact assembly consists of nickel silver springs, contacted with gold-silver contacts. The end of the spring is split and twin contacts are provided on each spring as a safeguard against bad contact when the springs are "made". Contact movement is limited by a moulded ceramic buffer block mounted between the contact mounting and the armature. Buffer blocks are obtainable in a variety of sizes to suit various types of contacts. (Make, Break, Changeover, Make before break Changeover).

Contact spring travel is obtained by lifting pins mounted in the appropriate contact springs. These pins are insulated from all other springs by insulating pips.

Operation. Upon current being passed through the coil of the relay, magnetic flux is induced in the iron core by the relay, assume the polarity at the yoke end of the core is South, then this polarity will be extended by the yoke to the armature, which will assume this polarity. Now, as the armature end of the core is of a North polarity, the South polarity on the armature will be attracted by the North pole on the end of the core.

The armature movement causes the lifting pins of the contact assembly to rise, operating contacts.

When current through the coil ceases, the flux in the core collapses to zero and the armature, deprived of its attractive force releases and moves to its normal position under the pressure of the contact springs, permitting the springsets of the relay to return to their normal unoperated position.

Q.5.—It is necessary to measure a current of 5 amps. The only instrument available is a 50-0-50 milliammeter. Describe how you would adapt this instrument to meet the requirement and calculate the resistance of the component used. The resistance of the milliammeter is 5 ohms.

A.—To enable this meter to read a value of 5 amps it will be necessary to provide a shunt across the meter of such a resistance that only 50 milliamps of the 5 amps applied will flow through the meter, the remainder flowing in the shunt.

The value of the shunt is calculated below.

As only 50 mA can flow through the meter the amount of current that must flow through the shunt is:

5Amps − 50 mA = 4950 mA.

Potential dropped across meter = Res of meter by current through meter.
= 5 ohms × 50 mA = 250 millivolts.

As the shunt will be directly across the meter this potential will be also dropped across the shunt.

Therefore Resistance of shunt

$$= \frac{\text{Volts dropped across shunt}}{\text{Current through shunt}}$$

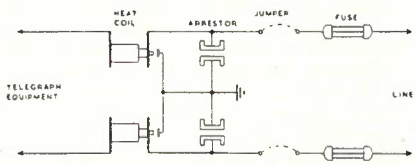
= 250/4950

Resistance of Shunt = .050505 ohms.

Q.6.—What methods are used for the protection of Telegraph circuits and equipment against damage by lightning discharges and extraneous currents?

A.—Telegraph equipment is protected from lightning discharges and extraneous currents by three components. These are:—

1. Fuses.
2. Carbon lightning arrestors.
3. Heat coils.



These three items are located on the Main Distributing Frame, the first appearance of the incoming cable or line when entering a Telegraph Office.

The Fuses are in series with the line and each consists of a tube of glass or porcelain with metal caps cemented over each end, a piece of fuse wire connects the two caps through the glass tube. The wire is designed to carry 1.5 amps indefinitely, but to operate within 30 seconds on a current of 3 amps passing through it.

The Carbon Arrestors consist of two carbon blocks, each having a surface coated with an insulating material about .0015″ thick. This thickness of insulation will break down when a potential of between 500 and 700 volts is applied across it.

The Carbon Lightning Arrestors are connected between each side of the line to earth, and are placed between the Fuses and Heat Coils. Therefore, when the insulation between the two blocks "breaks down" under a very high potential, the potential is applied to earth and not to the equipment, which it would otherwise damage.

The Heat Coils are inserted in series with the incoming line to protect the equipment from current which is not of sufficient value to blow the fuse but is high enough to damage the equipment should it be applied for any length of time.

The Heat Coil consists of a winding of from 3½ to 4 ohms wound on a bobbin through which a brass pin passes. The pin is secured to the bobbin by low melting point solder. One end of the wire terminates on the bobbin and brass pin whilst the other terminates on a brass cap on the heat coil case.

When the Heat Coils are mounted in a protector strip, they are under pressure from the two contact springs; one spring pressing on the brass cap on the case, the other pressing on the winding tending to push it along the brass pin.

In this manner the Heat Coil should carry 350 mA for 3 hours without operating, but should a current of ½ amp be applied to the coil for 3½ mins. the heat coil should operate.

The operation occurs by the heat generated by the current passing through the coil melting the solder securing the coil to the pin. As the coil and bobbin are under pressure, they will slide along the pin, exposing more pin which passes through a hole in the pressure spring and contact an earthing strip conducting the current to earth, preventing it from overheating any equipment to which the line may be connected.

The arrangement of the protective apparatus provided on a telegraph circuit is shown schematically in the sketch.

Q.7.—It is necessary to re-temper a ¼" Whitworth tap. Describe how you would carry out this operation.

A.—The tap, having lost its temper, would have to be rehardened prior to the retempering. This is accomplished by heating the thread of the tap in a blowtorch, care being taken to ensure that the tap is not left in the flame longer than necessary, because of the danger of "burning" the teeth of the tap.

This danger may be alleviated somewhat by keeping the tap revolving in the flame so that the thin edges of the thread will not be in contact with the flame all the time, whilst the body or land of the tap is heating.

When the tap thread is glowing a cherry red, it should then be plunged into tepid swirling water. The water should be tepid to prevent the tap cracking, due to the sudden change in temperature, and should be in motion (swirling) to prevent bubbles forming on the surface of the tap, thereby preventing the coolant from reaching the tap, resulting in soft spots in the metal. The tap is now dead hard and therefore very brittle.

After hardening, the tap must be tempered before it can be successfully used. To do this the tap should be polished over its length to enable the temper colours to be seen.

The tap is then placed in a tray containing fine, clean sand and placed over a gas flame. When the polished portions of the tap assume a dark straw colour it should be immediately plunged again in the water to cool it. The part of the tap to which the tap wrench is fitted should then be tempered by inserting it in the flame until it assumes a blue colour, care being taken not to heat the thread of the tap, and then plunging into water again. The tap is now ready for use.

Q.8.—Compare the advantages and disadvantages of Single and Double current Telegraph transmission.

A.—Double current telegraph transmission has the following advantages over single current telegraph transmission.

1. Increased Speed of Working.
2. Increased Range of Operation.
3. Greater Permanence of Adjustment.
4. The relays are less susceptible to false operation by external currents.

These advantages arise from the following reasons:—

1. **Increased Speed of Working.** Because the capacity of the line is charged and discharged faster with double current signals, and as the charge and discharge times of the line capacity has a large effect on the received signal shape, by decreasing these times, it necessarily follows that the received signal will be of better shape (squarer), permitting the receive relay to operate faster.

2. **Increased Range of Operation.** Because polarised relays are worked in their neutral or no-bias condition, and are, therefore, in their most sensitive condition, they are able to be operated by much lower current values.

The non-polarised relay used in single current telegraphy is given a decided bias by means of the retractile spring, to ensure its return to the space condition after the signal has been removed from its coils, and this bias has first to be overcome before the armature can be operated, resulting in higher current values necessary to operate these types of relays.

3. **Greater Permanence of Adjustment.** Because both the operating (Marking) and restoring (Spacing) currents are sent over the line and both of these will be equally affected by leakage. Therefore, although the value of received current may vary due to leakage effects the Marking and Spacing currents will be of equal value and provided the value of current received does not fall below the operate value of the receive relay the leakage will have little effect.

In single current, because only the operating current is sent over the line and will vary considerably with leakage it is necessary to be constantly adjusting the retractile or restoring force (spring) of the receive relay.

4. **The Relays are less Susceptible to False Operation.** In double current transmission, the relays are controlled to the marking and spacing conditions by steady negative and positive potentials, hence they are less liable to be falsely operated by crossfire or inductive disturbances.

Single current telegraph transmission has the main advantage that it is comparatively cheap to install, as only one main battery is necessary, as against two main batteries at the both stations required for double current transmission.

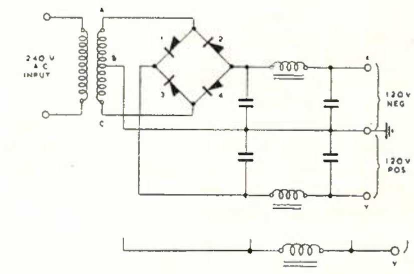
Q.9.—Draw the circuit of, and describe the operation of, a Rectifier suitable for supplying line current to a duplex morse set from the commercial power mains.

A.—The circuit shown is that of a transformer-rectifier set suitable for supplying 120 volts positive and 120 volts negative from the commercial power mains.

The transformer is a 1 : 1 ratio, the secondary being centre tapped, so that a potential of 120 volts A.C. will exist between points A & B and points B & C.

For one half cycle when the current is flowing in the secondary in the direction C to A, 120 volts exists between points C and B and current will flow from point B via earth and load to -ve output terminal, through rectifier 4 to point C.

Thus, point X is negative with respect to earth.



OUTPUT WITHOUT FILTER OUTPUT WITH FILTER

The 120 V. existing between points A and B will flow from point A via rectifier 1 to the positive terminal (Y), via load, earth and back to point B. Thus point Y is positive with respect to earth.

The next half cycle will be flowing in the opposite direction in the secondary, i.e., A to C.

The 120 volts between A and B flows to earth at B, via load to point X, via rectifier 2 back to point A. Thus for this half cycle also point X is still negative with respect to earth.

The 120 volts between B and C flows via rectifier 3 to point Y, via load, earth and back to point B. So for this half cycle point Y is still positive with respect to earth.

From the above description it will be seen that this transformer rectifier set will supply 120 +ve and 120 -ve from the power mains.

The condenser and choke network between the +ve and -ve D.C. output leads and earth is provided to smooth the pulsating D.C. output. The two graphs show the output of a rectifier set with and without smoothing networks.

Q.10.—Describe the motor stop function now in use on Model 15 Teletypes. What character combination is used to effect this combination?

A.—The Motor Stop Function now in use on Model 15 Teletypes is provided to enable any operator on a Teletype circuit, to cause the electric motors driving all other M.15 Teletypes on the circuit to stop. This function is normally operated when the transmitting operator has completed and confirmed his message.

The purpose of this function is to permit remote control of all motors on the circuit by any operator, thereby conserving power and preventing unnecessary motor wear.

While it is possible for any operator on the circuit to stop the motors, it must also be possible for any operator to be able to start all motors on the circuit again when he requires to send.

This is made possible by causing the motor to stop via a system of levers and contacts, the final action in the train of operations holds the motor stop contacts open per medium of a lever latched over an extension on the electromagnet armature when the armature is in the marking position. Now if the armature is operated to space (by opening the line at any "Break" key) and restored to Mark (by releasing the "Break" Key) the lever will release from the latch and, under spring tension, cause the motor stop contacts to close, once again providing power to the motor, which will commence to revolve.

Precautions are also taken to prevent the motor from stopping should the armature be locked to either mark or space by the locking lever.

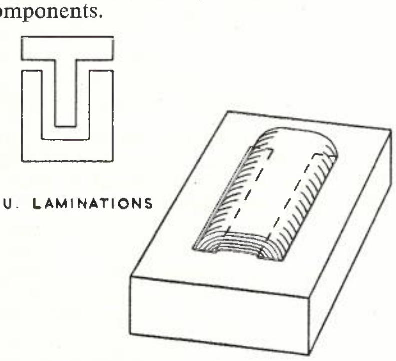
The code combinations used to effect the motor stop function are "Figs"—Blank—"H" sent from any keyboard on the circuit in that order. The "Blank" combination was inserted between the original "Figs"—"H" combination to permit this combination (Figs—H) to print £ sign for interoperation between Teleprinters and Teletypes.

EXAMINATION Nos. 3963 and 3964. TECHNICIAN, RADIO AND BROADCASTING

J. K. Smith.

Q.1.(a) Describe briefly the construction of a transformer suitable for use at a mains frequency of 50 cycles per second.

A.—A 50 cycle power transformer consists of a number of enamel insulated wire windings located in an assembly of metal leaves or laminations. The ends of the various windings, each group separately insulated, are connected to a terminal strip. Part of the transformer is enclosed in a magnetic shield. This shield offers a low reluctance path for the magnetic fluxes and, therefore, isolates the transformer from adjacent circuits and components.



T.U. LAMINATIONS

ASSEMBLED TRANSFORMER

The windings must have a low copper loss and are made as large in diameter as possible for the current drawn and the size of the transformer in order that the voltage drop is as small as possible.

The material used in the laminations is Stalloy for low "Hysteresis loss", and the laminating reduces "Eddy current" flow. The two losses combined are referred to as iron losses.

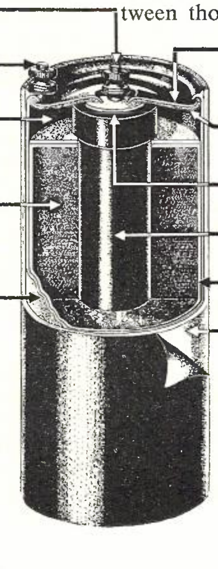
Q.1.(b) A transformer with its primary winding connected to a 250 volt mains supply is used to light a 5 watt lamp to full brilliance. The primary to secondary turns ratio is 100 : 1; what current is drawn by the primary windings, neglecting losses?

A.—If a transformer were 100% efficient then the power in the primary (E x I) would equal the power in the secondary irrespective of the turns ratio. As 5 watts are needed to light the lamp in the secondary, then the power source must supply only 5 watts.

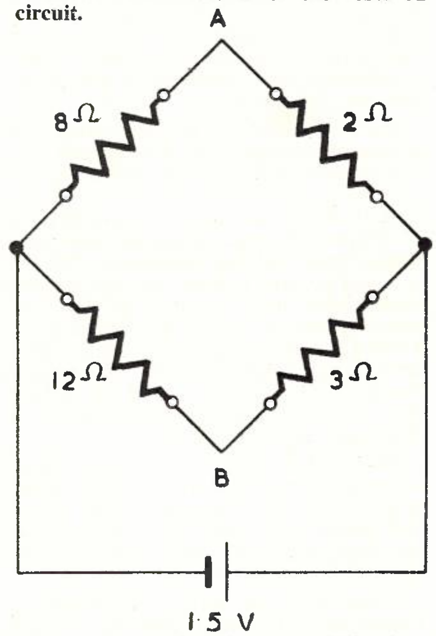
Supply voltage, 250 volts
Watts of Primary 5
Watts = Volts x Amps.
∴ Primary Current in Amperes
= 5/250.
= 20 milliamperes. Ans.

Q.2 (a) Describe, with the aid of sketches, a primary cell in use in the Department.

A.—A Primary Cell in common use in the P.M.G. is the Dry Cell. The essential elements of the cell are the electrodes and the electrolyte. Zinc is the negative electrode; a carbon rod placed in powdered carbon and manganese dioxide enclosed by a fibre sac is the positive electrode; and a paste solution of salammoniac is the electrolyte. Other features which go to make up the cell are zinc chloride added to the salammoniac to reduce corrosion of the zinc electrode case, and a depolarising mixture of ground carbon and manganese dioxide. The action of the depolarisation agent is important in maintaining the life of the cell. When the cell is doing useful work hydrogen gas is formed by chemical action on the positive electrode. The hydrogen forms a high resistance layer which increases the internal resistance and, therefore, affects the output of the cell. The depolariser reacts with the hydrogen to form water and another compound of manganese. The cell eventually discharges and this is seen by a contracting of the powdered carbon and manganese dioxide towards the carbon rod.



Q.2 (b) A bridge circuit of pure resistance is connected to a 1.5 volt cell in accordance with the diagram below. What voltage would be measured between terminals A and B? Determine the current in each section of the resolved circuit.



A.—The total resistance of the top arm of the bridge is 8 + 2 = 10 ohms and the total resistance of the lower arm is 12 + 3 = 15 ohms. There is the same potential difference 1.5 volts across both arms, therefore the current in the top arm is 1.5/10 = 0.15 amp. and in the bottom arm 1.5/15 = 0.1 amp.

The voltage measured between terminals A and B of the bridge will be the difference between the voltages across the 8 ohm and 12 ohm resistances.

Voltage across the 8 ohm resistance $E = I \times R = 0.15 \times 8 = 1.2$ volts and voltage across the 12 ohm resistance $= 0.1 \times 12 = 1.2$ volts.

There is the same voltage drop 1.2 volts across the 8 ohm resistance and the 12 ohm resistance, therefore the terminals A and B are at the same potential and no voltage will be measured between those terminals.

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