RECENT DEVELOPMENTS IN TELEGRAPH TRANSMISSION, AND THEIR APPLICATION TO THE BRITISH TELEGRAPH SERVICES

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SUMMARY

This paper gives details of many of the engineering developments which have taken place in the inland telegraph service of the British Isles during the past few years. Some account is also given of the theory and nomenclature of modern telegraphy and of the application of alternating currents to telegraph transmission.

Chief among the developments is the conversion of the main telegraph system of the British Isles to multi-channel voice-frequency working, which has resulted in the unification of the telephone and telegraph line plant. The introduction and rapid expansion of the private-wire services have also contributed to a renewal of interest in telegraph matters, and engineers have seized the opportunity to adapt for telegraph purposes many of the technical developments of other branches of the telecommunications art.

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(1) INTRODUCTION

In a paper read before The Institution in November, 1932, Mr. R. P. Smith* described the introduction of modern machinery and methods to the inland telegraph service of Great Britain. The developments referred to in that paper have had a far-reaching effect on the service and have been themselves an unqualified success. The main features of the changes were the standardization of the teleprinter for telegraph circuits and the concentration under specially-trained staff of all subsidiary and testing apparatus on racks segregated from the instrument room. Economies in staff and in space, together with increased stability of apparatus, resulted from these changes, but the network of cables and overhead lines remained unchanged.

It had been clear to engineers in recent years† that the use of underground cables solely for direct-current telegraphy was wasteful, and that modern developments in amplifiers and filters could be applied to enable the full frequency range of such circuits to be used.

In 1929 the Comité Consultatif International Télégraphique standardized the speed of the teleprinter, and on that basis in May, 1931, the spacing of the carrier frequencies to be used for voice-frequency telegraphy was also standardized.‡ In November, 1931, the Post Office installed and operated a London–Dundee 12-channel system which had been developed and manufactured in Great Britain and which met completely the requirements of the C.C.I.T. (Avis Nos. 511 and 516).§ This 12-channel system was followed in September, 1932, by the installation of a London–Glasgow–Belfast 18-channel system. The experience gained with these

* See Bibliography, (1).
† Ibid., (3) and (4).
‡ Ibid., (5) and (4).
§ Ibid., (6).
systems was such as to confirm the anticipated reliability and economy of this system of working, and the complete unification of the telephone and telegraph cable networks was clearly possible. In 1932 the introduction of demand telephone trunk working created a shortage of trunk telephone circuits, and as delay in the specification and provision of new cables had technical and economic advantages it was decided in January, 1933,
to convert practically the whole of the inter-urban telegraph network to voice-frequency working and to utilize for telephone purposes the telegraph cables so thrown idle.*

Installation of this network commenced in May, 1933, and by December, 1933, 504 channels had been installed; this number increased to 684 in December, 1934, and was added to from time to time until the present total of about 1000 channels was reached.

This transfer of the telegraph circuits from physical lines to voice-frequency channels completed the revolu-

* See Bibliography, (45).
tion that had taken place in the telegraph service, and by 1934 hardly an item of traditional telegraph plant remained in the inland service. Concurrently with these important changes the private teleprinter services which had been introduced in 1932 and which were referred to by Mr. Smith at the time of their introduction, have also prospered. In particular, the simplex point-to-point teleprinter service (tariff A), which includes provision and maintenance of the teleprinters, has been very successful. There are now more than 300 such circuits, and they produce a substantial revenue.

Cable companies, news agencies, and newspapers, make considerable use of duplex point-to-point circuits for speeds up to 100 words per minute Wheatstone, or the equivalent. These circuits (tariff B) are provided almost entirely by means of voice-frequency channels, and it is of interest to note that such important circuits as direct extensions of Atlantic cables are numbered among them. Some 58 full-time and 22 part-time circuits of this type are in operation.

Numerous privately-rented circuits remain on physical circuits where these are still available and where the renters have special requirements or use speeds greater than 100 words per minute Wheatstone. An increasing number of newspaper companies now rent telephone circuits on which they provide or rent equipment for alternative speech or pictures and multi-channel voice-frequency telegraphy.

A system of terminating public teleprinter circuits has also been introduced which gives "ancillary" facilities at head offices to improve operating conditions. The telex service giving the alternative of teleprinter services has been the introduction of broadcast systems. In these, facilities are provided and maintained by which a central office of a renter can transmit simultaneously to any reasonable number of outstations or separately, as required, up to the limit of the number of machines provided at the central office. These systems are finding considerable favour with police services and with news agencies.

It should be mentioned, perhaps, that there is considerable evidence to indicate that in many instances the traffic carried by these new teleprinter services was previously forwarded by post, and the increased revenue arising from these circuits is not offset very appreciably, therefore, by decreased telephone and telegraph revenue. From the renters' point of view the speeding-up of business achieved by substituting teleprinter communication for typewriter communications by post is in itself justification for the moderate expenditure entailed.

(2) FUNDAMENTAL CHARACTERISTICS OF TELEGRAPH TRANSMISSION

(a) Methods of Defining Telegraph Speed, Distortion, and Margin

The electrical communication of intelligence over a transmission link is achieved in normal telegraphy by using an arbitrary time code to represent letters, figures, and signs. Transmission is accomplished by effecting a series of changes in the electrical conditions at the sending end, the signals being characterized by specific time-intervals between successive changes in accordance with the code used. At the receiving end, transmission is completed by the recognition of these time-intervals by the receiver, thereby enabling the characters to be recorded.

In the proceedings of the C.C.I.T. the operations performed at the transmitter have been given the name "telegraph modulation"; the instants at which the characteristic changes occur are called "characteristic instants of the modulation," and the intervals between these instants "elements of modulation" (Avis No. 301: "Definitions Relative to Telegraph Transmission").

The electrical transmission wave is therefore characterized by changes in amplitude which at the origin are effectively instantaneous but which lose their sudden character during propagation through the line and terminal equipments. On this account the recognition, at the receiving end, of the original time-intervals may be a matter of some difficulty and it is usual to restore the abrupt nature of the changes by means of some form of relay. The latter should have the property of producing locally, instantaneous electrical or mechanical changes at instants corresponding to those at which the amplitude of the received wave is equal to some predetermined value. In general, changes in amplitude of the transmitted wave are accomplished and accompanied by transient effects. If these are of shorter duration than the shortest element of modulation the signals will be unaffected by previous signals under all conditions. Assuming this to be so, then in the absence of external disturbing influence the response of the system to a modulation will always be the same and the instantaneous changes produced by a perfect relay will always occur with a constant delay after the correspond-
ing operation at the origin of transmission. Under these circumstances the received signals would be in exact accordance with the operation of the transmitter and the system would be telegraphically distortionless. Actually, distortionless transmission is still obtainable when the duration of the transients exceeds the shortest modulation element, it only being necessary that transients due to one modulation shall have died away before the receiving relay operates in response to the next following modulation. This requirement sets a theoretical maximum transient time equal to twice the duration of the shortest modulation element. In practice such perfection is neither obtainable nor essential, but in all systems there is some limit to the permissible departure of the received signals from perfect agreement with those at the origin.

**Telegraph speed.**

The degree of imperfection is to a large extent dependent upon the relation between the duration of the transient effects and that of the shortest element of modulation. These two factors are therefore of primary importance in telegraph transmission, since the maximum rate at which information may be passed over a channel is inversely proportional to the duration of the shortest element of modulation. These facts have led to the use of the shortest element of modulation as the basis for the numerical expression of telegraph speed, which is defined as the inverse of the duration (expressed in seconds) of the shortest element of modulation. The unit of telegraph speed therefore corresponds to one minimum element per second and is called the "baud." This definition is readily applicable to Wheatstone, Baudot, and normal teleprinter systems, and can probably be made to apply to all telegraph systems, provided due care is taken in any particular case to determine the appropriate meaning of the phrase "shortest element of modulation."

**Telegraphic distortion.**

The process of reproducing the characteristic instants of modulation at the receiving end by means of some form of relay has been given the name "restitution of modulation," while the time interval between an instant of modulation and the corresponding instant of restitution is called the "restitution delay." As already stated, a telegraph circuit having a constant restitution delay is telegraphically distortionless, but in practice these delays may vary appreciably from one instant to another. With excessive deviation from constancy the correct interpretation of the received signals is either impossible or involves unduly meticulous adjustments. Numerically, the degree of distortion of the reproduced signals is expressed as the ratio of the differences observed between the restitution delays to the duration of the shortest modulation element. In practice it is usual to refer only to the greatest of these differences.

It will be seen that this definition refers to a complete telegraphic link which may be of utmost simplicity (e.g. a relay itself) or may be a complex system of transmission paths and apparatus. In either case it refers only to a particular set of conditions at the origin and the consequent conditions at the input and the output of each subsequent path or piece of apparatus comprising the system. As long as this is remembered, the definition has a useful practical meaning and is therefore becoming widely used. The C.C.I.T. has also given definitions for the distortion of a receiver and of a transmission path itself, but it is considered that these are less satisfactory in practical interpretation since the definition of distortion is such that it can only be applied to a complete telegraph link including specific modulating and demodulating components.

It has been found convenient to classify distortion as follows:

(i) **Characteristic.**—Distortion occurring consistently with any given series or combination of signal elements.

(ii) **Fortuitous.**—Distortion due to irregularities in any part of the circuit or apparatus.

(iii) **Bias.**—Distortion due to either the marking or the spacing elements of the signals being lengthened owing to asymmetry in the transmitting or receiving apparatus.

**Margin of receiving apparatus.**

The margin of a telegraph receiver is measured as the maximum distortion which may occur on any or all the signals which may be applied to it, compatible with perfect registration of all the symbols for which it is designed. Margin has been classified as follows: The "theoretical" margin is the margin calculated in accordance with the constructional data of the mechanism, assuming perfect conditions. The "effective" margin is the margin actually measured on the apparatus. The "nominal" margin is the minimum allowable value of the effective margin of machines in standard adjustment (Avis No. 302).*

Transmitted telegraph signals may be imperfect at their origin owing to transmitter distortion. This can be measured and given a numerical value as a ratio, in the same way as is done for telegraph distortion generally, by comparing the actual instants of modulation with those which would occur with perfect signals.

These definitions and terminology, together with the development of apparatus for measuring the quantities defined, have resulted from the desire on the part of engineers to put telegraph practice on a sound scientific basis. A large measure of success has been obtained, and apart from research and testing work the measurement of channel distortion and teleprinter margin is now a matter of routine in the maintenance of the inland telegraph service.†

(b) **Transmission Characteristics of Telegraph Systems as affected by Operating Requirements**

The rate of operation of a telegraph channel may be defined as the rate at which information is passed over the channel. This is usually expressed in words per minute, each word for this purpose being taken as consisting of five letters and one spacing signal. In ordinary telegraphy in which the letters, for the purpose of transmission, are represented by trains of impulses according to a predetermined code, the communication link has

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* See Bibliography. (6).
† The whole of the remarks and definitions in this section of the paper refer to the normal forms of telegraphy, making use of progressive codes. Where frequency, and not time, is the basis of discrimination, the following definitions are not necessarily applicable.
to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler the line requirements and the narrower the frequency consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler it is to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler it is to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler it is to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler it is to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler it is to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler it is to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler it is to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler it is to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler it is to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler it is to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler it is to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler it is to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler it is to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler it is to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler it is to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler it is to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler it is to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel. The lower the transmission speed the simpler it is to be designed to permit transmission at a speed consistent with the rate at which it is desired to operate the channel.

Table 1 illustrates the relative efficiencies of various systems of telegraphy from this point of view, for plain English.

At one end of the scale is cable code, a 3-position code developed for working on long transoceanic cables, and at the other picture telegraphy, whereby a facsimile reproduction of the original matter is obtainable. Intermediate is the Siemens–Hell writer, a form of picture telegraphy in which greater reliability is secured on radio links subject to disturbances, at the expense of a great increase in the baud speed.

It is of interest to note the connection between speed, accuracy, and the nature of the code used. Maximum speed is obtained when the number of combinations which it is possible to transmit is restricted to the normal alphabet. Thus with 5-unit systems the possible combinations are limited to 32. With the Siemens–Hell system the number of combinations which can be effectively drawn by the receiver must be many hundreds, but since use is only made of those having alphabetical significance the system must be somewhat wasteful of line time (or baud width). In the case of picture telegraphy the number of possible combinations that can be transmitted is practically infinite, and to use such a method for transmitting merely a limited number of alphabetical signs is essentially wasteful so far as line time (or baud width) is concerned. If, instead of speed, accuracy is considered, the order of merit of the above systems is reversed. Thus an incorrect element in the case of 5-unit code alters the printed character from one letter of the alphabet to another. In the case of the Siemens–Hell system a mere irregularity results which does not render the character illegible. In the case of picture telegraphy an incorrect element might well pass unnoticed.

Considerations of operating and engineering economics have led to the standardization of teleprinter working in the British inland service. A speed of 60 bauds has been fixed as standard by the C.C.I.T. for teleprinter communications (46) and this is equivalent to a maximum possible output of 71·6 words per minute for 7-unit working and 60·6 words per minute for 7½-unit working. Experience has shown that little is to be gained in the way of a sustained increase in operator output by an increase of the maximum output of the machine much above 60 words per minute. From the point of view of operator output, therefore, the teleprinter working at 60 bauds satisfies requirements, and although it is not quite so efficient in ratio of words per minute to bauds as some systems this disadvantage is outweighed by its relative simplicity and feature of direct instrument-to-instrument communication.

Although the economic use of line time is important, it is secondary to economic operating, and at present the tendency is to obtain operating economies by increased expenditure on plant. This tendency is likely to continue as technical developments become available for telegraphic application. The present interest in wide-band cables and television, for example, may lead ultimately to high-speed automatic facsimile methods being introduced in which, on heavily-loaded routes, the elimination of operating would more than repay the high cost of apparatus and the inefficient use of band width which such a method would entail.

(c) Transmission Characteristics of Telegraph Apparatus

The transmission characteristics of the telegraph apparatus itself, as distinct from those of the telegraph system, are related to the formation of the signals at the transmitter, their repetition at repeaters, and the translation of the signals into printed characters at the receiver.

Transmitters.

A telegraph transmitter in general consists of a mechanical means for producing the characteristic modulations of the telegraph transmission. An ideal transmitter would perform these modulations instantaneously and at the exact instants required by the code. The performance of a transmitter is measured by the degree to which it approaches this ideal.

In teleprinters the movements of the transmitting contacts are controlled by rotating cams. Such cams are cut to a high degree of precision, and the time displacement of any instant of modulation from its proper position, due to inaccuracies in the cams or co-acting parts, does not usually exceed 6 per cent of the shortest modulation element. Wear or maladjustment may, however, result in irregular distortion. The methods in use in the British Post Office for checking the performance of transmitters in respect of the foregoing points are dealt with later.

The timing of the modulations performed by a transmitter is also affected by the speed at which it is being driven. Variable speed will result in irregular distortion. All printing telegraph systems, however, include means for preventing or limiting cumulative distortion due to incorrect speed. In teleprinters the driving motor is governed to an accuracy of ± 0·5 per cent of a given speed, and, while normally the speed difference between machines is not greater than 1 per cent, satisfactory working is usually possible with appreciably greater
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The above does not detract from the practical utility of margin measurements of machines or of distortion measurements of circuits. These measurements in themselves ensure separately, correct adjustment of machines and circuits, and the present difficulty of exact correlation is, in practice, of only secondary importance.

Detailed examination of the margin characteristics of various types of telegraph apparatus have been made, and a number of references to this subject will be found in the Bibliography.

Regenerative repeaters.

Ordinary telegraph repeaters are well known and do not call for special comment. A regenerative repeater consists essentially of a telegraph receiver which, instead of using the translation to print a character, uses it to initiate a new transmission of the telegraph signal, devoid of distortion. A receiving perforator and automatic transmitter can therefore be used together as a regenerator. The aim in regenerative repeaters has been to reduce the translation and re-transmission operations to the utmost possible simplicity. A regenerator required to work on a teleprinter circuit will naturally operate on the start-stop principle, and broadly its transmission characteristics will be similar to those of a teleprinter receiver and transmitter. In one form of start-stop regenerative repeater, in which the translation of the received signals is performed electrically by arranging for the discrimination device to control the grid of a thermionic valve, an almost instantaneous discriminating period is possible, enabling the maximum amount of receiving margin to be obtained.

Errors of speed affect the margin and output distortion of start-stop regenerative repeaters in a similar manner to that described for teleprinters, but there is, however, one special case which requires mention. This occurs when the regenerative repeater is running slower than the sending transmitter. This causes the rest period between letters on the repeater to be shortened, so that the duration of the stop signal sent out is reduced. With 7-unit sending from an automatic transmitter, the stop signal is only one unit, and a reduction of its length due to speed difference might cause faults in the transmission, by reason of the greater distortion the shortened stop signal would suffer in transmission over the next repeater section. The shortest-length stop signal which the regenerator can send under the most unfavourable conditions is governed by the speed of rotation of the translator shaft. In teleprinters working on the 7-unit system the receiving shaft usually completes a revolution in 6-5 units. In the case of the regenerator mentioned, the time of a revolution is increased to 6-8 units, so that the shortest possible top signal is equal to 0-8 of a unit signal. With 6-8-unit reception the maximum permissible speed-difference is 3 per cent, allowing for 2 per cent on the teleprinter and 1 per cent on the regenerator. It has been suggested to arrange that the transmitter of the regenerator is automatically speeded up when receiving from a fast teleprinter, in order to prevent mutilation of the stop signal. This involves some complication of the repeater, and the difficulty can be entirely avoided.

* See Bibliography, (6).

Deception of the overall margin of the channel.

Incorrect speed will result in a reduction of margin, a speed error of 1 per cent being equivalent to a loss of margin of approximately 5-5 per cent on the fifth code element.

One of the new questions proposed in 1934 by the C.C.I.T. for study was the relation between the effective margin of a machine and the text distortion with which it will operate satisfactorily. In tests on voice-frequency multi-channel equipment it has invariably been found that a machine having a certain margin, measured by varying the instants of modulation with respect to the start signal, will operate without error on a circuit having the same figure of distortion, in spite of normal transmitter distortion and speed difference. This apparent discrepancy can, however, be shown to be due entirely to the differing conditions of testing and operating and to the general nature of the C.C.I.T. definition of distortion. The C.C.I.T. definition gives a measure of the efficiency of a telegraph circuit without specific reference to the instruments with which it is used, and therefore takes no account of the special conditions applying to the start signal of a teleprinter, which is preceded by a stop signal at least 14 units in length. The margin of the machine is measured by the maximum distortion on any element which will not cause a wrong selection, irrespective of the position of the element and the conditions of the preceding elements. It is frequently impossible, and, in any case, extremely unlikely, that the maximum distortion will occur on that element on which, under the same conditions, the permissible distortion is a minimum. On keyboard operation the limitations of the C.C.I.T. definition are even more apparent, and therefore measurements made in accordance with the definition result in a pessimistic estimate of the overall margin of the channel.

* See Bibliography, (4), (32), and (34).
by using 7½-unit transmission as is done in Great Britain. With this point in mind, the C.C.I.T. in 1934 recommended that the duration of the stop signal could be either 1 or 1·6 units (Avis No. 661).*

(3) APPLICATION OF VOICE-FREQUENCY METHODS TO SERVICE REQUIREMENTS

(a) Voice-Frequency System

Practically the whole of the inter-urban telegraph network has been converted from direct-current to alternating-current transmission using multi-channel voice-frequency equipment. Details of the voice-frequency apparatus used to build up this network have already been published,† and it is therefore proposed in this paper to give only the essential outlines of the system.

The 18 frequencies used are the odd multiples of 60 cycles from 420 to 2 460 cycles. These are generated by a multi-frequency machine, driven by a motor fitted with a centrifugal governor which regulates the field current and controls the speed to within ± 0·25 per cent. The output is permanently adjusted to 1 volt for each frequency, and ten 18-channel systems can be fed from one machine. The generators are provided in pairs, one working and one reserve, and in addition emergency reserve machines are held at the London and Glasgow centres.

A schematic circuit diagram is shown in Fig. 3. At the input to the sending filters are resistance coils by means of which the output to line may be adjusted. The outputs of the 18 single-section "send" filters are commomned to the apparatus side of the line transformer, the other winding of which is connected to the "go" side of the 4-wire cable circuit. At the receiving end, similar but double-section filters are commomned to the line transformer, the outputs of which are taken to the respective amplifier-rectifier panels via a potentiometer calibrated in decibels. The amplifier-rectifier is so designed that for all input levels above that required to cause grid current to flow in the rectifying valve the bias of the amplifier valve and its gain are automatically adjusted to compensate for variations in the level of the incoming signal. This characteristic is important as it ensures that the telegraphic distortion will not change with ordinary changes in line level, and even with big changes in level will not exceed workable limits. As a result of this method of providing automatic regulation it is preferable that the idle condition of the channels should correspond to the continuous transmission of tone and that the signals should consist merely of interruptions in this tone. This arrangement has the added advantage that the best running condition of the valves is obtained and also that an interruption to the 4-wire circuit is made immediately obvious by the racing of the teleprinters and by the continuous operation of the calling lamps and bells on the speaker channels.

(b) Line Conditions

The circuits normally used for multi-channel telegraphy are identical with zero-loss 4-wire telephone circuits except that the echo-suppressors and the 4-wire terminations are disconnected and the two sides of the circuit completely separated so that the same 18 frequencies can be used in both send and receive sides. The line levels for working on zero circuits are shown in

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* See Bibliography, (6).
† Ibid., (9), (16), and (17).
Fig. 4. The particular line arrangements shown are not essential, as 4-wire circuits with an overall attenuation up to 15 db can be operated; for example, in the case of the London-Brighton systems non-repeatered circuits of 6-5 db are used. The advantage of using zero trunk telephone circuits lies in the ease with which replacements can be made in the event of interruption of the working circuit. The organization is such that the average time taken for the change is 8 minutes.

(c) Power Supplies

The supplies necessary for voice-frequency equipment, apart from all-mains sets, are the usual 24-volt and 130-volt repeater-station supplies for filaments and anodes respectively, and in addition a ± 80-volt telegraph supply. The 24-volt supply for the multi-frequency generator motor may be separately fed from a motor-generator set or from rectifiers, but the common field of the stator of the generator must be fed from the filament battery. The 80-volt telegraph supply can be taken from existing telegraph batteries when conveniently situated, or, as is more generally the case, from a motor-generator set with the two 80-volt generators and motor on the one shaft.

It should be mentioned that a great deal of progress has been made towards the standardization of ± 80 volts for all telegraph purposes and the elimination of ± 24, ± 40, and ± 120 volts, which were employed for local- and main-line batteries under the former d.c. conditions.

(d) Maintenance

The maintenance of the voice-frequency network is carried out by normal repeater-station staff, who, it has been found, soon become familiar with the apparatus. Channels are tested at present at 3-weekly intervals, one channel per system being tested each day to ensure a daily watch on the level of the 4-wire circuits. Engineering speaker circuits (teleprinter) are provided between important centres to ensure close co-operation in testing.

In the case of the public telegraph circuits, channels are only handed over by the commercial staff for engineering attention after it has been proved as far as is possible by teleprinter tests that it is the channel itself and not a terminal teleprinter that is at fault. The present average duration of interruptions of commercial circuits due to causes attributed in any way to the voice-frequency system is between 4 and 5 minutes per week per channel. In the case of private-wire renters, the renters report faults by telephone directly to the voice-frequency terminal.

A relay test table is provided at all centres, and also in all but the smallest centres a test bay is included which embodies line and filter testing panels as well as a telegraph distortion measuring set.

In Fig. 5 the installation progress of the voice-frequency network is shown from June, 1932, when only one system between London and Dundee existed, to the present time. Several further systems extending to Scotland and Belfast were installed from time to time, and at the beginning of May, 1933, the conversion of the whole of the northern
telegraph system was commenced. This conversion was carried out in 13 months, and has been supplemented steadily since then to meet private-wire and increased traffic requirements and to provide uniformity in the method of working to the smaller towns. Fig. 5 shows also the improvement obtained in apparatus-fault liability and in maintenance labour costs.

In making the preliminary financial examination of the scheme for the complete transfer of the telegraph system to voice-frequency working the estimated engineering maintenance labour costs per channel were cut, as it was thought, to the bare minimum, and it is all the more gratifying, therefore, to find that these costs have now fallen 20 per cent below the estimated figures and 40 per cent below the costs for January, 1934.

Further reduction is anticipated as the staff become still more familiar with the system, and experience enables improvements to be made in methods and in apparatus.

(e) Commercial Facilities

As far as possible the voice-frequency telegraph network has been built up to enable teleprinter circuits to be made up readily for any of the public or private wire services without regard to the position of, or distance between, the terminal towns. One of the outstanding advantages of a standardized voice-frequency network is that all channels are identical and can be connected together without previous preparation to provide any desired routing. The direct-current ends of the channels are all terminated on the control boards in the telegraph instrument rooms for this purpose. On the major routes a speaker channel is provided for communicating between the supervising staffs at the more important instrument rooms to facilitate testing and "special event" work. The ease with which the large amount of special-event work can be carried out on the new system is remarkable. Some of these temporary arrangements are very extensive; for example, Fig. 6 gives the circuits required for the Doncaster Race Meeting. The arrangements frequently include "omnibus" circuits by which, for example, messages transmitted from one teleprinter are received simultaneously on teleprinters situated at Leeds, London, Manchester, and Glasgow. In such cases "combiner units" are plugged into circuit at the appropriate control boards. These units operate on the principle shown in Fig. 7, and have proved a very successful solution of the omnibus-circuit problem. The four operating windings of this unit are connected to the "receive" sides of the channels forming the omnibus circuit, and signals in
any one of these channels result in their retransmission from the contact of the unit over all the " send " sides of the channels in parallel. In order to maintain overall neutrality of the relay when less than four circuits are required it is arranged that the equivalent current for each unused winding is obtained from the inner springs of the jacks used for making up the circuit.

Complete facilities are provided by means of transfer circuits between the control boards and the concentrator for connecting any voice-frequency channel to any teleprinter position in the instrument room, or alternatively to any physical line circuit via appropriate panel-mounted relay or balancing equipment.

Adjacent to the control board, test and observation positions are provided, and also synchroscopes for checking the speed of either the local or the distant teleprinter motors. The test and observation positions consist of small steel-frame tables carrying a teleprinter and a panel fitted with milliammeters and keys. The tables are wired to test jacks on the voice-frequency control board and can be connected with plugs and cords to any channel without interrupting the service on that channel. According to the position of the keys the signals passing on either the send or the receive sides of the channel can be observed, or the circuits can be terminated at the test position and operated to the near or to the distant teleprinter.

It will be seen from the foregoing that through circuits are provided by the coupling of channels at the voice-frequency control boards, which, in effect, connect the send and receive relays of the channel on one route to the receive and send relays respectively of the channel on a second route. Theoretically it would be possible to design a network in which all coupling of channels could be carried out by means of filters. Such a scheme would have the advantage that relays would be unnecessary at the intermediate stations but would, in the case of an intricate network, such as that of the British Isles, lead to very complicated and non-flexible filtering arrangements. Under cable-breakdown conditions it is a tremendous advantage to be able to couple channels from one system to another, irrespective of their frequencies. The balance of advantage would probably, however, be with the filtering method in certain simple cases, such as, for example, on a very long and important international circuit in which end-to-end channels between capitals were required in addition to channels from these ends to an intermediate capital. Such channels might be required to form parts of still longer circuits, and the small constant distortion introduced by the filters might well be preferable to the additional relays that would be in circuit and under third-party maintenance if separate systems with relay coupling were adopted.

![Circuit diagram of combiner unit connected to three voice-frequency channels and one extension.](image)

(f) Effect of Linking Channels on the Overall Distortion of a Telegraph Circuit

This problem has received a considerable amount of attention during the past few years. The C.C.I.T. has had to consider the question in regard to international circuits, and of course the question is one of first importance in the consideration of switched telegraph systems.

The C.C.I.T. has laid down (Annex No. 331)* that the total distortion of a telegraph circuit must not exceed 28 per cent and that the distortion of each link in the circuit should not exceed 10 per cent when measured as a separate circuit. The study of the subject is being continued, but so far the theoretical examination is not of material value compared with the knowledge and experience which have been gained in the field.

In Great Britain the interest in the question relates chiefly to the linking of channels of the voice-frequency network. Much information has been acquired on this

* See Bibliography, (6).
particular aspect of the subject, but it must be remem-
bered that the results apply only to the particular design
of system which has been standardized in this country
and not to voice-frequency systems generally. If on this
system the overall distortion of a considerable number of
circuits consisting of one, two, three, etc., channels
linked together be measured and an average taken for
each number of links, these average figures will be
approximately additive. If, on the other hand, single
more than 25 per cent on any of the following signals:
reversals, half-speed reversals, signals in the ratio of
1 to 5, and "Paris" in morse; the last two tests being
repeated with the transmitting battery reversed. In
practice the "Paris" and "Paris" inverted signals are
found to be the best criterion of the channel from the
point of view of teleprinter working, and as experience
has shown that the 4-wire circuit level variations never
approach the acceptance test figures it will be seen that
examples are taken so that the separate distortions of
a number of particular channels are first measured
and then the overall distortion of them all linked, it will
be found that the result will seldom agree with the
arithmetic sum of the separate distortions.
This apparent discrepancy in the case of particular
channels is of importance only in relation to the design
and adjustment of systems. Design and adjustment
having once been standardized, it is the number that can
safely or economically be linked together at random that
is important.
The acceptance tests of the equipment demand that
the maximum distortion at 66 bauds and with a ± 7.5-db
variation in the level of the 4-wire circuit shall not be
these tests are essentially tests to prove and maintain
the quality of new installations and have to be inter-
preted to gauge the performance of the equipment under
practical conditions. It has been found that equipments
conforming to the acceptance tests invariably give a
satisfactory practical performance and are consistent
one with another.
The approximate additive nature of average overall
distortion on linked channels is shown in Figs. 8 to 11
for speeds of 30, 50, 66, and 80 bauds, respectively.
The height of the pillars in these diagrams represents the
number of separate tests made of the overall distortion,
using the word "Paris" as the test text. The channels
tested were taken at random over a long period by

various observers from many different 12- and 18-channel systems under normal working conditions of line and apparatus.

In practice, 100 words per minute Wheatstone is regarded as the maximum commercial speed for a single-channel circuit. This figure allows a margin for contingencies and is reduced to 90 words per minute for two linked channels. Many such circuits are operated by private companies and are giving satisfactory service at these speeds, the performance being in agreement with the distortion test results of Fig. 11 (80 bauds).

In order to determine the limits of channel linking for teleprinter working with normal conditions of channels and of teleprinters much experience and exhaustive tests are necessary. Brief tests made under good conditions may give extraordinary results such as good "songs" with 12 or more links, but exhaustive tests with all combinations of signals, fast keyboard operation, and allowable teleprinter-motor speed-differences, indicate that such results are not consistent enough to commercial.

It has been found by both engineering and traffic tests that, taking channels at random and machines at random, seven channels may invariably be linked and produce satisfactory results. Even so, there are other considerations which must be taken into account in providing circuits with an appreciable number of linked channels. The network of the British Isles is almost completely triangulated, i.e., under cable-breakdown or other emergency conditions, for example, London-Leeds circuits can be provided via Edinburgh or Birmingham or Manchester, etc., by coupling the direct-current extensions from the channels at the voice-frequency control boards in the instrument rooms. Margin must, therefore, be left on all circuits to allow for the extra channels involved in such re-routing. Again, there must be a direct connection between the margin of circuits and the maintenance required by machines, and, although this aspect is becoming less important as the improved testing facilities for speed and margin of teleprinters are introduced, it still requires consideration.

There is also the question of economy; a multi-link circuit costs in respect of interest and depreciation of capital and maintenance of terminal apparatus an amount which is proportional to the number of links, and with flat-rate traffic charges this is clearly an important consideration.

Further multi-link circuits become cumbersome to handle and must unavoidably suffer stoppages in proportion to the number of links thus suffering, in comparison with 1- or 2-link circuits. It is well known also how the delay in rectifying any trouble seems to increase in much more than simple proportion to the number of people concerned in that trouble.

In the present network the majority of circuits are single-channel circuits, but there are a large number of 2-channel circuits and a few made up of three channels giving perfectly satisfactory service. There would be no objections in particular cases to using four links, but the general objections to such a number becoming common are those just mentioned. It must be pointed out, however, that different standards would exist in...
the case of international circuits, where a flat message-charge rate would not apply. In this case suitable maintenance could be justified economically to ensure that good commercial circuits without regeneration could be made up of five or six links, and also the apparatus costs would be relatively unimportant.

(g) Effect of Line Length on Distortion in a Multi-channel System

Tests have been made to examine the effect of the attenuation, phase, and non-linear distortion in long telephone lines on the telegraph distortion of a multi-channel system. The diagram in Fig. 12 and the results averaged in Table 2 show the telegraph distortion measured on a system working over distances of 0 to 1100 miles; the last case involving 24 repeaters. It will be seen that in practice the effect of the number of repeaters and length of line is negligible.

(b) Valve Receiving Relays and Static Modulators

In the multi-channel equipment the amplifier-rectifier operates a telegraph-type relay which is associated with the voice-frequency equipment and works the telegraph receiving apparatus over d.c. extensions.

Consideration has been given from time to time to the possibility of replacing the receiving relays by valve relays. While, however, suitable valve relays for particular purposes have been developed* and give complete satisfaction for those purposes, a satisfactory economic general alternative to the electromagnetic relay is not available. Apart from 3-monthly routine cleaning and adjustment, receiving relays only require attention on an average once in 40 weeks, and it is doubtful whether a valve relay panel fulfilling the requirements would require less maintenance. The introduction of copper-palladium for contacts instead of platinum-iridium resulted in a large decrease in receiving-relay maintenance owing to the elimination of the tendency of platinum to weld and build up points on the contact surface. The introduction of series resistance into the leads to the teleprinter also gave a marked improvement from this point of view, by limiting the discharge of the condensers associated with the teleprinter electromagnet and the normal shunted condenser.

Contrary to the case of receiving relays, it has been definitely established that platinum or platinum-iridium contacts are much superior to copper-palladium for voice-frequency transmitting relays. In this case the contacts are called on to short-circuit the voice-frequency current at a point where the potential is a small fraction of a volt. Trouble which is well known to be associated with such conditions shows itself occasionally, particularly on high-speed circuits, where the incomplete

Fig. 12.—Effect of 4-wire circuit length on distortion at 30, 50, 66, and 80 bauds. Nine channels tested in each case, with "Paris" and "Paris" inverted.

Table 2

<table>
<thead>
<tr>
<th>Speed (bauds)</th>
<th>Length of circuit (miles)</th>
<th>0</th>
<th>200</th>
<th>900</th>
<th>1100</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>3.5</td>
<td>3.1</td>
<td>4.3</td>
<td>4.1</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>5.1</td>
<td>5.8</td>
<td>7.2</td>
<td>4.7</td>
<td></td>
</tr>
<tr>
<td>66</td>
<td>8.9</td>
<td>7.8</td>
<td>6.6</td>
<td>10.0</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>10.2</td>
<td>8.4</td>
<td>12.0</td>
<td>9.9</td>
<td></td>
</tr>
</tbody>
</table>

1100 miles; the last case involving 24 repeaters. It will be seen that in practice the effect of the number of repeaters and length of line is negligible.

* The average distortion (per cent) of 9 channels is given in each case.
suppression of the carrier in the spacing elements, due to high contact resistance, is liable to cause biased signals. The principle of using a non-linear conductor as a variable a.c. impedance by polarizing it with direct current, has of recent years received considerable attention owing to the availability of small copper-oxide rectifiers, which make almost ideal elements for the purpose. Various ingenious circuit arrangements have been devised in connection with telephone transmission, and in voice-frequency telegraphy similar principles can be used to modulate the outgoing voice-frequency currents instead of using electromagnetic relays. Such modulations, when controlled by square d.c. signals, produce an instantaneous change in the amplitude of the carrier, but, by arranging that the a.c. output is proportional to the d.c. input, the modulator in conjunction with a low-pass filter can be made to replace the sending relay and the associated band-pass sending filter in a multi-channel system. Sending filters are eliminated by this means in some systems in use on the Continent and also in the London–Leafield radio keying system, designed by the Post Office for keying radio transmitters at Leafield over landlines from London. This system, which also incorporates valve trigger relays at the receiving end, has proved advantageous and reliable since its installation in 1933. On the multi-channel voice-frequency network, experience has proved that static modulators are preferable in every way to electromagnetic transmitting relays, and increased stability and decreased maintenance costs have resulted from their use. The question of elimination of the sending filters is of less importance, as the saving involved is solely in first cost and is offset by the increased dependence on adjustment of the current conditions on the incoming physical extensions.

In the voice-frequency network, static modulators are being increasingly used, the particular arrangement being shown in Fig. 13. This type has been designed to be interchangeable, both mechanically and electrically, with the ordinary electromagnetic relay, so that it can be introduced on channels of existing equipment as and when convenient. Apart from the increased stability provided, these modulators give distortion figures which are slightly better with normal or high line levels, and considerably better with low line levels, than those obtained using good relays. This is due to the effect of the transit time of the transmitting contacts and to the effect of the quench condensers not being the same in the two cases, and the consequent effects on the biasing circuits of the receiving equipment. The spacing level of the tone sent out is about 34 db below the marking level, a figure obtained by using a very high-quality transformer. The controlling current required may be from 4 mA or less up to 20 mA, which is the maximum figure obtainable on the shortest extension.

In practice an important advantage of static modulation is that in addition to the elimination of send-relay faults (which preponderate in the ratio of 2 or 3 to 1 as compared with receiving-relay faults) no time is lost, when fault-localizing is being carried out, in deciding at which of the two ends of the circuit the relay requires adjustment.

(j) Four-channel Duplex System for Minor Routes

A 4-channel duplex system for extending the voice-frequency network to minor routes which may not justify the provision of a 12- or 18-channel system has been introduced. This equipment operates on repeatered or non-repeatered 2-wire circuits having an attenuation up to 18 db. Each channel transmits to line at 100 microwatts. The frequency-spacing is 240 cycles, the actual frequencies being 420, 660, 900, and 1,140 cycles per sec. in the one direction and 1,880, 1,620, 1,680, and 2,100 cycles per sec. in the other. The increased spacing allows a filter similar to the sending filters of the main-line equipment to be used for both sending and receiving. The equipments are made for either battery or all-mains supply, and the performance of the channels is identical with that of the main-line equipment.

(k) Super-audio (Supra-acoustic) Systems

The a.c. telegraph systems previously described operate on carrier frequencies lower than about 2,600 cycles per sec. and use the telephone channel to the exclusion of other services. There are in existence, however, telephone channels having a pass range extending above the highest frequency necessary for the commercial transmission of speech (2,400 cycles per sec.), which can accommodate one or more telephone channels, known as super-audio channels, in the unused portion of the range. Examples of this type of circuit are the extra light-loaded circuits (44 mH at 1,136 miles), having a cut-off frequency of 5,500 cycles per sec. and a useful pass range up to 4,300 cycles per sec., which were designed primarily for high transmission velocity, and unloaded or continuously loaded submarine cables, not equipped with carrier telephone apparatus. The extra light-loaded circuits referred to are unsuitable for music transmission or carrier telephone working, but can easily accommodate one or more carrier telegraph channels. It is immaterial whether the range below 3,000 cycles is used for speech or for multi-channel telegraphs.
There are two principal methods of providing super-
audio telegraph channels:—

(i) That in which the carrier frequencies are modulated
by the telegraph transmitter in the same manner as
is employed in the lower-frequency channels.*

In this case the carrier frequencies are generated by
means of oscillators, and the operation is in principle
the same as in voice-frequency systems. It is usual to
employ a greater frequency-spacing between adjacent
channels, chiefly because of the greater percentage
accuracy required in the separating filters. In addition
to the usual sending and receiving filters required where
more than one super-audio channel is provided, master
filters separating the audio telephone channel and the
super-audio telegraph channels must also be installed.

An example of this type of super-audio system is to
be found submarine cable, on which a teleprinter circuit has been operating on this basis
since December, 1933. The installation of a second
circuit is in hand, and ultimately six or more duplex
channels are envisaged.

(ii) That in which the principle of double modulation
is employed.†

The principle of double modulation is well known in
carrier telephony and it can be applied also to tele-
graphy.‡ In practice this is carried out by employing
a carrier telephone channel to carry the modulated
carriers of a voice-frequency multi-channel system.
Only one side-band, the lower, is transmitted, and thus
the high-frequency channels of the voice-frequency
system become the low-frequency channels of the super-
audio system. The standard carrier frequency for
carrier telephony in this country is 6 000 cycles per
sec., and therefore the frequencies of the super-audio
channels become 3 540 cycles, 3 660 cycles, etc. It
will be noticed that the principle of employing the
odd multiples of 60 cycles per sec. as carrier frequencies
is preserved.

There are obvious advantages in this method of
working. The same type of terminal equipment is
employed on both audio-frequency and carrier circuits,
and setting-up and maintenance does not differ from
normal practice. Further, the channel frequencies can
be obtained from the existing multi-frequency generators,
and difficulties in the design of filters for high frequencies
are avoided. This method necessitates, however, a high
degree of equality between the frequencies of the oscil-
lators in the modulating and demodulating equipment.
This is obtainable by means of temperature-compensated
coils or by thermostatic control. An experimental
8-channel system has been installed on this basis between
London and Newcastle. If experience with this system
is satisfactory it is probable that considerable use will
be made of it for the economic provision of channels for
all purposes.

In both systems of super-audio operation it is assumed
that the telephone repeaters en route will deal with both
speech and telegraphs, and to minimize the effects of
cross modulation it is essential that the peaks of speech
be limited to prevent overloading. Special monitoring
arrangements at the repeater stations may also be neces-
sary to prevent interference with the telegraph channels.

* See Bibliography, (24), (25), and (26).
† Ibid., (33).
‡ See Bibliography, (9).

(4) TECHNICAL CONSIDERATIONS RELATING TO
ALTERNATING-CURRENT TRANSMISSION

(a) Line Characteristics

Normally, a.c. or carrier telegraphy consists of modu-
lating a carrier wave in accordance with the movements
of a telegraph transmitter, the whole or part of the
available frequency-band width of normal telephone
circuits being used for the transmission path. The
sources of distortion in an a.c. transmission line are well
known, but the most important affecting carrier tele-
graphy are given below.

(i) Restriction of transmission frequency band.

The effect of restricting the transmission frequency
band is to delay the rise in the amplitude of the carrier,

and the building-up time from the first appearance of
the signal to the steady-state amplitude is equal to
(\frac{1}{2} f_2 - f_1), where \(f_2\) and \(f_1\) are respectively the higher
and lower cut-off frequencies.* In the practical case
this is only approximately true, as it is impossible either
to define the actual cut-off frequencies or to determine
exactly the building-up period. Nevertheless, the
simple formula will enable apparatus to be designed
according to the telegraph speed required of the channel,
provided due allowance is made for the imperfections
of filtering equipment. Thus Figs. 14 and 15 respectively
show the attenuation/frequency curve of a typical voice-
frequency channel and the envelope of the voice-frequency
signal. The calculated cut-off frequencies differ by
120 cycles per sec., but the available bandwidth will be
seen to be roughly 70 cycles, which agrees fairly closely
with the measured building-up time (14 milliseconds) of
the carrier, as shown in the oscillogram.

It is evident that, with simple means of rectification,
the maximum speed of a channel without appreciable telegraph distortion is equal in bauds to the available frequency-band width of the channel. It is also evident that in a.c. telegraphy the frequency band width required for a given telegraph speed is twice that required in d.c. telegraphy, where the carrier frequency may be regarded as zero and the upper and lower side-bands coincident.

(ii) Phase distortion.

The general effects of phase distortion in delaying the building-up of an a.c. signal are well known. The influence of phase distortion on telegraphic distortion depends very largely on the action of the detector in the subsequent restoration of the d.c. character of the signal, but, in any case, the effects of delay in the build-up of the signal are the same whether it is produced by phase distortion or by restriction of the transmission band. More information on this point is given later in the paper when the action of the receiver is discussed.

The electrical networks commonly employed in telephone transmission lines for phase correction are necessary on telegraph circuits only where transmission of a broad frequency band is required, such as in picture transmission. In the more usual type of telegraph transmission, the difference in delay time over the essential transmission band renders the use of special phase-correctors unnecessary provided the band is suitably restricted by means of filters. In multi-channel systems the filters must be provided to separate the channels; and in single-channel systems, although sending and receiving filters are not strictly required, they may be inserted where excessive phase distortion is present. The building-up time of a signal is then dependent on the width of the transmission band, and the effect of phase distortion is negligible except where the rate of change of the phase constant with respect to frequency is changing very rapidly.*

(iii) Non-uniformity of attenuation over the transmission band.

The effect of non-uniformity of attenuation over the transmission band is similar to that of phase distortion second and third harmonics of the carrier frequency, is also present in telephone lines. With the normal type of equipment, effects due to this cause are inappreciable, although it might be anticipated that in the multi-channel case production of third harmonics of (say) the first channel carrier (420 cycles per sec.) would interfere with the operation of the eighth channel (1260 cycles per sec.). The production of even harmonics due to non-linearity of valve characteristics is undoubtedly more serious, but as the carrier frequencies have been selected so that the resulting harmonics fall midway between channels, their effect is greatly reduced.

(b) Effect of Variations in Receiving Level

Alternating-current transmission, utilizing one carrier per channel, is equivalent to a single-current system, and the receiving relay requires a bias—either electrical or mechanical—to return the armature on the cessation of the signal; and as the restoring force is fixed, once the channel has been set up, variations in the level of the received signal produce bias distortion. It is essential, therefore, that means of overcoming the effect of variations in attenuation should be introduced; and it will be found that differences in the various designs of a.c.

* See Bibliography, (8).
telegraph receivers are largely due to the differences in the manner in which this problem is tackled. As in the case of single-current d.c. telegraphy, the importance of maintaining a definite signal amplitude is dependent on the shape of the signal envelope. That is, where the signal envelope is rectangular in form, the distortion introduced by a given change of amplitude is considerably less than where the wave-form rises slowly. It is necessary, in the former case, that the signal amplitude should be considerably more than the minimum operating current of the receiving relay, and also that the change of flux in the relay core should be similar in form to the change of potential of the received signal. The latter is very rarely the case, owing to the impedance of the relay being variable with frequency and also owing to the production of eddy currents in the relay core which delay the change of effective flux. Further, in the case of carrier telegraphy, it is necessary to smooth the demodulated signal by means of a low-pass filter, which delays the rise of current in the relay winding and therefore the change of flux in the relay.

In the majority of modern telegraph systems the speed of working in relation to the available frequency band is such that the a.c. signal reaches the steady-state condition immediately prior to the cessation of the signal, and the effect of variation in the signal level is evidently serious. The magnitude of the variation to be expected in the level of the received signal depends on the system to be employed. Multi-channel systems which are set up permanently on a particular circuit are designed to operate over a maximum range of 15 db, whereas the equipment employed on the telex service must deal with signals varying in level by at least 30 db. The effect of line-attenuation changes depends on the speed of transmission and the building-up period of the signal envelope. Thus, with building-up and dying-away periods of 14 milliseconds and a transmission speed of 50 bauds, the maximum distortion for 15-db change of level, if simple forms of rectifier and relay receivers are employed, is about 35 per cent.

(c) Design of A.C. Telegraph Receivers

To compensate for the effects of long building-up and dying-away periods and variations in the level of the received signal, all a.c. telegraph receivers employ some form of limiter. The commonest type of limiter depends for its operation on the change of grid-cathode impedance of a thermionic valve when the potential of the grid reaches the point where grid-cathode current commences to flow, and also on the rectifying property of the grid-cathode circuit. In its simplest form the grid limiter is shown in Fig. 16. The normal relative potentials of the grid and cathode depend on whether the valve is being used as a rectifier or an amplifier, but the limiting property is not affected by this. A signal of large amplitude applied to a receiver of this type operates the receiving relay at the beginning of the building-up period of the envelope; and, when the peak amplitude exceeds the normal grid bias, grid-cathode current flows and charges the grid condenser. Thereafter, only the peaks of the half-waves produce grid current and only the top part of the signal produces anode current. If the time-constant of the condenser and resistance is great compared with the time between successive half-waves, the effective portion of the signal is at the top of the envelope, and, if the amplitude of the signal is reduced, the signal in the anode circuit ceases as soon as the amplitude of the a.c. signal on the grid falls below the additional grid bias built up on the grid condenser.

As the operating point on the cessation of tone is dependent upon the biasing voltage produced by the flow of grid current, it is possible to control the position of this point by controlling the biasing voltage developed. Where the sending impedance is of the same order as the grid-cathode impedance, the grid condenser is quickly charged, and therefore the biasing voltage approximates to the peak voltage of the applied signal; and conversely if the sending impedance is high the condenser is charged to only a small fraction of the signal peak-voltage. Thus the operating point of the relay can be controlled by adjustment of the sending impedance, and this is most conveniently done by including in the grid circuit a resistance not shunted by the condenser, as shown in Fig. 17. During the quiescent period between signals the condenser discharges through the shunting resistance, and therefore the time-constant of the circuit influences the relay operating point on the envelope of the next signal.
received. Thus, if the time-constant is high compared with the length of the quiescent period, the third operation occurs at approximately the same amplitude as the second; and if the time-constant is low, the third operation occurs at the same amplitude as the first. The relay-operating points of the envelope can therefore be controlled by adjustment of the values of the components in the grid circuit, the optimum values being dependent upon the conditions of working of the system.

Where it is possible to arrange for tone to be transmitted in the idle periods, the longest period of no tone is equivalent to 8 elements, and a receiver having a large time-constant gives the best operating conditions. In this case, all operating points occur at approximately the same amplitude, which may be arranged to be equal to half the peak amplitude. If all operations occur at half the peak amplitude, there can be no telegraph distortion, but in practice this is not possible because the additional bias built up by the signal must fall slightly during the no-tone periods and also because the building-up of the charge is not instantaneous. It is possible, however, to reduce the 35 per cent distortion, previously mentioned, to about 12 per cent.

In cases where it is not possible to transmit tone in the idle condition, the M-to-S (mark to space) operating point after a period of rest is always at the beginning of the building-up period of the signal. The best S-to-M operating point is therefore at the beginning of the dying-away period, and, with a hang-over time shorter than the shortest tone-off period, the next M-to-S operation would be at the beginning of the next build-up. No telegraph distortion would be introduced, but in practice it is found that the time-constant cannot be reduced to the required value because the rate of die-away of the condenser voltage must be less than that of the signal, and therefore there is some distortion of the second and subsequent M-to-S operations. This can be reduced by arranging that S-to-M operations occur later in the die-away, in which case the total distortion is divided between the M-to-S and S-to-M operations. The maximum distortion is reduced in this way, but it is evident that in the extreme case, where the first M-to-S operation occurs at the commencement of the building-up period and all subsequent operations occur at half the peak amplitude, the maximum distortion measured as a time-interval approaches half the build-up time of the signal envelope. This arrangement is employed in the equipment used in the Post Office telex system. It is interesting to note that when component values are adjusted so that all operating points after the first occur at half the peak amplitude, the average current in the anode circuit is constant over a wide range of signal level, and this fact may be used as an indication that the required conditions have been obtained. In this particular equipment, the extra resistance in the grid circuit is unnecessary owing to the high step-up ratio of the input transformer. In order to utilize the mid-portion of the signal envelope the effective grid bias should obviously be equal to half the peak voltage of the signal plus half the effective grid swing, and that portion of the grid bias due to the charge on the condenser should be equal to half the peak voltage minus half the effective grid swing. The curves given in

Fig. 18 therefore show the average direct current in the anode circuit, the actual voltage produced across the grid condenser, and the calculated half peak voltage. It will be seen that there is very close agreement between the calculated and measured voltages.

In the multi-channel system used in this country the correction is made partly in the rectifying valve and partly in a preceding valve amplifier. In this system the flow of grid current in the rectifier and the consequent charge on the grid condenser, bias both the rectifier and the amplifier. The result is that the rise of current in the rectifier anode circuit is delayed owing to the reduced amplifier gain, and it is arranged that the anode current in the rectifying valve reaches a predetermined value, at which the receiving relay operates, when the signal applied to the amplifier reaches half the peak amplitude. The return operation of the relay takes place at approximately the same point of the envelope.

(i) Effect of half-wave rectification on receiver distortion.

The receiving circuits described employ half-wave rectification, and the phase of the carrier at the instant of modulation has some influence on the time-interval between the operations of the transmitting and receiving relays.

In the worst case, where the length of the signal is equal to an odd multiple of one half-cycle, the effective length of the rectified but unsmoothed signal may vary by the length of one complete cycle, and therefore the maximum possible distortion in milliseconds is equal to 1 000/ff, where f is the carrier frequency.

In practice, the low-pass filter, which retards the change of current in the receiving-relay winding, and the bias-current adjustment, modify this result. The maximum difference of the time-intervals between the operations of the transmitting and receiving relays is equal to one half-cycle, at both the beginning and the end of a signal; but, by adjustment of the bias current, the mean interval between the operation of the transmitting relay and the corresponding operation of the receiving relay, for the commencement of a signal, is
made equal to that for the end of a signal. The maximum difference of time-interval corresponding to the two operations is then equal to one half-cycle, i.e. 1000/N milliseconds, and the distortion is equal to 100N/2 milliseconds, where N = telegraph speed in bauds.

With full-wave rectification, which has been employed in experimental receivers constructed in the Research Laboratories of the British Post Office, the distortion is reduced to one-sixth of a complete cycle, i.e. 1000/(6N) milliseconds.

(ii) Direct operation of machine telegraph receivers from thermionic valves.

Where direct operation of machine telegraph receivers is required, further amplification of the limited signal will usually be necessary and this may be provided in a variety of ways.

First, further valves are employed as amplifier of the d.c. component or as rectifier and amplifier of the a.c. component, with the operating winding of the receiving magnet in the anode circuit. Some types of voice-frequency equipment for telex operate on this principle.

Second, the limiting valve is followed by dry metal rectifiers, and further valves are employed as a d.c. amplifier.

Third, the limiting valve operates as a rectifier, and the transients obtained on build-up and die-away are amplified by means of a push-pull amplifier and operate the receiving magnet on a double-current basis. This is the system employed at present on the voice-frequency equipment for telex in this country.

(iii) Operation of sensitive relays.

The usual method of operating relays in carrier-current telegraphy is directly in series with the anode of the limiting valve.

As the carrier operation is effectively single-current, the receiving relay requires either mechanical (spring) or electrical bias to restore the armature on the cessation of the operating current. Owing to the high impedance of the relay winding at carrier frequencies a path for the a.c. component is required, and this usually takes the form of a condenser connected directly across the relay winding.

There is some slight advantage in using the anode supply for the bias current, as variations in the anode voltage produce similar variations in the operating and biasing circuits, and therefore tend to compensate one another. The compensation is, however, not completely effective.

Another method of operating the relay is in a bridge circuit, in which the valve forms one arm of the bridge. A bias winding is, of course, unnecessary and a form of double-current operation is produced. It is well to remember, however, that the operation is, in effect, single-current, with electrical bias, and it possesses no particular advantage over the simple method discussed above.

(d) Transmission Problems peculiar to Telex Services

A diagram of the subscribers' apparatus used for the telex system is shown in Fig. 19. The transmitter consists of a single-valve oscillator and the receiver of a rectifying valve which combines the functions of rectifier, limiter, and echo-suppressor, followed by a push-pull amplifier, which amplifies the transients obtained on the growth and die-away of the rectified voice-frequency signal sufficiently to operate the teleprinter without intermediate relays. The echo-suppressing feature is required to cater for short trunk circuits not equipped with the telephone-type echo-suppressors; and is obtained by increasing the time-constant of the grid resistance and condenser to cover that period wherein an echo may be received.

The effect of hang-over time in the grid resistance and condenser on distortion has been discussed previously, and in this particular case the resulting distortion may amount to half the building-up time of the signal. No filters are included in the equipment, and thus the delay in the building-up of the signal is due only to phase distortion in the circuit. The resulting telegraph distortion on the longest lines in this country is about 13 per cent and, as the carrier frequency is low (300 cycles per sec.), the repeaters and line transformers account for practically the whole of this.

For international working, the carrier frequency of 300 cycles per sec. is considered to be too near the cut-off of many foreign circuits for satisfactory transmission; and, because phase distortion at low frequencies, being dependent on the number of repeaters, would become serious on long circuits, the question of using a higher frequency was examined. A frequency of 1,500 cycles per sec. has now been internationally agreed upon, and this frequency will also be used for the inland service.

The choice of a frequency higher than 300 cycles per sec. is restricted on account of the use of the band between 500 and 1,000 for signalling on the telephone circuit, together with the greater cross-talk at the higher frequencies. At frequencies between 1,000 and 1,200 cycles per sec. the degrading effect on articulation is particularly bad, owing to the sensitivity of telephone...
receivers at those frequencies. At 1 500 cycles per sec., however, it has been found that the sending level can be maintained at such a point that main-line repeaters can be fully loaded without causing an appreciable loss of articulation in an adjacent telephone circuit.

The operation of voice-frequency telegraphy on ordinary telephone lines with intercommunication facilities introduces special additional problems not experienced on point-to-point services. The most important of these, from an engineering standpoint, are the operation of echo-suppressors and the effect of line noise.

(i) Operation of echo-suppressors.

It is essential that the operation of echo-suppressors on trunk circuits should be sufficiently rapid to prevent the possibility of the passage of reflected currents. The time of operation necessary to prevent this will, of course, be dependent on the length and composition of the particular circuit and on the location of the echo-suppressor. The hang-over time must also be such as to allow of the reception of the "answer back" signal.*

The operating time of the hitherto standard echo-suppressor used in Great Britain is about 20 milliseconds, and provided that the transmission time from the echo-suppressor station to the receiving terminal and back is greater than this, no difficulty is experienced. Where the transmission time is less than this, it is possible for the reflected signal to operate the other half of the suppressor and tend to suppress the originating signal. Some trouble has been experienced on circuits having a short transmission time and it has been overcome by arranging that the suppressor, in addition to suppressing the return repeater, suppresses also the amplifier of that half of the suppressor which should not operate.

The hang-over time of the limiting circuit in the convertor has been increased to provide for echo-suppression for periods up to 60 milliseconds. It is therefore unnecessary for the beginning of a reflected signal to be fully suppressed. On short-circuits this is important, because too-rapid build-up of the suppressing voltage produces a surge on the line which may cause errors in the telegraph transmission and, in extreme cases, instability of the echo-suppressor and repeater.

The hang-over time is limited by the rapidity with which the "answer back" signal is transmitted. On the teleprinters used in Great Britain, a period of 160 milliseconds elapses before the "answer back" unit begins to transmit, and as it is unnecessary for the first letter-shift signal to be received a maximum hang-over time of 310 milliseconds is permissible. This figure should be increased by the transmission time of the circuit from the suppressor station to the receiving terminal and return, but in many cases this is negligible.

In the modified standard echo-suppressor used in Great Britain, the operating time is approximately 10 milliseconds and the hang-over time 270 milliseconds. A diagram of the modified circuit is shown in Fig. 20.

(ii) Effect of line noise.

Line noise is most commonly of the form of short disturbances of considerable amplitude, similar to the atmospherics of radio engineering. The chief source of disturbance is in exchange switching operations, where momentary bridging of one line to another can occur. It has been found that, in practice, at least 95 per cent of the disturbances are of less than 2 milliseconds duration, and the majority of those are of less than 1 millisecond. A short disturbance may give either an "extra" or a "failure" in the received signals. If the disturbance is received whilst a character but no tone is being transmitted, the equivalent of a period of tone results. If the amplitude of the disturbance is large, the grid condenser in the receiver may be charged to

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* See Bibliography, (31).
Fig. 21.—Experimental convertor embodying noise discrimination on a time basis

Fig. 22.—Current in teleprinter electromagnet winding, with armature clamped.
(a) Current on letter "Y" (S, MSMSM, M).
(b) Current on carriage return (S, SSSMS, M).
(c) Current in magnet: 0-5-millisecond disturbances. 10-millisecond timing lines.
such a point that the next voice-frequency signal is suppressed and the result is equivalent to a period of no tone. The amplitude of the disturbances is usually of the order of 2 volts, but in exceptional cases may reach 20 volts.

Discrimination between the disturbances and the voice-frequency signal can be made on an amplitude basis, on a frequency basis, or on a duration or time basis. Discrimination on an amplitude basis can only be made by reducing the absolute sensitivity of the receiver to a minimum. This requires that the transmitter input to the line be fixed at the maximum power permitted by considerations of repeater-overloading and of cross-talk. For telex services in this country the sensitivity required is such that the equipment must operate on an input of 0.1 volt, and for international working 0.05 volt. Thus, a number of disturbances remain which on an amplitude basis are liable to mutilate transmission.

As the total energy of a d.c. pulse is spread over an infinitely large number of frequencies, a certain amount of discrimination between signals and disturbances can be obtained by restricting the received band of frequencies. It follows also that it is impossible to discriminate completely, as part of the energy will undoubtedly fall within the transmission band. The result is that the disturbance received after the filter is of smaller amplitude but greater length than the original pulse, and the narrower the transmitting band width the greater is the effect on both amplitude and length. The restriction of the transmitting band therefore improves the signal/disturbance-voltage ratio, but the gain is limited by the bandwidth necessary for transmission with a reasonable minimum of distortion. Thus, with a carrier frequency of 1 600 cycles per sec. and a band width of 400 cycles per sec., the amplitude of the disturbances produced by the application of a d.c. voltage from a low-impedance source is reduced in the ratio of about 4 to 1, but the length is increased from a very small value to about 3 milliseconds. The effect of a large proportion of disturbances is nullified, therefore, but the remainder which are still comparable in amplitude with the signal are more likely to result in false characters owing to their greater length and the consequently greater chance of interference with a particular operation of the receiving electromagnet.

Because of the short duration of the disturbances in comparison with the shortest signal element, duration forms the best basis of discrimination. This method can be applied by reducing equally the rates of growth and die-away of a signal, so that signals shorter than a certain length of time cannot operate the receiving relay.

Fig. 21 shows how the system has been embodied in an experimental a.c./d.c. single-current convertor for use on telex circuits. The network in the d.c. output circuit produces such a wave-form in the change-over from M to S (mark to space), and vice versa, that a signal shorter than 7 milliseconds does not exceed the effective value of the bias current. As the retarding network comes after the limiting valve, the sensitivity to disturbances is not dependent on amplitude providing this is comparable with the normal maximum signal amplitude. The presence of a band-pass filter reduces the amplitude of the disturbance, and therefore to a certain extent guards against excessive charge being produced on the grid condenser.

Oscillograms of current in the teleprinter-magnet winding are shown in Fig. 22. Such disturbances do not operate the teleprinter whilst signals are not passing, but, if they occur during transmission, precipitate or retard operations of the magnet armature. The errors in transmission are therefore roughly proportional to the number of change-overs in the character; letters such as "T" (S, S S S S M, M) being almost immune, and letters such as "Y" (S, M S M S M, M) showing the greatest number of errors.

The effect of a disturbance immediately preceding or following a signal operation has been examined using apparatus embodying the circuit of Fig. 21, and the results are shown in the curves given in Figs. 23 and 24. In these curves it has been assumed that the amplitude of the disturbance is roughly the same as that of the signal, and therefore the suppression of a signal following a disturbance of greater amplitude has been ignored. Several interesting points are brought out by these curves. In the first place, if the disturbance precedes the signal operation the maximum distortion which results is equal to the length of the disturbance. Thus, with a band-pass filter having a transmitting bandwidth of 400 cycles per sec. by which any short disturbance is lengthened to 3 milliseconds, the distortion of a M-to-S operation can reach a maximum of 15 per cent at 50 bauds, a figure which should be well within the margin of the receiver. Secondly, if the disturbance immediately follows a signal the distortion is again

![Figure 23](image-url)
15 per cent. A short interval between the end of the signal and the disturbance can introduce distortion of between 15 and 37 per cent, depending on the duration of the interval, but provided that the interval is less than 3 or greater than 7 milliseconds (the shortest interval in which the relay will operate) the distortion is not more than 25 per cent, a not-unreasonable figure for the margin of the receiver. In the worst cases, the distortion due to a disturbance at a certain interval after the end of a signal is more than it would be if there were no interval and the disturbance were increased in length by the duration of the interval. For example, a 5-millisecond disturbance after an interval of 7 milli-

![Diagram](image-url)

**Fig. 24.**—Effect of disturbance following signal.

The figures on the curves denote duration of disturbance, in milliseconds.

seconds results in 76 per cent distortion; whereas, if there were no interval and the disturbance were increased to 12 milliseconds, the distortion would be only 60 per cent. To a lesser degree, this is also the case for shorter intervals; and is due to the combination of the transients produced by the signal and the disturbance delaying the fall of current in the magnet winding.

The curves also show that, if possible, the transmitting band width should be such that short disturbances are lengthened to not more than 2 milliseconds in order that the distortion may not exceed 25 per cent for any position of the disturbance. This requirement can be met by increasing the band width of the receiving filter or by cutting out the filter, but there remains the possibility of disturbances of large amplitude charging the grid condenser and suppressing telegraph signals following the disturbance. This effect can be counteracted by the use of a received-current-limiter, which precedes the voltage-limiter in the converter, as is shown in Fig. 21. The object of the current pre-limiter is to limit the grid-condenser charging current to the maximum signal current which the converter is designed to receive. The pre-limiter itself consists of a network containing copper-oxide rectifiers which are in series with the receiver and carry direct current. The a.c. signal is superposed on the d.c., increasing the instantaneous value of the total current in one rectifier and reducing it in the other. As the current in one rectifier approaches zero, the series impedance between the line and the converter increases rapidly, and therefore the peak value of the signal current is limited practically to the direct current in the rectifier circuit.

Although this charging-current pre-limiter limits also the signal voltage received by the converter, its effect, in this instance, is not the same as that of the widely used voltage-limiter which operates by producing a shunt across the receiver when the level of the received signal exceeds a predetermined value. The grid-circuit-limiter of the receiver operates as a voltage-limiter on a very short signal or disturbance and is, in fact, more effective than a voltage pre-limiter could be, because the former limits the signal to the minimum receiving level whereas the latter can only be designed to limit the signal to the maximum receiving level if distortion of the signal is to be avoided.

(5) DIRECT-CURRENT TRANSMISSION

So far as the British inland service is concerned, direct-current methods have become of considerably less importance since the extension of multi-channel voice-frequency working. Apart from short local lines, and extensions from voice-frequency systems, direct-current working is mainly employed for the utilization of by-product circuits in telephone cables, and for working on submarine telegraph cables to the Continent and numerous islands off the shores of Great Britain. The by-product circuits in use are phantoms in star-quad telephone cables and double-phantoms in multiple-twin telephone cables. Details of the methods used when such circuits are employed for the provision of private wires have already been published.*

In the case of extensions from the voice-frequency system the windings of the voice-frequency transmitting relays are connected through a fixed resistance of 3,000 ohms to earth while the operating current is supplied over the line from a double-current earthed ± 80-volt battery via the transmitting teleprinter contacts. In the reverse direction the voice-frequency receiving relay transmits double current from an earthed ± 80-volt battery to line and eventually to the teleprinter electromagnet or receiving relay. Under these conditions it is found that at teleprinters requires a considerable length of line (actually about 30 miles of 20-lb. telephone conductor or the equivalent) can be used without appreciably increasing the overall distortion of the circuit above that of the channel itself. This is without the inclusion of additional relays in the circuit and with simple filters inserted to prevent interference with telephone circuits. By inserting suitable

* See Bibliography, (27).
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receiving relays in the two sides of the circuit and connecting the teleprinter electromagnet and the voice-frequency send relay to the local contacts of these relays the length of line can be increased to upwards of 100 miles of 20-lb conductor or the equivalent, without appreciably increasing the overall distortion of the circuit above that of the voice-frequency channel alone.

(a) Sub-audio (Infra-acoustic) Circuits on Submarine Cables

It has not been found necessary to make use of sub-audio circuits in the British Isles, with the exception of several cases in which submarine cables are involved and the provision of special equipment is warranted. Such a case is that of the London–Jersey duplex teleprinter circuit, which is composited with the Channel Islands telephone circuit on a single-core unloaded submarine cable. Two duplex teleprinter circuits have also been installed on the continuously-loaded submarine telephone cable between Blackpool and Port Erin (Isle of Man). These circuits are noteworthy for the low transmitting voltages used (approximately 7 volts) in order to avoid the risk of affecting the characteristics of the loading material on the cable conductors, and so giving rise to cross-talk on account of minute changes in inductance. The terminal arrangements at Blackpool are shown in Fig. 25. Rectifiers were used to provide the line current, to avoid the necessity for special insulated batteries for each circuit. A sending-end inductive shunt was used as a convenient method of reducing distortion and compensating for the relatively high resistance of the transmitting portion of the circuit. The potentiometer and shunt entail a considerably higher current output from the rectifier than is used in the line, but this is not in fact of practical importance. Other points of interest are the artificial line used in place of the conventional balance, the necessity for smoothing the vibrating circuit of the receiving relay, and the transformer in the line circuit. The last item is introduced to prevent the telegraph apparatus from producing a loss on the double-phantom telephone circuit which works on the two phantom circuits on which the telegraphs are composited. Smoothing of the vibrating circuit is provided to prevent noise on the telephone circuit.

A sub-audio case of a somewhat different character was that in which a telephone circuit between Jersey and Guernsey was obtained by making use of two cores of a 3-core telegraph cable already in use for telegraph circuits from Jersey to London, without change in the operating conditions of the telegraph circuits. The use of the normal 80 volts on the telegraph circuits entails surge currents up to 200 mA in the inductances of the battery-circuit smoothers, but by paying special attention to the design of the filter coils in the telegraph circuits it has nevertheless been possible to raise the cut-off frequency of the line filters to 200 cycles per sec. The coils are made up on a laminated mumetal core and for a 0.56-henry coil having a d.c. resistance of 7.5 ohms the change of inductance at 50 cycles per sec. for currents from zero up to 200 mA was less than 1 per cent. The result of the relatively high cut-off and the large surge currents possible has been that the characteristics of the

---

Fig. 25.—Blackpool–Douglas sub-audio teleprinter equipment at Blackpool.
telegraph circuits are essentially unaltered. Tests showed that with the arrangements adopted, an incoming telephone level, at the junction of the high- and low-pass filters, of as low as \(-35\) dB would still give a satisfactory signal/noise ratio on the telephone channel.

Fig. 26 is a diagram of one form of rectifier unit developed for the exclusive supply of the telegraph currents where it is not desired to use the common rectifier unit referred to above, for example, on account of the non-standard voltage of \((55 + 55)\) volts.

(b) Use of Rectifiers for D.C. Telegraph Currents

All-mains teleprinter sets have been in use at small offices having a.c. power supply for some years.* Where a d.c. power supply only is available central battery working has been resorted to, but small rotary transformers are now being introduced for obtaining double-current supply. The a.c. all-mains arrangement makes use of a rectifier unit having an output of approximately 110 volts at 0.75 amp. The arrangement is such that

![Fig. 26](image)

Fig. 26.—Rectifier unit for direct-current extension from multi-channel voice-frequency system.

... used for the supply of \(\pm 80\) volts for working into a multi-channel voice-frequency terminal over a direct-current line. The rectifier units are joined up on the voltage-doubler principle, the double-current supply being obtained by means of a potentiometer. This method avoids any possibility of battery bias, and the rectifiers are used somewhat more efficiently than with the bridge scheme. The value of the potentiometer \((2000\, \text{ohms} + 2000\, \text{ohms})\) has been kept high to avoid the power for driving the teleprinter motor and for a double-current line and local supply of \(\pm 55\) volts are all obtained from one rectifier. The use of a single unit in this way is permitted by the fact that the high-capacity rectifier necessitated by the motor has a comparatively low internal resistance. Rectifier units of considerably lower capacity than the foregoing have been

![Fig. 27](image)

Fig. 27.—Rectifier unit for duplex working (loop or earth).

\(\Phi\) Inductance only required on longest lines.

... an unduly heavy load on the rectifiers. The 10-\(\mu\)F condensers shunting these resistances reduce the loss in transmission efficiency on account of the high resistance of the potentiometer and rectifier.

Table 3 gives the output characteristic of the rectifier unit shown in Fig. 26.

It will be observed that the voltage on the off-load side of the potentiometer rises considerably This
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voltage, however, never appears across the line terminals, and in fact the shape of the line-voltage curves is identical with that obtained using a battery. Rectifier units of this and similar types are also being used to provide the

<table>
<thead>
<tr>
<th>Volts across potentiometer</th>
<th>mA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working side</td>
<td></td>
</tr>
<tr>
<td>95</td>
<td>125</td>
</tr>
<tr>
<td>75</td>
<td>135</td>
</tr>
<tr>
<td>50</td>
<td>150</td>
</tr>
<tr>
<td>Idle side</td>
<td></td>
</tr>
<tr>
<td>125</td>
<td>15</td>
</tr>
<tr>
<td>135</td>
<td>30</td>
</tr>
<tr>
<td>150</td>
<td>60</td>
</tr>
</tbody>
</table>

Table 3

Table 4

<table>
<thead>
<tr>
<th>Type of circuit</th>
<th>Length (miles)</th>
<th>K x R (µF x ohms)</th>
<th>Sending shunt ( henrys</th>
<th>ohms</th>
<th>mA</th>
<th>volts</th>
<th>Characteristic, distortion at 50 bauds</th>
</tr>
</thead>
<tbody>
<tr>
<td>40-lb. double-phantom</td>
<td>260</td>
<td>108 000</td>
<td>9</td>
<td>800</td>
<td>10</td>
<td>43</td>
<td>5</td>
</tr>
<tr>
<td>25-lb. phantom</td>
<td>120</td>
<td>80 000</td>
<td>3</td>
<td>400</td>
<td>5</td>
<td>23</td>
<td>5</td>
</tr>
<tr>
<td>40-lb. loop</td>
<td>220</td>
<td>130 000</td>
<td>0.7</td>
<td>800</td>
<td>4</td>
<td>46</td>
<td>5</td>
</tr>
</tbody>
</table>

line and local currents on teleprinter private wires. For working over long distances, and also where a lower line voltage is required, the unit can be used in the manner shown in Fig. 27, which is a diagram of the sending end of a differential duplex circuit with rectifier

Table 4

supply. A sending shunt is used which may consist of a plain resistance or of a resistance and inductance, and, by proper adjustment of this shunt, transmission equivalent to, or better than, normal battery operation can be secured.

Typical results obtained in the laboratory on different types of artificial underground cable are given in Table 4.

(6) TESTING

(a) Frequency Control and Synchronism

Modern communications engineering is becoming more and more dependent on the accurate control of speed and frequency. A telegraph circuit working on a multi-channel voice-frequency circuit is an instance of this. The motors of the teleprinters themselves must all run as nearly as possible at equal speeds in order to have maximum margin available to cover line and incidental distortion. The multi-frequency generators must run at correct speed in order that the frequencies generated shall lie in the centre of the filter bands and so allow room for the signalling side-bands. If the multi-channel system itself is operated on a carrier channel the frequencies of the oscillators in the modulating and demodulating equipment must again be equal for the same reason.

(i) Teleprinter speeds.

Steady improvement has been made in the maintenance of correct teleprinter speed, and it is now safe to say that the speeds of co-operating machines seldom differ by more than 1 per cent. It was often claimed in the early days of teleprinter working that speed differences of 4 or 5 per cent could be tolerated, but clearly it is preferable to run at correct speed and retain a margin to meet less tangible sources of trouble.

Speed is checked by means of stroboscopes and synchronoscopes. The former were originally the sole method of speed testing, and consisted of viewing a mark on a rotating shaft of the teleprinter through the window of a tuned vibrating reed. The accuracy of the test is not high, and synchronoscopes have been introduced which have resulted in a marked improvement in the general accuracy of teleprinter speeds. The circuit of the synchronoscope is shown in Fig. 28. The teleprinter to be tested may be either adjacent to or remote from the synchronoscope panel; the letter "V" or other suitable character is transmitted continuously from the teleprinter transmitter (either directly or over the telegraph circuit in the case of a distant machine) into relay B of the synchronoscope panel. Relay B, and also, therefore, relay A, operate once per character, the latter connecting the power supply intermittently to one side of a series of six neon lamps arranged in a circle. These lamps are energized in rotation from a brush driven from a mains-operated synchronous motor but geared down to the standard speed of the teleprinter transmitter. If, therefore, the teleprinter speed is correct, the same lamp flashes with each character transmitted. If, however, it is fast or slow, the flashes rotate at a speed which can be readily estimated and translated into the percentage speed error of the teleprinter. It will be observed that the method is dependent on the accuracy of the supply frequency. Experience has so far indicated that this may be relied upon to 0.2 per cent, which is adequate for the present purpose. To cover cases where controlled-frequency a.c. mains are not available, a 50-cycle valve-maintained tuning-fork unit has been developed.

The ultimate solution to the question of teleprinter
speed control may be found in the use of synchronous motors. The problem of design is not readily capable of solution, however, owing to the conflicting requirements of noise, space, heating, starting torque, and running torque, while the difficulty of providing an accurate alternative supply in the event of mains failure must be borne in mind. A quantity of motors are now under field trial, but a decision as to their general use has not yet been made.

(ii) Multi-frequency generators.
These are governed electromechanically to an accuracy of $\pm 0.25$ per cent. At the lowest frequency (420 cycles per sec.) this error amounts to only $\pm 1.05$ cycles per sec., but at the highest of the 18 frequencies (2460 cycles per sec.) the error becomes 6 cycles per sec., which is the limit laid down by the C.C.I.T. (Art. No. 511). It will be seen that the necessary percentage accuracy of the frequency of the carrier increases in proportion to the frequency. It is unlikely that greater stability of a direct-current-driven multi-frequency generator than $\pm 0.25$ per cent can be obtained in practice, and therefore if it is desired to continue the normal series of channels at 120-cycle spacing appreciably above 2460 cycles per sec. it is best to do this on a carrier basis. In practice the multi-frequency generators are checked stroboscopically from a neon lamp flashing from a stable oscillator. The frequency of the oscillators is 1200 cycles per sec., corresponding to the 6th-channel frequency. This frequency is designed to give certain specific test signals when transmitted over the channel. This permits of an exactness in the setting-up and maintaining of channels which was never secured by the older methods using the telegraph apparatus itself to check the working of the channel. The independent and indisputable nature of the check given by telegraph distortion measurements has been of great value in both the installation and the maintenance of the voice-frequency network. Individual channels are set up independently of the system of telegraphy which may be worked on them when extended to an instrument room or renter's office, and also independently of the fact that they may be required to form one link in a series of tandem-connected channels.

Stroboscopic distortion measuring sets have been found the most convenient type for measuring line distortion suffered by certain specific test signals when transmitted over the channel.
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In these sets the timing of the received signals is measured by means of radial flashes displayed on a circular time-base, the flashes being arranged to occur at the instants of modulation, i.e., when the receiving-relay armature moves across to the opposite side. The period of the time-base is arranged to be such that when the signals are distortionless the flashes are superposed. When distortion is present the flashes which should occur in the one place are spread over an arc, the extent of which gives a measure of the distortion present. A schematic diagram of the connections of the distortion-measuring set which is installed at all multi-channel voice-frequency terminals is given in Fig. 29. The stroboscope takes the form of a cathode-ray tube on the screen of which bright radial flashes denote the operations of the receiving relay. The circular time-base is produced by means of the oscillator and a phase-splitting mask, and is used for varying the length of the start signal from normal. This is to enable varying amounts of distortion to be introduced into the transmitted signals, so that by sending these signals into a teleprinter the limit of permissible distortion before errors occur may be determined, thus giving a measure of the margin of the machine. The stroboscope consists of a neon tube mounted behind a radial slot in a rotating disc. Two methods of flashing the lamp are used. The first of these causes an instantaneous flash each time the receiving-relay armature moves on to the opposite contact. This method is used for distortion measurements, the distortion being measured by the displacement of the flashes from their true position on the scale, the flash corresponding to the "start" signal being taken as the reference point. A typical display for a distorted signal is shown in Fig. 31. The points at which the flashes would occur on a distortionless signal are shown dotted. The second flashing circuit is used for testing for transit time and breaking or bounce at the transmitting contacts of teleprinters or telegraph relays. In this case the lamp is flashed immediately the moving contact leaves

![Diagram of the connections of the distortion-measuring set.](image-url)

Test transmitter

System Under Test

Test oscillator

Test receiver

(c) Teleprinter Distortion and Margin Tester

Complementary to the above line-testing distortion set, a tester specifically designed for testing teleprinter circuits and apparatus has been introduced. The test signals are generated by a special transmitter designed to give a distortionless output. The transmitter gives signals having the following ratios of mark to space: 1/1, 2/2, 5/1, and 1/5. The test word "Paris" in Morse, either "straight" or "reversed," is also available. These signals have been found to be sufficiently varied to meet all ordinary requirements in the setting-up of telegraph channels, but the standardization of a series of signals is under consideration by the C.C.I.T.

The use of an oscillator for driving the transmitter and receiver enables tests to be made over a wide range of telegraph speeds (usually 30 to 120 bauds) and facilitates adjustment of speed when the apparatus is receiving from a distant distortion testing set.

* See Bibliography, (34) and (37).
† Ibid., (5). The signals have now been standardized. See Bibliography, (6), Avis, No. 311.
‡ Ibid., (6).
one side and is not extinguished until it reaches the opposite contact, and the breadth of the flash indicates the length of the transit time. Also, if breaking or chattering is present, flashes are produced each time this occurs.

The tester is being used in mechanics shops to check the transmitting and receiving mechanisms of teleprinters and to determine the causes of inefficient operation. It has also found considerable use in connection with the design of teleprinter circuits and mechanisms, as for this purpose the full stroboscopic display of a character is advantageous. In certain cases it is useful to send the teleprinter letters from the transmitter at a lower rate than normal, a period of marking or spacing of 150 milliseconds or more being interposed between the letters, and this facility has been provided on sets used in laboratory investigations.

(d) Automatic Testing Transmitter

This is an arrangement whereby continuous repetitions of a test message in teleprinter code are provided for testing teleprinters and teleprinter circuits; it is particularly useful when frequent or protracted tests are required. Reversals are also available, as well as the usual test sequence of alternate “R”s and “Y”s. Means are provided whereby, if desired, the signals may be given marking or spacing bias up to 25 per cent. The device, which was originally developed to enable a telephone operator to communicate with a telex subscriber who has his line switched to teleprinter, is shown schematically in Fig. 32. The transmitter is a distributor having one segmented ring to give signals in the 74-unit code and a second segmented ring for reversals. A 7-bank, 100-contact, rotary switch is made use of, and when sending the test message the wipers are stepped once per revolution of the distributor via one segment of the reversals ring. This segment is chosen so that the wipers move while the stop signal is being sent out. The contacts of banks Nos. 1 to 5 are wired to positive and negative battery according to the code for the message, while the wipers are wired to the five code segments on the distributor. A homing arc is provided so that before the first message is sent out upon the operation of the “message” key, the switch...
returns to the home position, whereupon relay C operates and locks. When relay C operates, the transmitting relay and impulsing circuit are switched through and the message commences. The "RY"s are obtained by the operation of a key which connects the contacts of relay B to the distributor segments in place of wipers Nos. 1 to 5. This relay operates on alternate contacts of bank No. 6, and its contacts are wired so that when normal the code for letter "Y" is obtained and when operated the code for letter "R." The switch steps once per revolution of the distributor, so that the letters "R" and "Y" are sent out alternately.

(e) Testing of Telegraph Relays

While the stability of modern telegraph relays is such that adjustments are infrequent, the loss of margin that can result from maladjustment warrants the use of special relay testing equipment. The C.C.I.T. has laid down (Avis No. 618)* principles for the adjustment of relays which have been embodied in the relay test tables and test panels used in the British Post Office. The tests cover the continuity and sensitivity of the line windings, neutrality, contact time, and, when applicable, continuity and neutrality of vibrating coils.

(7) TREND OF DEVELOPMENT

In the case of telephony, voice-frequency signalling methods and improvements in transmission technique have led to development in the direction of extending the automatic system to include the trunk circuits, so avoiding the delays and costs of intermediate operating. Similarly in telegraphy, the elimination of probably 50 per cent of the operating transactions and delays would be possible by means of through automatic switching from the office of origin to the delivery office. The present voice-frequency network makes a framework for such a scheme which would have been completely impracticable under the old physical line conditions. Telegraphy is now in a position to share in the increased progress is assured. The teleprinter, with its continual progress is assured. The teleprinter, with its

In conclusion, the authors wish to thank all those who have directly or indirectly assisted them in the preparation of this paper; and also Sir George Lee, the Engineer-in-Chief of the G.P.O., for permission to publish the information contained in it.

* See Bibliography, (8).
† Ibid., (47).
DISCUSSION BEFORE THE INSTITUTION, 19TH NOVEMBER, 1936

Mr. F. Gill: A portion of what I am about to say has been derived from the paper read before The Institution by Donald Murray in 1924.*

The frequent references in the present paper to the recommendations of the C.C.I.T. constitute a testimony to the very valuable work performed by that body.

The authors use the phrase "If . . . with the teleprinter as a mere accessory of the telephone. . . ." If the teleprinter is an accessory of the telephone system, I presume it must be based on economy; but this method seems to require that one shall use telephone long-distance circuits, say, between London and Glasgow, and therefore be charged the same fees as for telephone circuits, thus losing the economy of the narrow-band telegraph circuits. I should have thought that there was a better economic case for an independently-operating telegraph system.

Telegraph history, as presented in documents, is gloomy. The figures for the 12 years ending March, 1935, show a decrease in gross income of nearly 30 per cent, but in spite of this the yearly deficit has been improved by 14 per cent. The number of telegrams decreased from 71 millions to 44 millions; if we add the messages telegraphically. The total number of telegrams transmitted over the telegraph equipment must be greater than appears in the official records. I think the total volume of communications functions of the two services, one arrives at these fundamental differences: the telegraph constantly repeats its