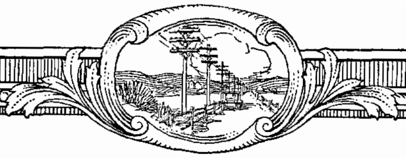
ELECTRICAL COMMUNICATION

JULY 1940

Volume 19, Number 1

www.americanradiohistory.com



ELECTRICAL COMMUNICATION

A Journal of Progress in the Telephone, Telegraph and Radio Art

BERNARD C. HOLDING, EDITOR

EDITORIAL BOARD

F. Gill W. Hatton R. A. Mack
H. M. Pease Kenneth E. Stockton C. E. Strong

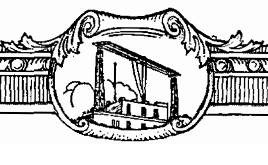
Issued Quarterly by

Standard Telephones and Cables Limited

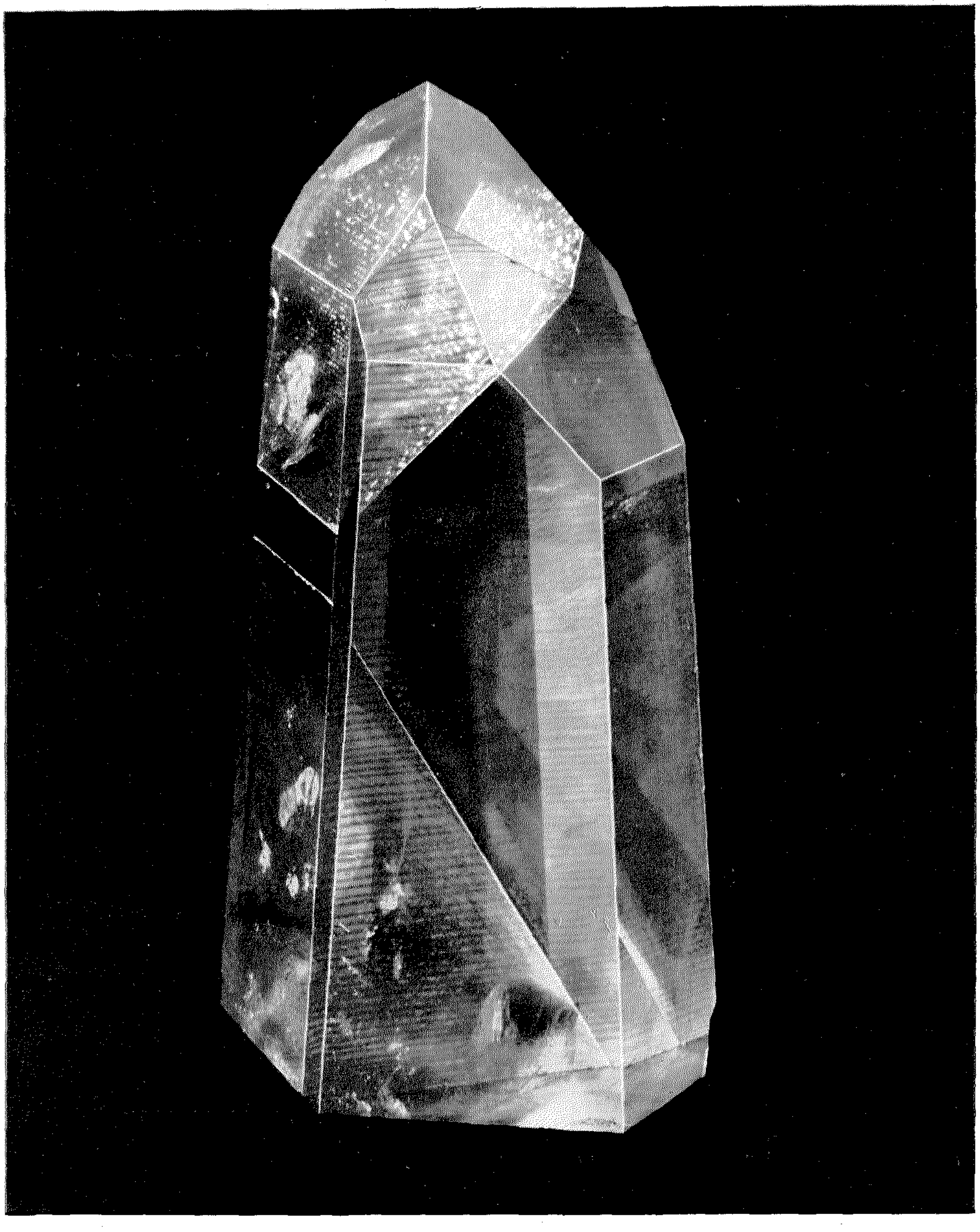
Connaught House, 63 Aldwych, London, W.C.2.

Volume XIX July, 1940 Number 1

PAGE



www.americanradiohistory.com



Natural quartz rock sectioned to show the principal planes used in cutting low-temperature coefficient crystals for quartz-crystal oscillators and filters.

www.americanradiohistory.com

The Sydney-Melbourne Type J Carrier Telephone System*

By J. T. O'LEARY,
Bell Telephone Laboratories, Inc., New York, N.Y.,

J. B. SCOTT,
Standard Telephones and Cables, Pty., Limited, Australia,

and

A. M. THORNTON,
Standard Telephones and Cables Limited, London

INTRODUCTION

THE open-wire route between Sydney and Melbourne has a history as old as the telephone art itself. Constructed first in the year 1858 as a telegraph route, it has served as one of the main arteries in Australia's communication system. The first telephone channel was opened in 1907. Since then, by the continued application of modern developments, it has taken care of the ever-expanding traffic between the two largest cities in the Continent.

The carrier current art has played a prominent part in the development of this route. The business growth that came after the close of the last war was largely met by the application, first of the type B, and later the type C carrier telephone systems, each of which provided three additional telephone circuits on a particular pair. Later, a special carrier programme circuit was applied to serve as a connecting link between radio broadcasting stations.

Now that the route is again rapidly approaching the saturation point with respect to these types of systems, the latest open-wire carrier system has been called upon to provide the necessary circuits to meet the increase in the volume of traffic. This new system is known as the type J system, and provides 12 channels on a single pair, in addition to the three channels already derived from a type C system and the normal voice frequency circuit. The total capacity of a pair thus equipped is 16 telephone channels.

Five years ago, in order to operate successfully the large number of carrier systems between Sydney and Melbourne or intermediate points, the Postmaster-General's Department reconstructed the top crossarms on the line to give an insulator spacing of 9 in., 18 in., 9 in., instead of 14 in., 14 in., 14 in., and a vertical spacing of 28 in. between arms. At the same time additional transpositions were inserted, the frequency range covered being suitable for type C systems, i.e., up to 30 kc. This modification was applied to the top three arms between Sydney and Goulburn and the top two arms between Goulburn and Melbourne.

As the amount of traffic increased still further, the Department was faced with a major line reconstruction to accommodate still more type C systems or an alternate cable scheme. Either of these projects would involve a very large capital outlay, particularly as the great bulk of the traffic is between the two terminal cities and, consequently, new circuits are required over the whole distance. The development of the J system opened up the possibility of obtaining additional channels on the line without undue expense. The ultimate scheme could then be deferred, or else proceeded with by instalments and the cost spread over a considerable period. Thus, for example, it would be practicable to commence laying a cable at the ends of the route where the traffic density is highest, and still obtain sufficient through circuits on the intermediate open-wire line by means of the C and J systems.

With these economic aspects in mind the Department initiated a series of measurements on the line to ascertain its capabilities. The

---

* Reprinted from *The Telecommunication Journal of Australia,* June, 1940.

www.americanradiohistory.com

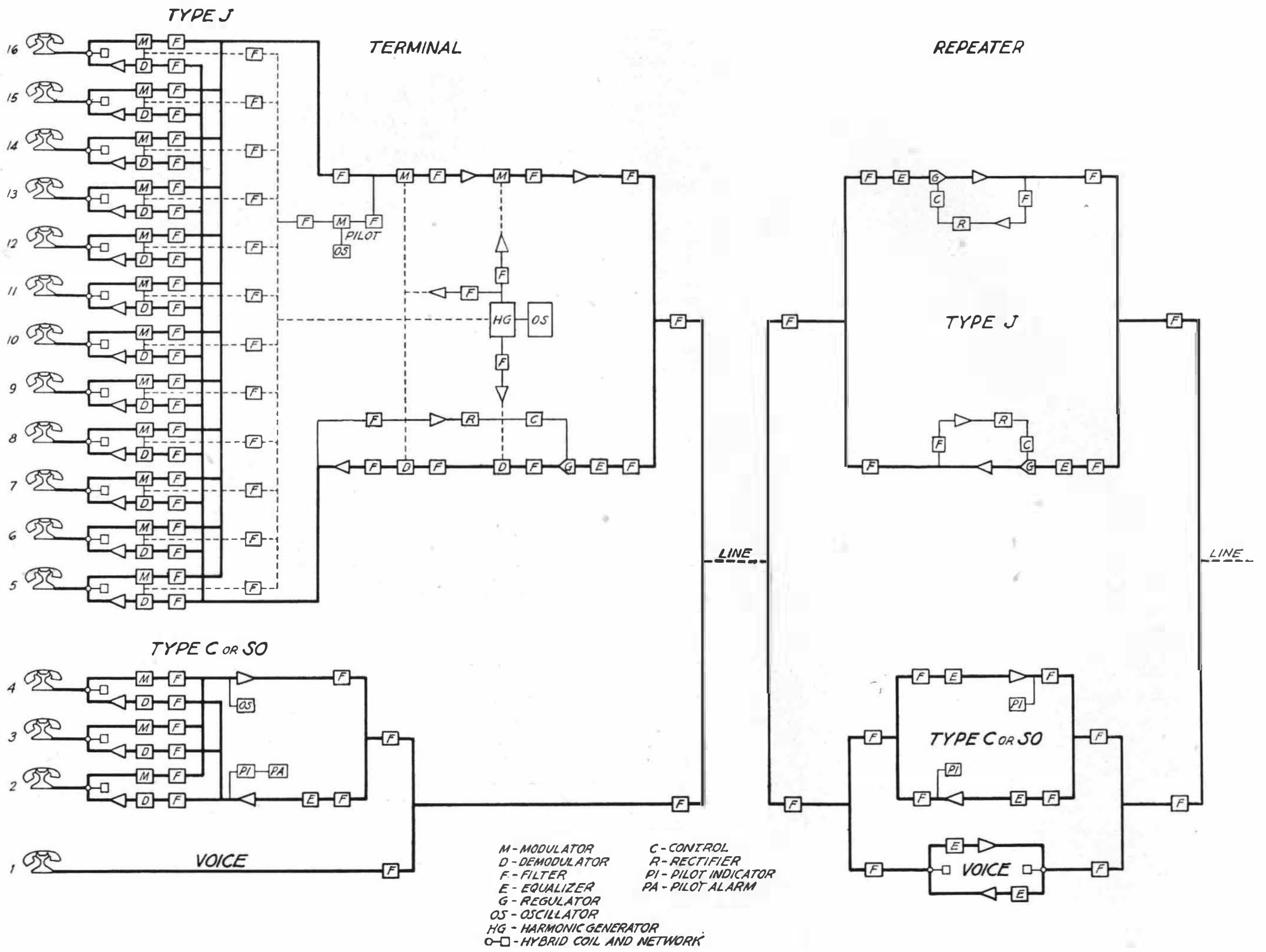


Fig. 1—Terminal and repeater layout.

www.americanradiohistory.com

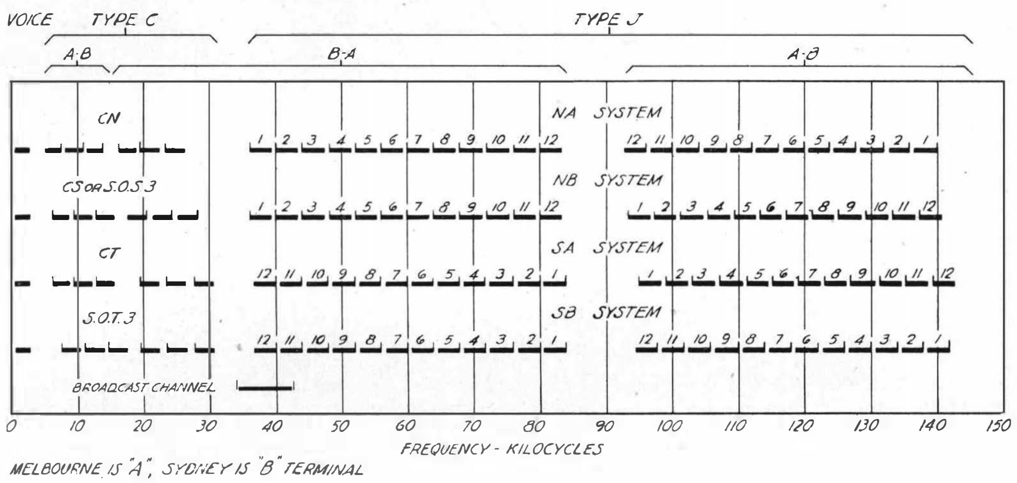


Fig. 2—Frequency allocation.

results showed that at least one of the carrier transposed pairs had general transmission characteristics quite suitable for a J system, and that very little additional work on the line would be required, except in the treatment of "in" and "out" loops at some of the repeater stations.

Consideration has also been given to the application of more than one J system to the route, and this aspect is discussed in a later section of this article.

BRIEF DESCRIPTION OF J SYSTEM

A full description of the J system, which was developed by the Bell Telephone Laboratories, has been given in the *Bell System Technical Journal*,[1] and it is not, therefore, proposed to give more than a brief outline of the system itself in this article, the main object of which is to describe its application in Australia.

Circuit Arrangements

Figure 1 shows the schematic arrangement of the terminal and repeater equipment of the 12-channel system, and also the 3-channel system associated with it on the same pair.

In principle, the J system is similar to existing 3-channel systems, inasmuch as different frequency groups are used in the two directions of transmission, and hence equivalent 4-wire operation is obtained over the open-wire pair. The four frequency allocations available are shown in Fig. 2, the one equipped between Sydney and Melbourne being the NA type.

The inputs of the 12 channels pass from the 4-wire terminating sets to the copper-oxide modulators and the band filters, and then to a common transmitting group circuit. At this point a single frequency pilot current is introduced, and is protected by a narrow band elimination filter which prevents interference in the pilot channel from the sideband of the adjacent channel.

The frequency range occupied by the channels at this stage is 60–108 kc, as shown in Fig. 3. This diagram also indicates the frequency translations and the carrier frequencies used in the subsequent stages of modulation and demodulation.

The channel and pilot currents are modulated in the first group modulator by a 340-kc carrier, and the sideband occupying the range 400–448 kc is selected by the transmitting band filter and passed on to the intermediate amplifier and second group modulator. In this stage of modulation the carrier frequency employed depends on the direction of transmission ; at the Sydney terminal it is 484 kc, and at the Melbourne terminal it is 308 kc. The output currents then pass through a low-pass filter having a cut-off of about 200 kc, and

---

[1] For references, see end of article.

the sidebands which now occupy the frequency range required on the line are amplified by the transmitting amplifier and proceed via the directional filters and line filters to the line.

The receiving portion of the terminal equipment operates in a similar, but inverse, way in order to produce from the received line frequencies the primary group of 60–108 kc for the final stage of demodulation to voice frequencies. The group receiving circuit also contains a regulating amplifier which automatically inserts or removes artificial line under the control of the incoming pilot current in order to maintain a constant output level to the receiving channel equipment, despite changes in the line attenuation. This apparatus has already been described in the article[1] cited above.

The primary modulation stage to the 60–108 kc range is common to the latest types of carrier systems, e.g., the 12-channel cable system, the open-wire J system and the coaxial system. This choice of frequency range enables crystal filters to be efficiently used as the channel band filters, with consequent improvement in quality. In the case of the J system, some of the frequencies required on the line overlap those produced in this primary group, and consequently two stages of group modulation are required to make the necessary frequency translation without interference.

The repeaters of the J system are similar to those of the C system in principle, but a regulating amplifier is used to insert or remove artificial line as at the terminal, while a fixed gain power amplifier actually supplies the gain and basic equalization required for the preceding repeater section.

The carrier supplies are primarily derived from a valve controlled by a tuning fork in an oscillatory circuit which feeds a fundamental frequency of 4 000 cycles into a small coil. This coil, which has a permalloy core, is operated in a magnetically saturated condition, and the

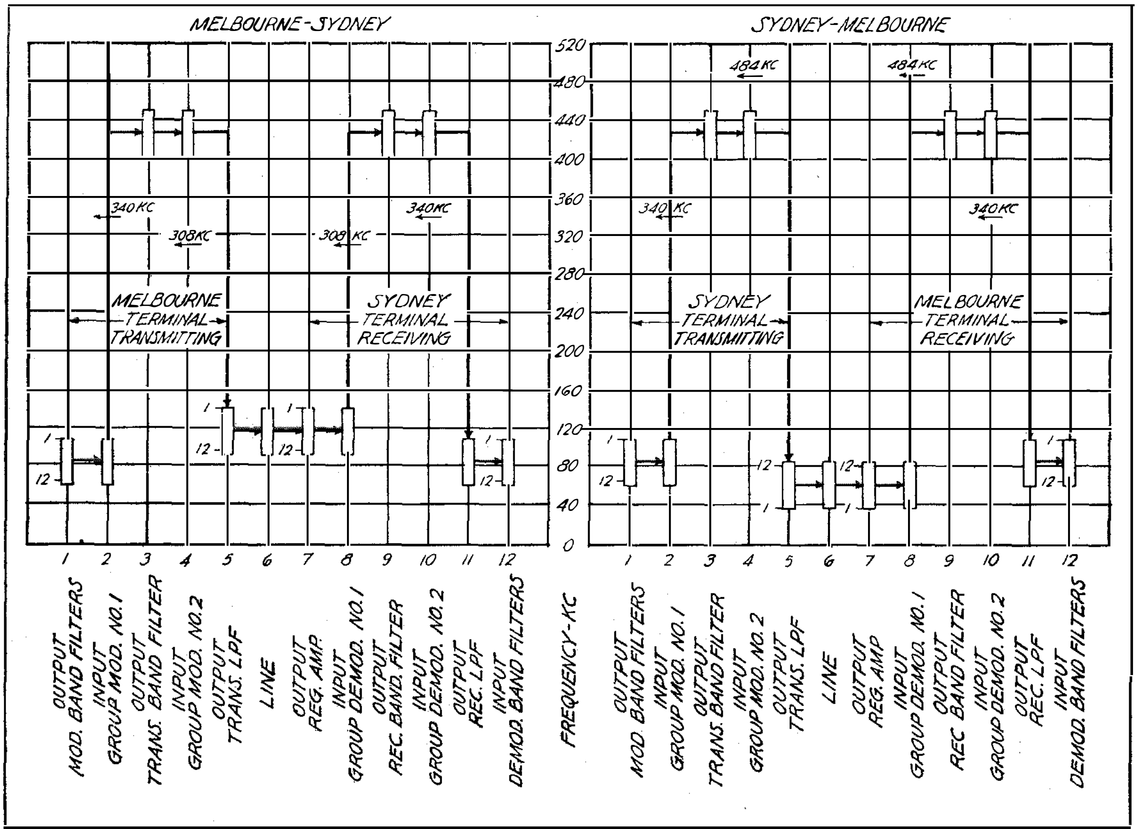


Fig. 3—Frequency translations of NA system.

output from the circuit is rich in odd harmonics of 4 kc. The even harmonics are obtained from an associated copper-oxide modulator.[2] From the harmonic generator circuit are obtained all the frequencies required for the channel modems and also for the group modulators and demodulators, although the group carriers require some degree of amplification in order to obtain the necessary power. The general arrangement of the carrier supply circuit is illustrated in Fig. 1. Actually as many as ten systems can be supplied from one common set of apparatus, which is duplicated, the emergency supply automatically being brought into service in the event of failure in the regular supply.

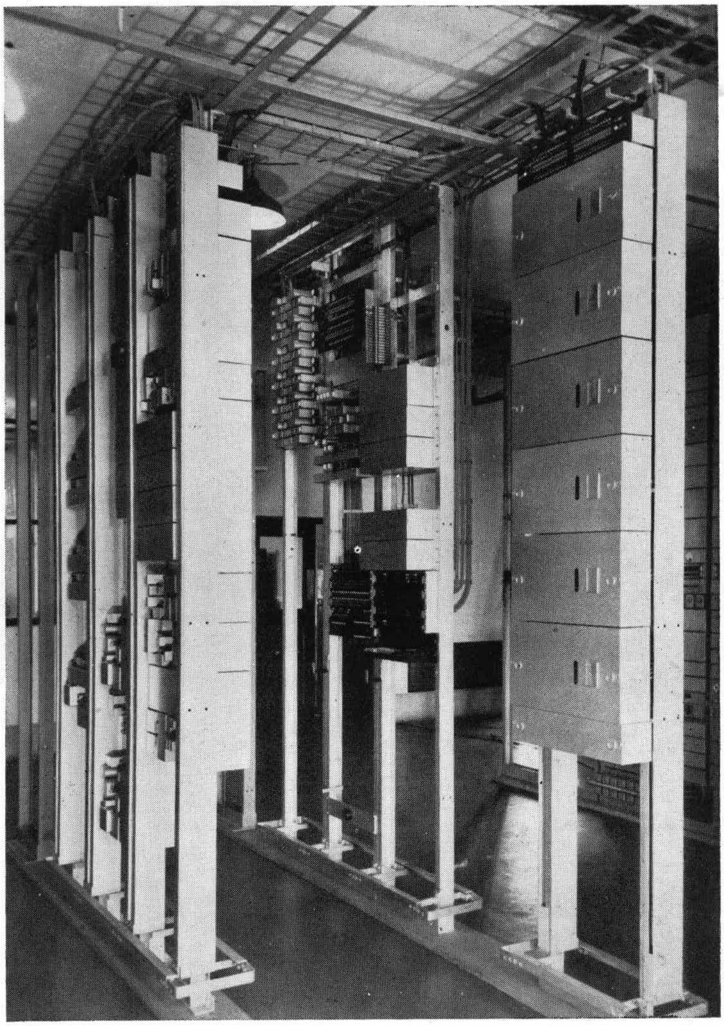


Fig. 4—Terminal equipment at Melbourne.

Equipment

The accompanying photographs show that the apparatus itself follows modern practice in general, although certain changes have been made in the framework construction of some of the bays in order to provide suitable runways for the wiring. This is illustrated in Fig. 4, which shows the Melbourne terminal equipment. Three of the bays in the right-hand row are of the usual channel-iron construction, while the remaining bays employ the built-up frameworks which enable interpanel and interbay wiring to be connected directly into the panels and at the same time to be accessible from the front. Provision is also made in the side troughs for shielding and segregation of the wires. In the left-hand row are the channel and group carrier supply bays and group terminal bay. At the right-hand end of the other row is a channel bay, while beyond this is a line bay mounting cable terminal, protectors, line filters and high frequency patching jacks. The miscellaneous bay and 4-wire terminating bay complete the installation. A great deal of this apparatus is common to several systems, and three more systems could be provided by the addition of six further bays.

Figures 5 and 6 show two views of Euroa unattended auxiliary station. Apparatus associated with the repeater proper mounts on the left-hand bay in Fig. 5. One such bay is required for each repeater. Figure 6 shows the north and south line filter bays with space on either side for additional line filter bays or crosstalk suppression filter bays as required. A trench in the floor runs between the manholes which are located in the corners of the room, and the disc cables are brought in at the bottom of the bay instead of at the top as is usual. Above the protectors are located the loading unit, the line filters and high frequency patching jacks. The miscellaneous bay at the end of the row mounts fuse panels for miscellaneous power supplies and the alarm trunk unit.

Power Supplies

The J system is designed to use the 24-volt filament and 130-volt anode batteries which normally serve existing C type carrier apparatus at main repeaters and terminals. The valves have indirectly-heated cathodes, so that it is possible to utilize a plate potential of 154 volts obtainable from the two batteries in series.

At auxiliary repeater stations where it is desirable that the apparatus should work without attention over a considerable period, a new type of power plant is used. The main battery consists of 70 cells connected in series and maintained at 152 volts by a floating charge from a mains-operated rectifier. The battery is tapped every 10 cells, and the various heater circuits for the valves are connected across the sections of 21.7 volts in such a way that a uniform drain is obtained on all sections. Variable rheostats are bridged across each segment of the battery in order to balance out departures from uniformity due to minor differences in valve heater elements. The negative end of the battery is earthed, and the full potential of 152 volts is available for the anode circuits. A simplified schematic of the arrangement is shown in Fig. 7 and a photograph of the power plant at Euroa is reproduced in Fig. 8.

The rectifier for the main battery is mounted near the top of the bay. This unit consists essentially of two three-element mercury vapour tubes operating as a full-wave rectifier from a single-phase A.C. supply. The output current depends on the phase relation of the voltage applied to the grids of these tubes with respect to their plate voltages. When a heavy load is demanded from the rectifier, the grid voltages are arranged to be in phase with the plate voltages. As less current is required, the control circuits adjust the grids towards the out-of-phase condition. Control of the charging rate

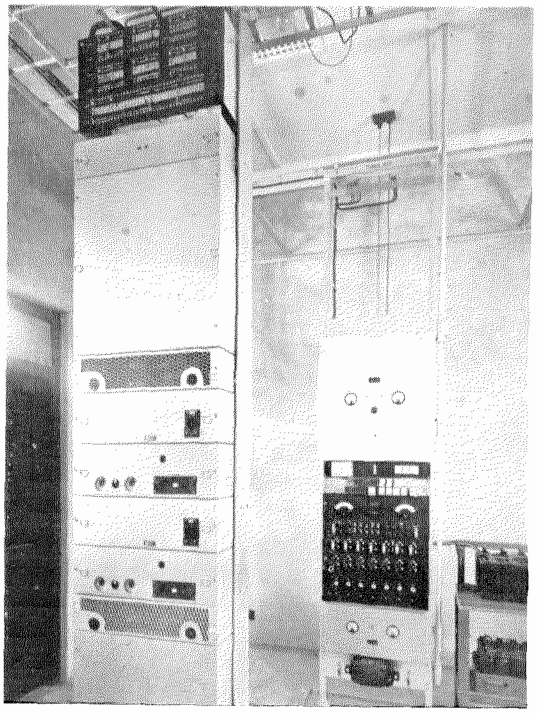


Fig. 5—Repeater bay, Euroa.

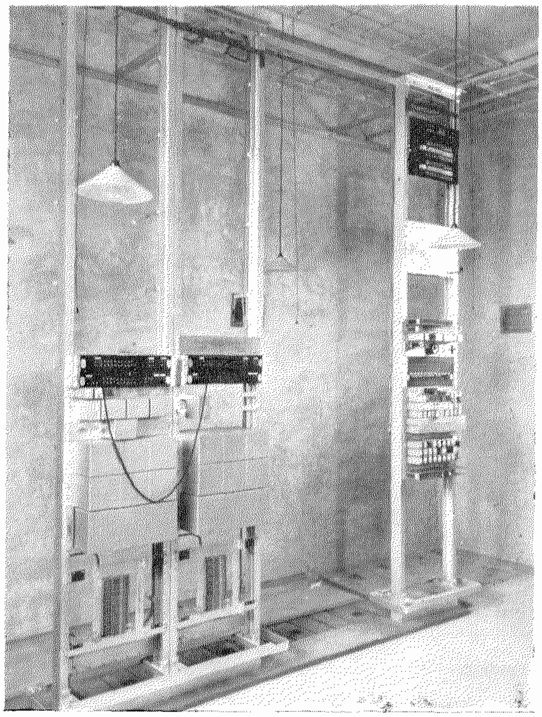


Fig. 6—Line filter bays, Euroa.

www.americanradiohistory.com

may be manual or automatic as desired. Under normal operating conditions the rectifier is charging under automatic control to maintain the battery at a constant voltage of 152, and the rate, therefore, is just sufficient to supply the repeater and to make up any losses.

In the event of a mains failure, the repeater load is taken from the battery, and if the failure exists for some time the battery voltage will be lowered and the available reserve may be considerably depleted. Restoration of the supply would cause the rectifier to charge at an excessive rate unless adequately safeguarded, and so after a power failure it automatically charges at a constant safe current of approximately 8 amperes until the battery voltage reaches 156, whereupon a high voltage contact is operated on a voltmeter relay, and the rectifier returns to its normal condition to supply a floating charge which will maintain a constant voltage of 152 again. Automatic regulation involves the use of two additional valves, and associated apparatus, which are replaced by a simple rheostat circuit when it is desired to control the charge by hand.

Faulty operation of the plant is indicated by alarms which are registered locally if the office is attended, or, in the case of an unattended office, are relayed to the nearest main repeater station. In Fig. 8 the main distributing panel can be seen located between the upper and lower rectifier panels on the bay. Push buttons on this panel enable the voltage of each section of the battery to be read separately, while the balancing rheostats are adjusted by means of a screwdriver from the front. The total drain on the 152-volt battery at an auxiliary station is approximately 1 ampere for each type J1 repeater.

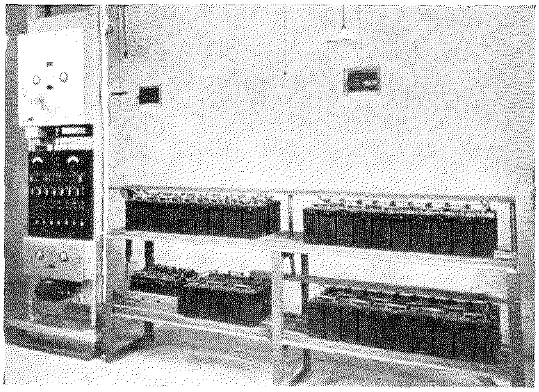


Fig. 8—Power plant, Euroa.

The lower rectifier panel shown in the photograph is used to charge the small 24-volt battery which can be seen at the extreme left on the lower shelf. This battery is used to supply the relays of the repeater regulators and certain other miscellaneous circuits in which the drain is intermittent, and which could not be uniformly spread over the 152-volt battery. The 24-volt rectifier is a single valve type which automatically holds the battery to a

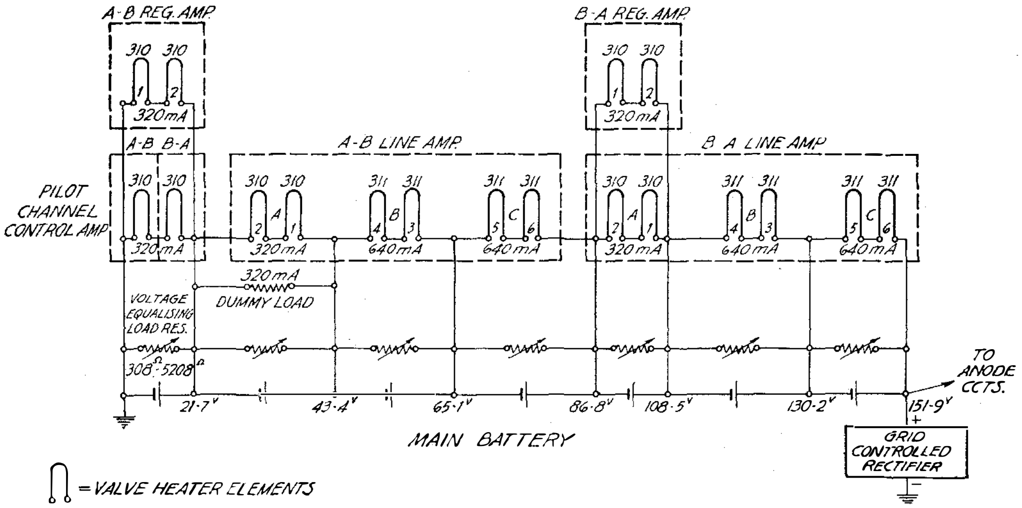


Fig. 7—Simplified schematic of main battery circuit at auxiliary repeaters.

mean constant voltage, although it does not supply sufficient current to cope with the momentary drains on the battery.

When the mains supply fails, the small motor generator at the bottom of the bay is used as an emergency supply of A.C. current to the synchronous motors which drive the pilot channel regulating condensers. Under such conditions it starts automatically, and runs from the 152-volt battery until the mains supply is restored.

Of the six auxiliary repeaters on the route, five are equipped with this type of power plant. At Cootamundra use is made of 24 and 130-volt batteries which already exist. Cootamundra is, therefore, treated as a main repeater station in this respect, and uses filament circuits designed to operate from an unregulated 24-volt battery. The valves used at both main and auxiliary repeaters have identical electrical characteristics, but differ slightly in heater construction and power consumption. Ballast lamps are necessary at main repeaters and terminals where unregulated 24-volt filament batteries are employed.

PROBLEMS INVOLVED IN EQUIPPING ONE J SYSTEM

General

In considering the Sydney–Melbourne route it was decided that, initially, one J system should be installed on the line with as little additional work and expense as possible. Existing offices would be used for repeater stations, even if these were not necessarily the most suitable from a transmission point of view. The final choice of stations and the distances between them in route miles are given in Fig. 9, together with the lengths of "open-wire" loops on which the lines are brought in from the trunk route to the repeater station buildings. At one station only, i.e., Euroa, was a new building erected, and this was constructed and equipped as a completely unattended auxiliary repeater following the latest practice.

It is not proposed to deal here in detail with the problems which arise due to the extension of the frequency range on the line from 30 to 140 kc. These have been adequately described in a previous article.[3] Briefly, the chief difficulties to be met are the general increase in line attenuation at the higher frequencies, the possible irregularities due to absorption and the increase in crosstalk. Short lengths of terminal and intermediate cable become more critical.

Line Attenuation

Typical attenuation-frequency characteristics are shown in the table for the various wire gauges found on the route.

TABLE I

Typical Measured Line Attenuation Values (Dry Weather)

Frequency	Loss in db. per Mile		
	200 lb.	300 lb.	600 lb.
30 kc	0.145	0.130	0.095
50 kc	0.180	0.160	0.115
100 kc	0.250	0.228	0.170
140 kc	0.295	0.268	0.205

Figure 9 also shows the wet and dry weather losses at 140 kc for the pair which was ultimately chosen as the normal working line for the J system (pr. 3499–0).

The density of the wires on the crossarms falls away somewhat over the centre portion of the route, but four through pairs were considered as possible working or patching pairs for a J system. From an inspection of the transposition diagrams and the results of certain measurements made along the route by the Administration, the opinion was formed that circuits would be subject to absorption peaks in the following order :

1. 200 lb. Pair No. 3499–0 (best)
2. 600 lb. Pair No. 399–0
3. 300 lb. Pair No. 521–2
4. 200 lb. Adjacent to No. 3499–0 (worst).

The relative positions of these pairs over a considerable portion of the route is shown in Fig. 10. In planning the system, consideration was given to the use of the 600 lb. pair for the J system owing to its lower attenuation and suitable location on the top crossarm. However, as most of the pairs on this route are 200 lb., and as the measured attenuation characteristics favoured 3499–0, it was eventually decided to use 3499–0 as the normal line. The age of the 600 lb. pair was a further argument against its use for regular operation. This left the 600 lb. pair as the first choice for the spare line, but because it was desirable to have fairly close similarity of impedance and attenuation characteristics between the normal and spare lines, it was not chosen. Eventually the 300 lb. pair was used as the spare line. This had good characteristics except for a slight absorption peak at about 90 kc.

During the initial line-up of the system it was necessary to take into account the difference in size between the regular and spare pairs. As the 300 lb. pair offered less attenuation than the normal 200 lb. pair, the setting of the regulating condenser for the normal pair had to be such that it could introduce enough loss to compensate for the change to the patch line. This, of course, reduced the available range of compensation for severe weather conditions, but only to the extent of about 8–10 per cent., and sufficient range is, therefore, available to meet any conditions likely to be encountered on this route.

Crosstalk

In dealing with one system the crosstalk

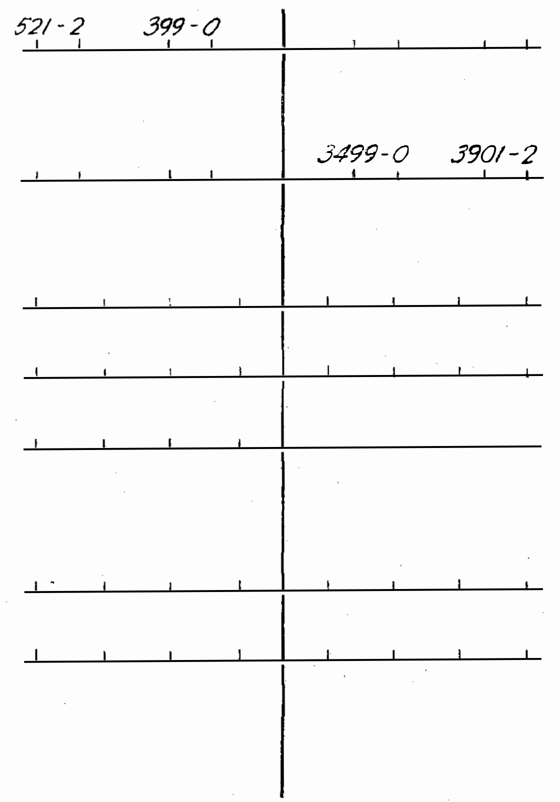


Fig. 10—*Typical pole head diagram.*

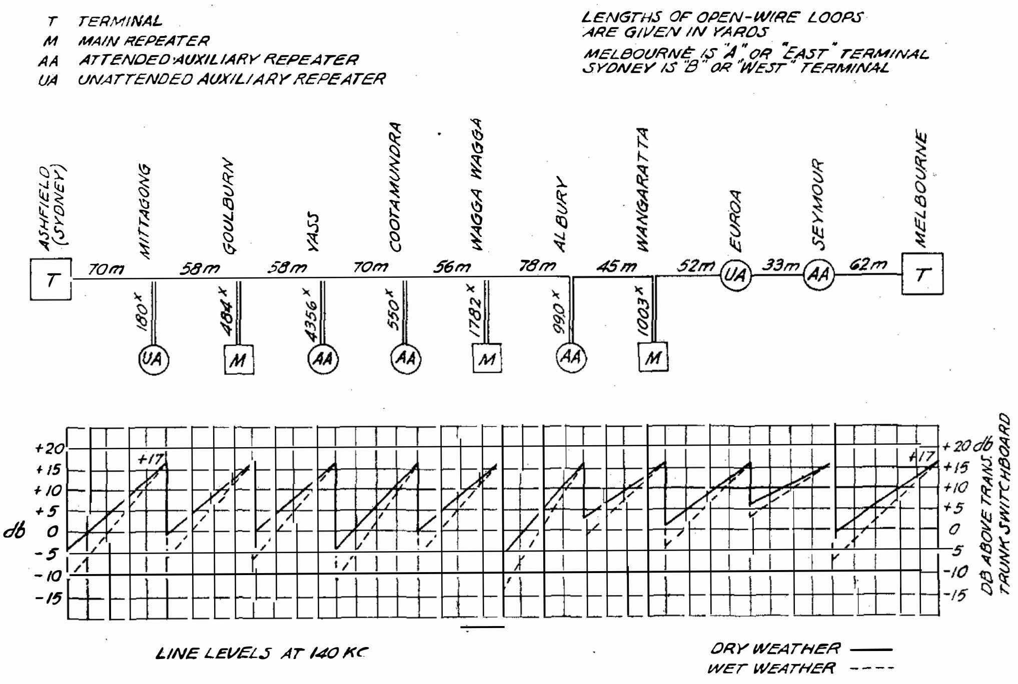


Fig. 9—*Line layout and level diagram.*

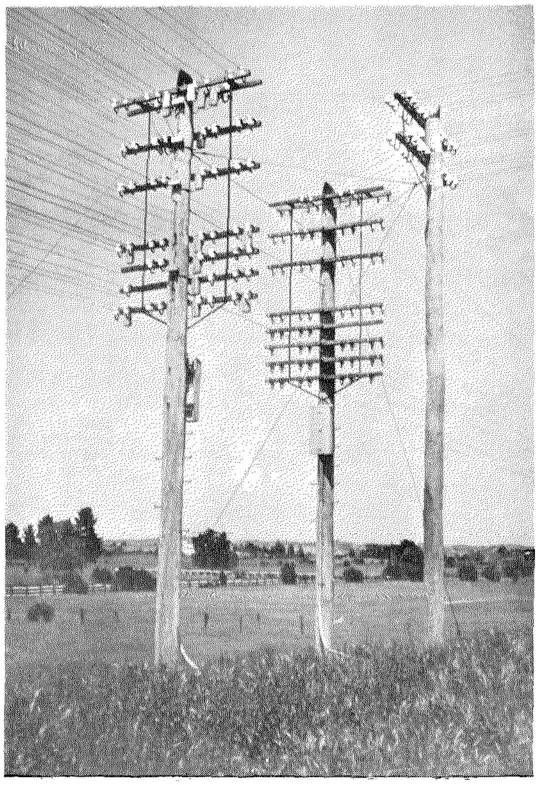


Fig. 11—Typical Y-pole arrangement.

problem is not acute, but is confined to keeping down the coupling between the two sides of a repeater in order to provide an adequate singing margin. As can be seen from Fig. 9, open-wire loops are required at most stations to bring the J and other pairs from the main route into the stations. The problem was thus complicated by the introduction of near-end crosstalk between the "in" and "out" pairs on the loop. In places where long loops occurred, it was necessary to re-transpose and select pairs. At Wangaratta a new loop for the J normal and spare leads had to be erected as, previously, all the carrier pairs entered the station through a continuously loaded cable. A typical "Y" pole arrangement at the junction of the main route and open-wire loop is shown in Fig. 11.

The crosstalk paths involved are indicated in Fig. 12, which illustrates the arrangement at an auxiliary station such as Yass. Here some pairs go straight through on the main line, while others, including the J pairs, are taken into the station over the loop. The type J repeater is shown. The direct near-end crosstalk path in the loop is shown by A, and the interaction crosstalk path by B. One of the important components of the interaction crosstalk is that resulting from conversion of transverse currents in the J pair to longitudinal currents in that and other pairs on one side of the repeater. These currents then flow back to the other side, and enter the J pair as transverse currents again. Such crosstalk is controlled by longitudinal choke coils which were inserted in all pairs on the north side of the repeaters, and in the J normal and patch pairs on both sides of each repeater. The longitudinal choke coils marked X were used as additional protection for the lead-in cable, loading units and line filters where long open-wire loops existed.

Another important component in the interaction crosstalk is that due to near-end metallic circuit coupling between the J pair and other pairs on both sides of the office. In the case of multi-system operation this would require a crosstalk suppression filter in all pairs at the auxiliary stations. On the Sydney–Melbourne route, with only one system involved, this is a negligible factor except in the case of one pair combination. This particular path is from 521–2 (the spare J pair) back into itself on the other side of the office by way of 399–0. If the J system were operating on 521–2 on both sides of the office simultaneously the singing margin would not be adequate. A special crosstalk suppression filter was inserted in 399–0 at all auxiliary points to overcome this difficulty.

The type of crosstalk paths which are of interest at a main repeater station in the case of a single system are shown in Fig. 13.

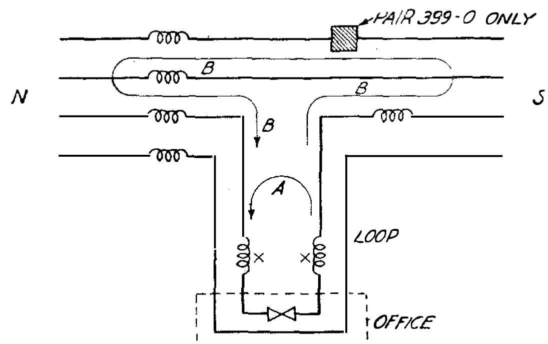


Fig. 12—Crosstalk paths—auxiliary office with loop.

www.americanradiohistory.com

(1) Path A indicates the direct near-end coupling between the J pairs in the entrance loop, and must be reduced by careful transposition and segregation.

(2) Path B shows the longitudinal currents in the north line returning and coupling longitudinally in the loop, and on the south line and back again on the south entrance pair as transverse currents. Longitudinal choke coils were fitted on the line in the positions indicated to reduce this form of crosstalk.

(3) Path C shows crosstalk currents from the north J pair returning on another pair and being amplified in the B–A direction of a type C repeater. The amplified currents return on the south J pair due to coupling on the south line. This type of crosstalk requires a "roof filter" in the type C repeater on the pair which is involved. Similarly a "roof filter" was necessary in the circuit of the carrier broadcast channel repeater.

    For other through circuits, or terminating circuits which might be connected through at the switchboard, dependence is placed upon low line crosstalk and high losses in the office equipment or cord circuit to avoid the need for any special treatment. In particular cases the total coupling may be too high and require the use of crosstalk suppression filters, as on pair 399–0 at the auxiliary offices.

Paths B and C, mentioned above, apply particularly to Wagga Wagga, as Goulburn and Wangaratta had separate loaded cables for the non-J type C pairs, and consequently less coupling.

Treatment of Cables

On the assumption that satisfactory singing margin requirements for the first system could be met by the suitable choice of pairs in the loops, and the use of longitudinal choke coils, the utmost benefit from these loops was sought in order to bring the J pairs as close to the equipment as possible in open wire. This reduced the entrance and lead-in cables to a minimum. At all stations it was found more convenient to use a new type of disc-insulated cable for the J pairs rather than paper-insulated cables where such existed.

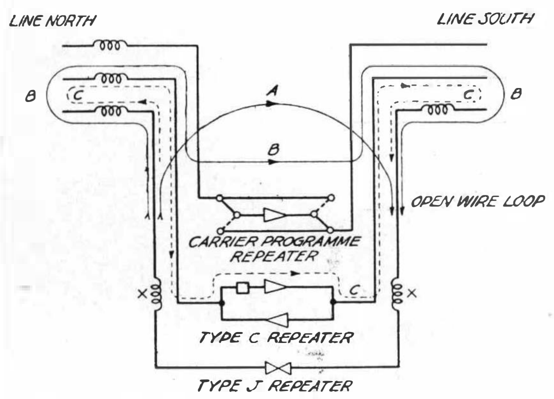


Fig. 13—Coupling paths affecting singing margin at main repeater station.

The new cable consists of four 16 A.W.G. conductors in star-quad formation supported by hard rubber disc insulators, so that the conductors occupy the corners of a square of quarter-inch size. The insulators are small and spaced at intervals of one inch, so that the effective insulating medium is air or gas. The pairs in this cable, formed by the diagonals, have a capacitance of only 0.025 microfarad per mile, which enables their impedance to be matched with the open-wire line by loading at an interval of 600 feet. When loaded the cable introduces a loss of approximately 1.2 db. per mile at 140 kc. Apart from the desirability of having low losses in the entrance cables, it is also necessary, from consideration of crosstalk, to avoid reflection due to impedance mismatch at the junction of the open-wire line and entrance or intermediate cables. It was contrived that the majority of the lead-in cables on the Sydney–Melbourne route were quite short, i.e., less than 150 feet in length, and these could be satisfactorily loaded by means of a single adjustable loading unit located at the equipment end of the cable. This unit was adjusted to give the best values over the J frequency range when measuring the return loss between the cable, terminated in the equipment, against a 600-ohm resistance. The measurement was made on the cable at the junction of the open-wire line, 50 feet compensating leads being used in order to make the connection to the top of the pole. Apparatus set up for actual measurements is shown in Fig. 15. A 600-ohm resistance was used as a reference impedance in lieu of the line because it was impracticable to take the line out of service during these measure-

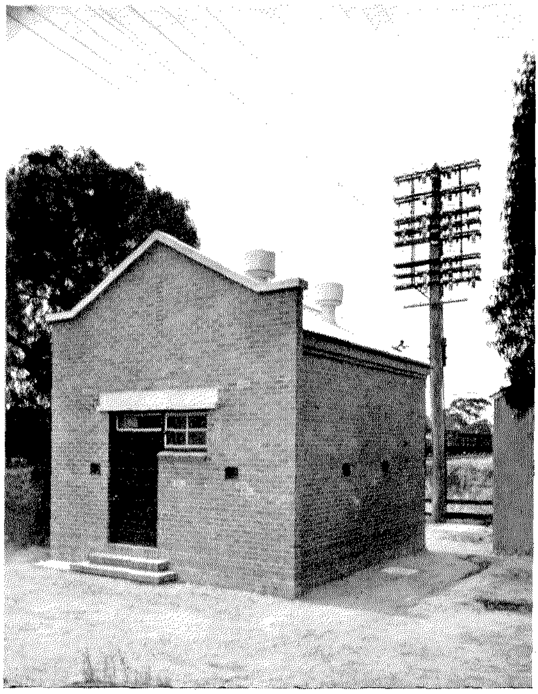


Fig. 14—Euroa repeater station.

ments. The general objective of these adjustments was to obtain return losses better than 26 db., which corresponds to a reflection coefficient of 5 per cent.

Cables longer than 150 feet were necessary at the following places:

Melbourne Entrance Cable	870 feet
Melbourne Intermediate Cable ..	468 feet
Yass In and Out Entrance Cables ..	871 feet
Seymour In and Out Entrance Cables	210 feet

The Melbourne entrance cable and the Yass cables were loaded with terminal loading units and one intermediate load in each case. The presence of only one intermediate loading point enabled the building-out of the sections to be made at the terminal loads only. The loading coils at the line end of the cable were mounted on the crossarms of the junction pole itself, as near to the J pair terminal insulators as possible. In this way the leads from the coils to the longitudinal chokes, protectors and open-wire connections were kept very short.

The intermediate cable under the railway crossing in North Melbourne required terminal loading coils only. Similarly, at Seymour, there was no necessity for an intermediate load, but as the cable section was slightly greater than could be compensated by a single loading unit at the office end, an additional coil was mounted on the pole.

Throughout the route one pair in the disc cable was used for the J pair and the other for the spare line. Terminal loading coils at the junction poles and intermediate loading coils were provided for the spare pair, but the loading unit and line filters at the equipment end were only provided for the main pair, patching being performed on the line side of the loading unit. With no crosstalk problem involved, it was found that the adjustments of these units, when made for the main 200 lb. pair, were also satisfactory for the spare 300 lb. pair.

After the building-out adjustments on the various loading units were completed and the return loss requirements met, crosstalk measurements were made between the pairs in a quad, and also between pairs in the "in" and "out" quads at repeaters. Where necessary, crosstalk balancing condensers associated with the loading coils were adjusted to give optimum results.

Transmission Aspects

Figure 9 shows the power levels at 140 kc

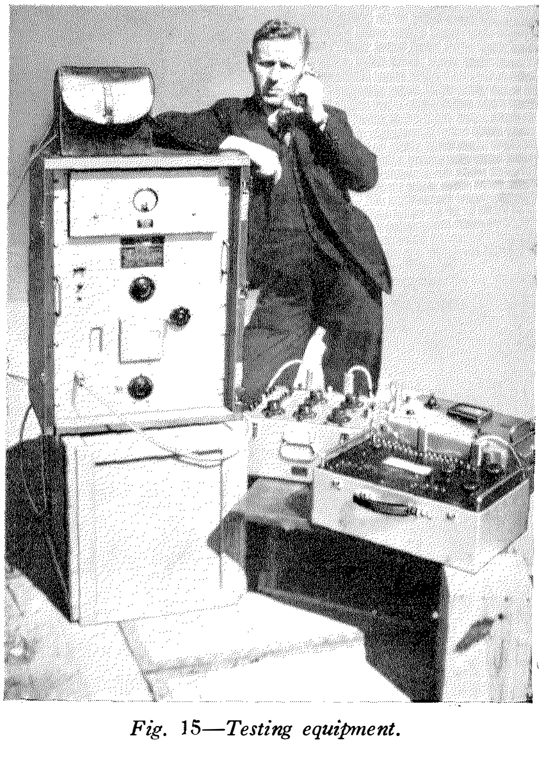


Fig. 15—Testing equipment.

www.americanradiohistory.com

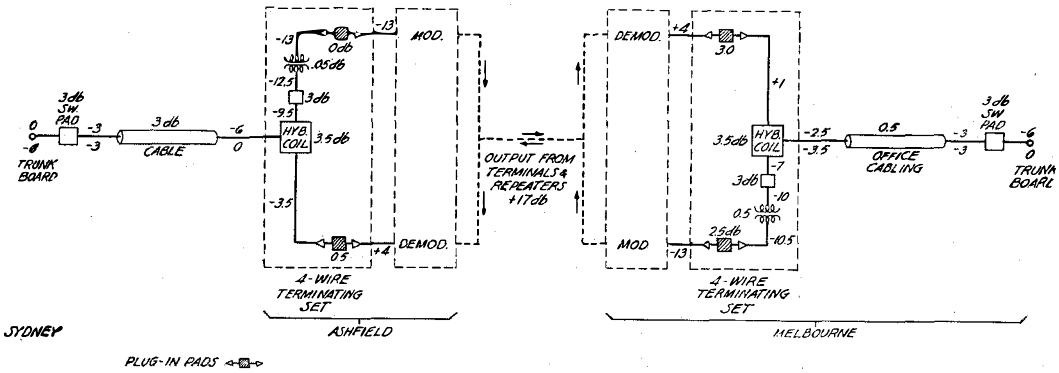


Fig. 16—*Overall transmission levels.*

between Melbourne and Sydney. The output per channel from each terminal repeater is 17 db. above the transmitting trunk testboard level, and the pilot channel power at these points is 10 db. below 1 milliwatt. The circuits are lined up between the trunk boards to give an overall loss of 6 db.; which includes 3 db. switching pads and the loss in the cable between the Ashfield terminal and the Sydney office. Plug-in pads are inserted in the 4-wire terminating sets to enable the system to work at its correct levels of −13 db. to the modulator, and +4 db. output from the demodulator. The arrangement is illustrated in Fig. 16.

Figure 17 shows a typical loss-frequency characteristic measured from "MOD. IN" to "DEMOD. OUT." The broad band obtained by the use of crystal filters is evident.

The noise measured on the individual channels at the time the system was placed in service was approximately 15 db. above reference noise of 10^{-12} watt at a point corresponding to −6 db. in the circuit. These measurements were made in October, and it should be appreciated, therefore, that somewhat higher values of noise may be experienced during the bad static season.

Interchannel crosstalk was measured by observing the interference produced on the eight idle channels when zero volume talkers were speaking on four channels selected arbitrarily. The measurements were made by different observers, using one of the disturbing channels for comparison. The values obtained were satisfactory, although this represented a severe test condition, since the chance of obtaining a combination of such high-volume talkers is very small. Such crosstalk was unintelligible, of course, and some additional tests were made by measuring the actual noise produced in the disturbed channels. These values also were within the desired limits. Under actual working conditions, with traffic passing on 11 channels, no appreciable increase in noise was noticeable on the remaining channel due to interchannel modulation.

As anticipated, crosstalk into the carrier broadcast channel operating in the range 34–42.5 kc on one of the pairs on the route caused considerable difficulty, and when this was in operation it was necessary to close channels 1 and 2 of the system to prevent interference. Although it might have been possible to modify the circuit arrangements to enable these channels and the broadcast system to work satisfactorily when the programme was being transmitted in the Sydney–Melbourne direction, the interference increased greatly when the direction of the programme circuit was reversed. The treatment of the broadcast channel is still under consideration.

TESTING AND MAINTENANCE

Very little routine testing is required for the maintenance of the system. The automatic gain controls maintain the repeaters at their proper output levels, and the daily line-up, as

www.americanradiohistory.com

performed in the C type systems, is unnecessary. A monthly check of the overall equivalent will usually be sufficient, small changes in the individual channels being corrected by the demodulator potentiometer at the receiving terminal. For this purpose the ordinary voice frequency testing apparatus existing at the terminals is adequate.

In order to make the necessary installation tests and adjustments, and for subsequent periodic and fault locating tests, some newly developed high frequency measuring equipment was provided. This consisted of an oscillator, a transmission measuring set, an impedance bridge and an amplifier detector. The oscillator has a frequency range of 50 to 150 000 cycles. It is of the heterodyne type, and is adjusted simply by rotating a handle, the frequency setting being observed on a moving cinematograph film. This greatly adds to the rapidity with which such tests as quality, crosstalk and return loss measurements can be made. The transmission measuring set employs a thermocouple, and is carefully shielded to enable its full attenuation range of 100 db. to be utilized at frequencies up to 150 kc. The amplifier-detector is employed where the sensitivity required is greater than that provided by the thermocouple in the transmission measuring set. The impedance bridge finds its chief use in adjusting the loading to meet return loss requirements. All this apparatus is shown in Fig. 15.

The remaining important periodic tests are checks of the valves and grid battery voltages at monthly intervals. A testing socket is fitted on all panels containing valves, and when the vacuum tube test set is plugged into the panel, heater and plate current and cathode activity measurements may be made on the valves without interfering with the operation of the system. The Sydney–Melbourne system is taken out of service for a certain period during each week, when traffic is at a minimum, to enable ageing valves to be changed. When more tube test sets, which have been ordered, are available, it will be possible to make measurements at all stations at approximately the same time, and to restrict this removal from service to a monthly interval.

Unattended auxiliary repeater stations are normally visited once a month on a routine basis in order to test the valves and check the power plant. Where attendance is fairly readily available, as at Euroa and Mittagong, more frequent visits for inspection purposes may be arranged as desired. In case a fault develops during normal operation of the system, an alarm is relayed to the controlling main repeater station via the alarm trunk circuit. The various alarm circuits, e.g., blown fuse, power failure, etc., are connected to contacts of a selector switch at the auxiliary repeater. Another selector switch with its associated relays is located in the main repeater, the connection being provided between the two by means of a D.C. telegraph circuit. The occurrence of an alarm condition at the auxiliary stations causes the main station selector switch to step, and this in turn causes the auxiliary station selector to step under the control of the main station. On arrival

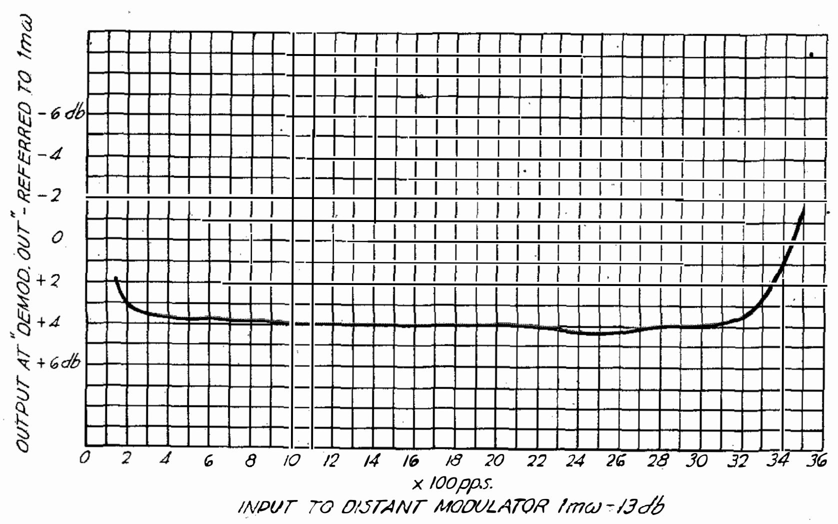


Fig. 17—*Typical channel quality curve.*

at any alarm contact, visual and audible signals are given at the main station, indicating the particular alarm conditions prevailing at the auxiliary station. The attendant at the main station thereupon takes the necessary action.

The majority of the auxiliary repeaters on the Sydney–Melbourne route are located at points which already have some form of attention available, and consequently at these stations the alarm trunk units are replaced by a simplified circuit working in conjunction with lamp indicators. Mittagong and Euroa are equipped as unattended stations, and their alarms are taken to Goulbourn and Wangaratta, respectively.

The Sydney–Melbourne system is established to work on a 24-hour basis, but this involves a maintenance problem, since the spare line is not equipped with repeaters or line filters, and consequently patching must be carried out on individual line sections. At attended stations in the daytime this operation is performed by a mechanic, but at night, when the station is unattended, the night telephonist is required to change the circuit under directions from the controlling station. At Mittagong the equipment is located in the same room as the telephonist who carries out the changeover to the spare line at all times. At Euroa office, which is completely unattended and located about half a mile from the office, the mechanic is called in by the Wangaratta station.

PROVISION OF FUTURE SYSTEMS

The important consideration in establishing additional systems on the Sydney–Melbourne route is that of crosstalk between the systems. Crosstalk coupling tends to increase with frequency, and, unless a line is especially transposed for the higher frequencies, may reach very high values. Even when a line is so transposed there are additional requirements imposed on the symmetry of the line, particularly pole spacing and wire sag, and also on the accuracy of the impedance matching at the end of each line section.

Special provision must also be made for the suppression of interaction crosstalk at repeater stations, since the problem is no longer one of merely providing a satisfactory singing margin. The treatment in this case calls for eliminating the present practice of operating north and south pairs over a common entrance loop. This can be done, either by constructing a new repeater station at the end of the open-wire loop, or by bringing one direction in over the loop and the other over cable which is available at all points in question. The use of the cable would require the erection of a small building at the open-wire end to house the line filters. Crosstalk suppression filters would also be required at the auxiliary stations on all non-J pairs, and possibly at some of the main repeaters.

Measurements which have been made over the Sydney–Melbourne route indicate that no more than minor transposition changes will be required to obtain line crosstalk conditions which will permit a second J system of the SA type to be operated. This gives the maximum staggering advantage with respect to the NA system.

ACKNOWLEDGMENTS

The authors wish to express their appreciation for the invaluable co-operation of the engineering and installation staff of the Department during the planning, installation and testing of the system. They also wish to thank Messrs. C. J. Griffiths and C. Anquetil for the photographs which are included in the paper.

REFERENCES

(1) "A Twelve Channel Carrier Telephone System," by B. W. Kendall and H. A. Affel, *Bell System Tech. Jour.*, January, 1939.

(2) "Magnetic Generation of a Group of Harmonics," by E. Peterson, J. M. Manley and L. R. Wrathall, *Bell System Tech. Jour.*, October, 1937.

(3) "Line Problems in the Development of the Twelve Channel Open-Wire Carrier System," by L. M. Ilgenfritz, R. N. Hunter and A. L. Whitman, *Bell System Tech. Jour.*, April, 1939.

Fundamental Transmission Planning of Telephone Networks

Local and Toll Area Planning to meet the C.C.I.F. Recommendations

By BRUCE H. McCURDY

PART II.—ALLOCATION OF TRANSMISSION STANDARDS IN THE NATIONAL NETWORKS

EDITOR'S NOTE: *Part I of this article which appeared in our July, 1939, issue, dealt with the general transmission problem imposed by the new C.C.I.F. recommendations regarding the maximum permissible transmitting and receiving losses in the national systems if the agreed overall limits for an international connection are to be met. In Part II some of the practical steps necessary in co-ordinating national design so as to meet these international limits are discussed.*

IV. RECAPITULATION OF THE GENERAL OVERALL REQUIREMENTS

In Part I of this article it was shown that in order to meet the new C.C.I.F. requirements for the overall reference equivalent on international connections, the typical national system shown in Fig. 3 must meet the following requirements as regards reference equivalent and attenuation :

Case A.—The General "via" Connection.

Transmitting.

$X+a+b+(c)_t$ = 2.35 nep. (20.5 db.)
$X+a+(d)_t$ .. = 2.35 ,, ,,
$X+e+(f)_t$ .. = 2.35 ,, ,,
$X+(g)_t$ .. = 2.35 ,, ,,

Receiving.

$X+a+b+(c)_r$ = 1.85 nep. (16.5 db.)
$X+a+(d)_r$ = 1.85 ,, ,,
$X+e+(f)_r$ .. = 1.85 ,, ,,
$X+(g)_r$ .. = 1.85 ,, ,,

Case B.—The "Terminal" Condition.

Transmitting.

$a+b+(c)_t$ .. = 1.95 nep. (17 db.)
$a+(d)_t$ .. = 1.95 ,, ,,
$e+(f)_t$ .. = 1.95 ,, ,,
$(g)_t$ .. .. = 1.95 ,, ,,

Receiving.

$a+b+(c)_r$ .. = 1.45 nep. (12.5 db.)
$a+(d)_r$ .. = 1.45 ,, ,,
$e+(f)_r$ .. = 1.45 nep. (12.5 db.)
$(g)_r$ .. .. = 1.45 ,, ,,

As far as the C.C.I.F. is concerned, the allocation of losses and the assignment of limiting reference equivalent values for the various parts of the national network can be made in any way convenient to the national Administration or operating company so long as the above values are met as seen from the international switching points. Consequently, the national Administrations and operating companies have full opportunity to make these allocations so as to produce the maximum overall economy within their respective networks. Their problem is, therefore, the co-ordination of their various local, provincial and national standards with the established international standards in such a way that the latter may be met without forcing, in any part of the network, design standards which are uneconomical when viewed from the purely national standpoint.

V. ALLOCATION OF LOSSES IN THE NATIONAL NETWORK FOR NATIONAL SERVICE

1. National Transmission Standards

Presumably there will be already in existence a set of national transmission standards for both local and long-distance service which the Administration or operating company will have set up as a result of its own experience. It is not the purpose of this paper to discuss what trans-

www.americanradiohistory.com

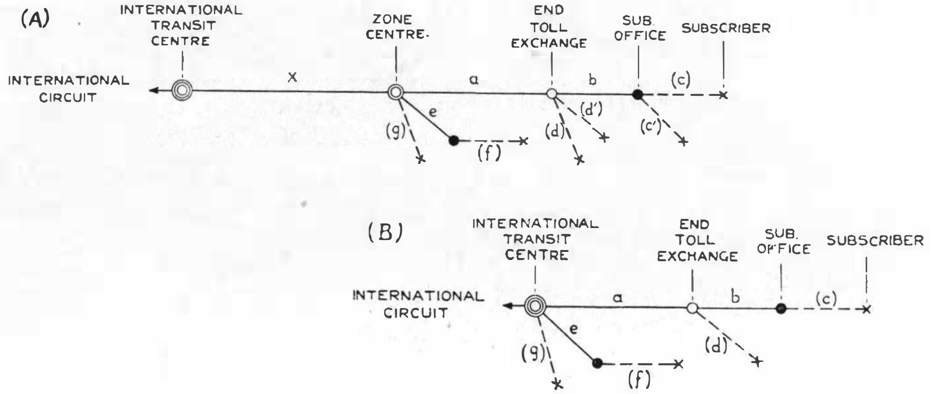


Fig. 3.—Typical national connections.

mission standards should be adopted; there is an extensive literature on the subject, and most Administrations have decided the limiting overall standards to which they wish to work. A few fundamental factors may, however, be mentioned for the sake of completeness.

In the first place, it may be said that there is a range (in the present volume method of rating) between about 10 db. and 25 db. within which a change in volume will very slightly affect what we may term "subscriber satisfaction."* The average subscriber will notice a slight difference in volume between, say, a 10 db. overall connection and a 25 db. overall connection, but only in exceptional cases, such as the presence of excessive noise, will his conscious effort in talking vary appreciably. Below 10 db. it is very doubtful whether the subscriber would consider increased volume to be representative of a better grade of transmission, and there are very definite indications that, as we approach a zero overall connection, the increased volume actually becomes a source of annoyance, causing the subscriber to hold the receiver away from the ear to avoid the shock of the louder sounds.

Above approximately 25 db., the performance of the connection as viewed by the average subscriber drops rapidly with volume until at about 40 db., the limit set by the C.C.I.F. as the maximum permissible overall loss for an international connection, the service becomes uncommercial. However, although the performance deteriorates gradually from 25 db. to the 40 db. upper limit, the subscriber will usually make certain allowances as the talking distance increases; always assuming, of course, that the connection is commercial and does not involve undue strain.

Leaving aside economics, it would be desirable to maintain transmission always within the 10–25 db. range. Expense, however, usually makes this impracticable and we are faced with the choice between a "perfect" service at an excessive price and a "satisfactory" service at a reasonable price. In simple language, the ordinary subscriber wants as near perfect service as he can get on the type of service which he uses most, i.e., the local service. He would like the same on long-distance service, *but* if the cost can be made somewhat more reasonable by departing slightly from the ideal standard, he is willing to accept this slightly lower grade of service, *provided* it does not induce any undue conscious strain. From the operating company or Administration standpoint, the problem is to keep as near the "ideal" standard as is consistent with the rates which the average subscriber is willing to pay; in other words, to give the subscriber the best possible value for his money, keeping in mind his tolerances as the length of connection increases, but not taking advantage of them to force upon him a lower grade of transmission than he should fairly be expected to accept.

As a result of the above factors, the practice

---

* This should not be confused with "subscriber reaction" as determined by repetition rate or other similar rating methods.

www.americanradiohistory.com

has generally grown up of giving a limiting grade of transmission on various types of calls somewhat along the following lines :

Limiting Local Area Standard.	
Business area to business area ..	18–20 db.
Business area to residential area ..	20–22 ,,
Residential area to residential area ..	22–24 ,,
National Long-DistanceStandard.	
Limiting subscriber to subscriber loss	30–35 db.

A survey recently made by the Fundamental Plan Committee of the C.C.I.F. showed that most European Administrations have set up standards more or less in accord with the above limits. It indicated, however, that in attempting to meet the overall national standard and the international standards, circuits of a grade much better than that required for purely local and national traffic were supplied in many parts of the various plants ; for this reason it would appear that the plant was, in many instances, more expensive than necessary.

2. *Co-ordination of Local, National, and International Standards*

With some items of plant, such as subscribers' sets and local loops which are used both for local connections and for long-distance connections, it is obvious that they are subject to, and must meet, a number of specific conditions. The subscriber's loop and subset, for instance, must meet three sets of conditions : (*a*) those imposed by the local area standard ; (*b*) those imposed by the national long-distance standard ; and (*c*) those imposed by the C.C.I.F. limits for national transmitting and national receiving losses.

It might be argued here that these three sets of standards could be met by means of adjustable gains introduced when a given link is prolonged to form part of a longer connection. There are technical, operating and economic disadvantages which make such a procedure impracticable except when the longer circuits are inter-connected to form a single built-up circuit. The introduction of gain every time a circuit is prolonged involves added costs and operating disadvantages, and can be done only when the cost of the necessary equipment and the increased operating costs can be shown to be less than the savings which would be obtained if each link were designed to meet only its own specific local requirement.

Furthermore, such factors as echo, crosstalk, and stability place a definite limitation on the amount of gain that can be introduced, and regardless of whether the gain is introduced at the switching point or is incorporated in the original set-up of the circuit, the cost of the individual circuits is very nearly a function of the *net* loss at which they work on the built-up connection, and not the loss to which they may be designed for the purely terminal case. Consequently, the proper allocation of loss to the various parts of the network and the proper economic balance between the various parts of the network resulting from these allocations of losses will have a very direct effect on the overall cost of the service provided.

There are, of course, numerous ways in which the engineer may arrive at a distribution of losses which will give minimum overall costs. As has been mentioned in Part I, it would be possible by making a series of trial-and-error analyses with different loss allocations, to arrive at an exact distribution of losses which, *for a given network*, would result in minimum overall costs. The more extensive the network, the more complex such an analysis would be ; and when we approach the problem presented by a general national network such as those existing in the various countries of Europe, the determination of an *exact* distribution of losses to each unit of the plant is beyond the range of practical accomplishment. It is, furthermore, made impracticable by the fact that no telephone network can be considered as being static : its form, the number of subscribers and lines, is constantly undergoing changes ; the type of service being given varies from year to year, and the relative costs of each type of plant are changing as the art progresses.

Consequently, even though we might conceivably arrive at a theoretically exact allocation of losses to give minimum overall costs for a given layout, it would not be valid when the size of the network, the type of service given, and the relative costs of the various units of plant varied from those assumed in the original calculation. Therefore, both from the standpoint of practical accomplishment and in order to cater as effectively as possible for changing conditions,

www.americanradiohistory.com

it is necessary to attack the problem from a rather more general standpoint.

It would be well to emphasize, however, that this broader treatment should not be taken as a reflection on the value of fundamental plan studies. The fact that a solution which is exact to the last decimal point is impracticable should not warrant throwing away the very important savings which can be obtained by a " partial " solution. And the savings which can be obtained by even a "partial" solution, if properly carried out, are sufficiently great that they may well spell the difference between a satisfactory service at a reasonable cost on the one hand, and either an unsatisfactory service and/or unreasonably high costs on the other. The main purpose of this article is to show how the complex overall problem may be broken down into a series of relatively simple problems each within the range of practical solution, first within themselves and then with regard to their bearing on the rest of the plant.

3. *Basic Divisions of the Overall Network*

The key to an effective breakdown of the complex overall problem into a number of relatively simple sub-problems lies in the proper selection of the groupings of the plant which are to be studied as individual units. Obviously, these units must correspond with some basic characteristics of the plant and/or the service being given, and have certain fundamental characteristics in common. Experience has shown that probably the best common denominator in such a breakdown of the overall problem is what may be termed "major field of use," that is, the network should be divided into units, each of which is characterized by a certain definite major field of use.

There is, for instance, the local exchange network comprising the subscribers' sets and associated loops, all connected to a single central office exchange. The major field of use of this unit of the network is the interconnection of subscribers within a given exchange area. Next in line in this method of grouping would come the junction plant: the lines which provide for the interconnection of a group of such local exchanges either directly or through a "group centre." There may be two classifications of so-called junction plant: that used merely to interconnect a unified group of centres, such as the various centres which make up a large multi-office city area, and that used to concentrate the long-distance traffic of the local centres at a central distribution point (the "group centre" or "end toll exchange" of the standard C.C.I.F. circuit). In such a case the junctions used only for local service do not enter into the long-distance allocation problem except in so far as their design may have affected the loss allocation in the loop plant of the associated group of local exchanges.

The next major division would be the long-distance plant proper. The sub-division of this latter into "provincial networks" and "national" or "regional networks," is not so self-apparent as in the case of the sub-divisions just mentioned. If, however, the traffic flow is studied, it will be seen that there is usually a very definite grouping of circuits into "provincial" and "regional" which, if well defined and established, will aid greatly in the efficient planning of the overall network. Actually, of course, this selection of "group centres," "zone centres" and "regional centres," is a study in itself. The essential steps involved have already been covered in the article previously mentioned entitled "Toll Plant Engineering."

It is not the purpose of this paper to discuss the question of the toll centring plan proper, since it is essentially a traffic and commercial study. It should be stated, however, that without a logical and well defined toll centring plan, effective study of the efficient allocation of transmission losses in the overall plant will be practically impossible. The toll centring plan is the medium through which the general overall performance can be translated into performance requirements for the individual circuits, and it is for this reason that the C.C.I.F. has requested each Administration to provide the Fundamental Plan Committee with a diagram of its "standard circuit" and either a list giving the classification of all centres or a diagram such as Fig. 4, which is the toll centring plan of the Rumanian Telephone Company's system.

4. *Design Characteristics of the Basic Divisions of the Network*

Having prepared a general toll centring scheme, it will be found that the various groupings of the

www.americanradiohistory.com

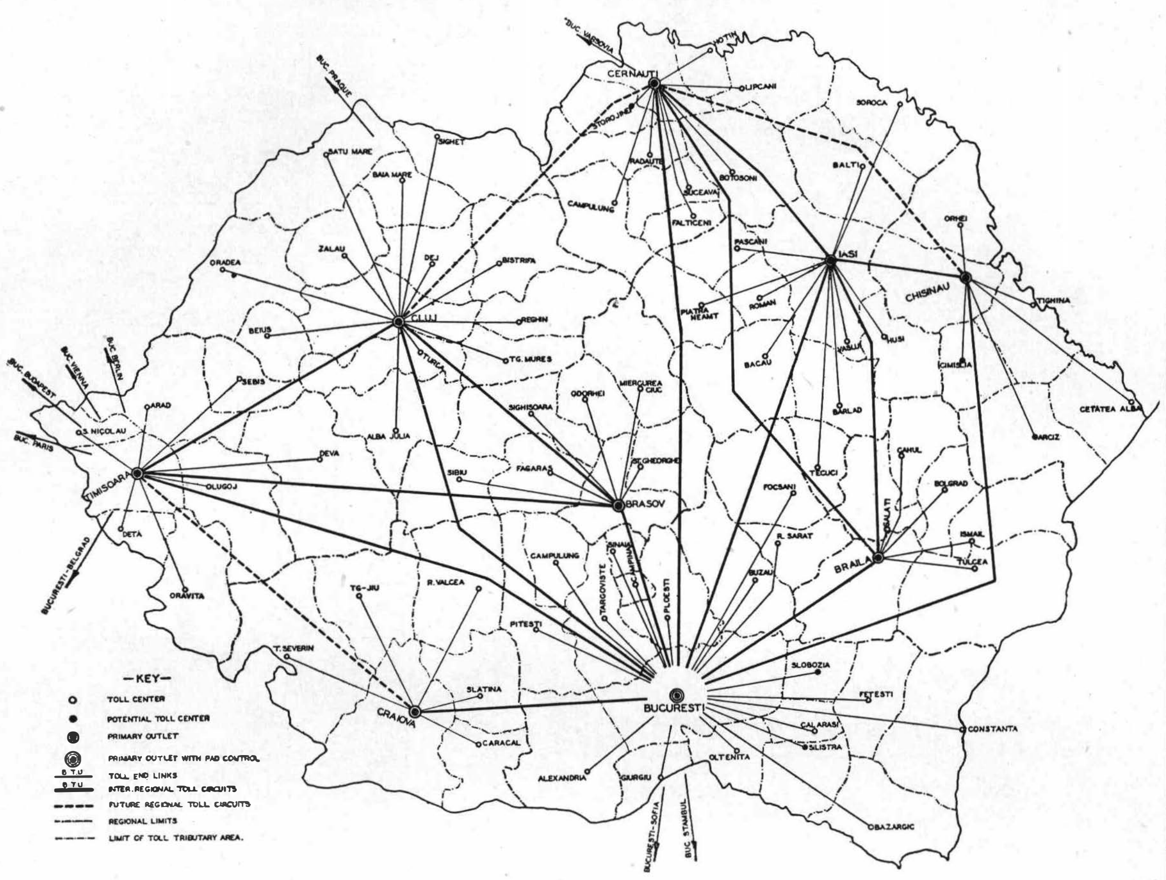


Fig. 4—Toll centring plan for Rumania.

network, in addition to being characterized by a given major field of use, will also have certain very definite design characteristics, especially with respect to the cost-vs-equivalent* relationships, which are of vital interest to the fundamental planning engineer. These may be summarized as follows:

(a) The Local or Exchange Area Network

In general the local loop will be non-loaded and non-repeatered. In certain special cases the loading of extra-long loops will be justified, but the above statement will hold for the general case. Consequently, the cost will increase more or less directly with the grade of transmission set as standard for the local area. Using a typical subset, the relations between the grade of transmission and the copper required for the loop will be as shown in Fig. 5.

Actually, of course, the cost of a single loop is small as compared with the cost of a junction circuit, and even smaller as compared with a long-distance circuit. The great number of loops, however, as compared with junction circuits and long-distance circuits, makes it essential that the former be designed as economically as possible. It is a very safe starting point in the allocation of losses to assume that no exchange area plant should be up-graded beyond the point necessary to meet purely local requirements unless it can be proved that the costs of such up-grading are less than the resultant savings which can be made in the junction

---

* In this paper the term "equivalent" is used to denote transmission equivalent, and should not be confused with "reference equivalents" which implies a direct or indirect comparison with Master Reference System by voice and ear test (telephonometric measurement). On occasion in the present paper, the word "equivalent" has been used to denote the net loss of a circuit which is defined as the insertion loss of the circuit between 600-ohm impedances.

www.americanradiohistory.com

and long-distance plant with which it must interwork.

(*b*) *Junction Plant*

In general, due to the short lengths involved, and the fact that D.C. supervision is often required, it will usually be found that junction plant will not be repeatered, but may, and often will, be loaded. Consequently, as in the case of the local loop, there will be a fairly constant increase in the cost of a given junction as the equivalent at which it must work is decreased. The slope of this cost-vs-equivalent curve will not be as great as in the case of the local loop, nor will the number of junctions be as great as the number of loops. Consequently, the statement just made, that no local area plant should be up-graded beyond the requirements of purely local service unless it can be proved that this up-grading will result in a greater saving in the plant with which it must interwork, still holds.

However, it is by no means a foregone conclusion that a study of the relative costs of loop plant and junction plant, when made, will not in certain cases favour the up-grading of the local loops. This is especially true in the case of a large multi-office area where there is a large amount of inter-office traffic, and consequently a large number of junction circuits involved. In fact, economy demands that in such a closely inter-related area a series of so-called "loop and trunk" studies be made with various assumed losses in the junction plant in order to determine the point of minimum costs for the loop-plus-junction plant as a whole.

(*c*) *The Long-Distance Network*

In the long-distance network, the use of repeaters to reduce the attenuation of the circuit makes the cost-vs-equivalent curve a somewhat irregular one. Theoretically, there is no reason why this curve should not be more or less smooth as is the case for loop plant and junction plant, the cost increasing gradually as the equivalent is decreased, provided one assumed a multiplicity of gauges, repeater spacings, etc. In actual practice, however, the practical and economic advantages of standardizing on a few gauges of conductor, the use of standard repeater spacings in order to allow concentration of repeaters at certain fixed intervals, the use of a standard repeater, etc., far outweigh the possible savings which might result if each individual circuit and its associated equipment were designed strictly in accord with its length and required equivalent.

The result is that in actual practice the cost-vs-equivalent curve of modern long-distance circuits is a series of flat steps, and there are wide ranges over which the cost of the circuit is practically independent of equivalent. This is especially true with the advent of carrier-on-cable technique, in which the circuits provided are inherently of low equivalent, there being practically no economic advantage in favour of keeping them (at least in the via or transit condition) at higher equivalents.

In fact, if we were to start afresh, with no existing plant to consider, we might say that the loss allocated to the long-distance plant could be set at any (positive) value required. Unfortunately, however, there is in existence a large amount of plant providing 2-wire and 4-wire circuits which must be utilized for a considerable period to come. The circuits provided by this existing plant, mainly because of the limitations of echo, stability and crosstalk, have certain definite limitations with regard to the equivalent to which they can be made to work satisfactorily, and which will, therefore, impose certain restrictions on the loss allocation which can be made to the long-distance network. They may, and undoubtedly will, at some time in the future be

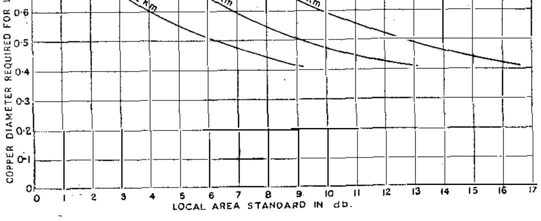


Fig. 5.—Relations between grade of transmission and copper required for various lengths of loop.

www.americanradiohistory.com

replaced by circuits utilizing the newer technique, and in making the long term studies of future loss allocations this fact should be given full weight. For the moment, however, they must be taken into account in any loss allocation that is made.

One of the advantages of a definite switching plan with specific loss allocations for each type or classification of circuit will be the possibility of gradually segregating these circuits and assigning them to the part of the network (terminal circuits, toll end links, short-haul transit service, etc.) where their higher net losses will have the least possible effect in limiting the possible loss which can be used up in loop and junction plant, the costs of which, as has been explained, are a very definite function of the loss which can be allowed to them.

To summarize, therefore, we may say:

(*a*) *Local Plant*

Cost increases rapidly with decrease in the permissible loss. Although the cost of each individual unit is small, the number of units is so large when compared with junction plant, and even larger with regard to long-distance plant, that every possible economy should be exercised in their design.

(*b*) *Junction Plant*

Cost in general rises as permissible loss is reduced, although the rate of this increase is not as great as in the local loop plant. In the case of large inter-office areas with a large amount of junction plant, it will be necessary to make a detailed "loop-and-trunk" cost study with different losses allocated to the two classes of plant in order to determine the most economical division of losses between the two.

(*c*) *Long-Distance Plant*

With new technique, cost is almost independent of equivalent, down to very low values (especially in the transit condition). With existing plant, and wherever 2-wire and 4-wire voice frequency circuits are used in the plant, cost will increase slightly as the equivalent at which the circuits must be worked is decreased; but there will always be wide ranges over which a difference in equivalent will not be accompanied by an appreciable change in costs.

VI. INHERENT LOSSES

Having prepared a general switching plan in which the various fundamental parts of the overall network are specifically defined with regard to their field of use and the part they play, if any, in the general long-distance connection, and having assigned to each class of service a certain limiting transmission standard to be met, and having available cost data giving the general cost versus equivalent relationship applicable to the network in question, the design engineer is in a position to study the question of loss allocations which will allow his various local and national standards of performance to be met without forcing in any part of the network a more costly grade of plant than is necessary to meet its major field of use; or, if some up-grading of plant is required, to determine where this upgrading can be made with the least increase in overall costs.

In the paper "Toll Plant Engineering" previously referred to, a method of attack was outlined which involved the determination of what was termed the "inherent loss" of each general classification of plant. "Inherent loss" was defined as the loss which would be encountered in each major classification of plant if it were designed as economically as possible to take care of its major field of use. The major field of the local loop, for instance, is the interconnection of the subscribers in a given local exchange area in such a way that the local transmission standard (say 18 db.–24 db.) will be met.

It might be argued that, having set the local standard, we have automatically established the "inherent" local loop loss, and that no further study is required. Actually, certain practical features of operating design limit the local loss, and a study will show that, except for the larger areas, the actual loss encountered will hardly ever reach the value which has been set for the limiting permissible subscriber-to-subscriber loss. In most countries, cables with conductors smaller than 24 gauge (0.51 mm) are not used. In a few countries, such as Spain and Rumania, 26 gauge (0.41 mm) has been found practicable and economical for a part of the local distribution, especially in the central portion of the larger cities, where the demand is heavy and the savings of both copper and duct space are therefore, appreciable. For light runs requiring less than 100 pairs, and where it is necessary to enter the cables at intervals to make circuit rearrangements, the savings involved in the use of this smaller gauge are usually not sufficient to offset the increased practical difficulties of splicing and maintenance. It is doubtful if conductors smaller than 26 gauge can be foreseen for general use, even though the gradual increase in the efficiency of subsets would allow it from a transmission point of view.

The modern subset is extremely efficient and, except from the standpoint of using up such of the older types of subsets as are in stock, there is practically no economic advantage in using a subset of lower performance than those now available. The older types of subsets in stock can be used in the portions of the plant which, because of the short loops involved, have large margins in transmission.

The general result is that in the smaller outlying towns and villages it will usually be found that even though the local standard may theoretically still be the same as that for the larger areas, in actual practice the loss which has been set as the permissible standard is never reached. In other words, there is actually a margin available which can be used up by the junction, and possibly even the long-distance connections, from these centres, without in any way increasing the cost of the plant in the local areas.

In the large multi-office areas with a number of exchanges, the case will be somewhat different. Practically the whole permissible loss will be used up in the local loop, and in many cases an actual limitation of the loss below the permissible exchange area standard will have to be made to allow for the unavoidable loss in the inter-office junction plant. As has already been explained, the amount by which the local loop can be limited in favour of the junction plant will have to be determined by a series of "loop-and-trunk" studies. Having made this study for the group area as a whole, we shall find that from the standpoint of the long-distance connection, there will be again a definite "inherent loss" for the group area as a whole which may or may not be the same as the theoretical limiting standard set for the group area. In other words, having designed the group area as economically as possible, as determined from the result of the loop-and-trunk studies, and then examined the result as seen from the group centre through which each of the exchanges involved receives its long-distance service, we may still find that there is a margin in transmission which may be utilized in, say, the provincial network which interconnects the various group centres. Whether or not there is any margin, we do have a definite starting point from which to work, since we know what loss such areas present, as seen from the end of the long-distance network when they are engineered as economically as possible to meet their major field of use.

In considering the "inherent loss" in the various parts of the long-distance network, the same general procedure would be followed; that is, we should examine the resultant equivalent for each general classification of long-distance plant such as, for instance, the provincial network. This latter would be designed to meet as economically as possible the long-distance standards within the provincial area, after obtaining the proper economic balance between the local-plus-junction plant, on the one hand, and the provincial long-distance plant on the other. The same would be true with the major or inter-regional network.

In these two latter phases of the problem it will be necessary to take into full account, as has already been mentioned, the effect of using existing circuits of the older type and the limitations which echo, crosstalk and stability impose on the equivalent to which such existing circuits can be reduced. The economic phase of this portion of the problem will be a balancing of the economics involved in using existing circuits with relatively high losses, as against new circuits with lower losses.

The inherent losses which were found in the Rumanian plant are given in the paper on "Toll Plant Engineering," and it may be of interest to summarize them here, together with a few notes on how they were arrived at. It was found, for instance, that if the various parts of the network were each engineered as economically as possible to meet this major field of use, as explained above, the practical features of design coupled with the size of the areas and lengths of circuits of various types involved were such that the "inherent losses" were as follows:

www.americanradiohistory.com

(1) *Inherent Local Losses*

Type of Centre	Inherent Limiting Losses in Local Plant as seen from the Toll Board			
	Average Limiting Loss for all Centres of a Given Category		Maximum Loss Encountered in Any Exchange	
	Transmission	Receiving	Transmission	Receiving
Bucharest "International Transit Centre" ..	—	—	15.3 db.	6.1 db.
Zone or "Provincial Centres"	9.1 db.	0.6 db.	11.2	3.2
Toll or "Group Centres"	7.1	0.2	9.9	1.9
"Tributary" or "Secondary Toll Centres" ..	2.2	1.2	4.3	3.5

NOTE: In the original article mentioned the figures given were in terms of inherent "toll terminal losses." The "toll terminal loss" is the average of the transmitting loss and the receiving loss, and is used as a matter of convenience when, as in the case of the Rumanian network, the same type of subset and the same general methods of local distribution are used throughout the national system. In the case of international connections and in national systems where there is not a uniformity of equipment and methods of local distribution, it will be necessary to deal with the transmitting and the receiving losses separately; for this reason the original figures have been broken down into their corresponding transmitting and receiving components.

(2) *Inherent Long-Distance Losses*

(*a*) *Toll End Links or "Provincial Circuits"*

The first general analysis of the provincial networks showed that the inherent loss in the various circuits of this class was very closely dependent on circuit length, due to the fact that they were mostly open-wire copper circuits without repeaters. In other words, if we plotted a curve showing the general distribution of inherent losses met with in this class of plant, it would follow almost exactly the distribution curve of circuit lengths. This curve, for Rumania, is shown as Curve A of Fig. 6. It was found, however, that if we designed each provincial circuit to a grade that would only meet the transmission requirements imposed by the problem of interconnecting the centres at its two terminals, it would be necessary to provide cord circuit repeaters at practically all provincial centres for use when a built-up connection involving two such links was required. A further study was, therefore, made in order to determine the relative economies involved between a plan in which cord circuit repeaters were used, and a second plan, in which all circuits within a given provincial zone were so engineered that on single-switch connections *within the zone* no cord circuit operation was necessary. In every provincial zone area it was found that it was more economical to design the plant in such a way that these intra-zone connections could be given *without* the use of cord circuit repeaters. Designing the circuits in this way, it was found that the distribution curve of inherent provincial circuit losses would then follow a curve such as that shown by Curve B of Fig. 6.

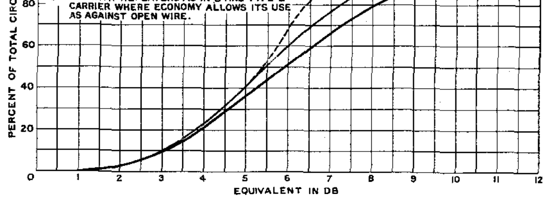


Fig. 6—*Toll fundamental plan for Rumania. Inherent equivalent of toll circuits.*

A third factor which had still to be investigated was the possible future use of other types of facilities, such as single-channel carrier, to provide the provincial circuits. It was found that, except for very short distances, it would be more economical to provide as many of the circuits as possible by means of single-channel open-wire carrier than to use voice frequency circuits. A certain amount of copper had, of course, to be strung in order to provide the base circuits for the carrier. Based on traffic projections over a period of years, a study was made of the possible economic use of carrier and the possibility of allocating carrier to all the longer circuits which showed the higher equivalents. Drawing the final distribution curve of the equivalents which would be encountered

www.americanradiohistory.com

in the provincial network, when each provincial network was thus engineered as economically as possible to provide for its major field of use (i.e., intra-provincial traffic), the actual inherent line losses met with would follow a distribution curve as shown in Curve C of Fig. 6.

(b) Major or Inter-Regional Network

A similar study was made of the inter-regional or major long-distance network interconnecting the various provincial centres, taking into account the same factors as noted above; that is, the practical economies involved in using various possible types of facilities and the economies involved in using cord circuit repeaters as against bringing the equivalent of the various circuits down to the point where cord repeater operation would not be required.

The economic advantages of three-channel open-wire carrier in this longer-haul network and the eventual extension of the 12-channel carrier-on-cable circuits in the cable network now being installed have made it possible to provide practically all the major long-haul circuits by means of these inherently low equivalent circuits. The result is that when these circuits are designed to give the necessary equivalent on purely terminal connections between the zone-centre or provincial-centre local areas, practically every one of them will have available inherent unused gain such that it can be worked at zero db. on transit connections without any increase in cost over that which would obtain if it were worked at a higher loss.

VII. PRELIMINARY ALLOCATION ON BASIS OF INHERENT LOSSES

The inherent losses encountered in other networks will vary, of course, from country to country, but the same procedure can well be adopted to give a first approximation of losses, although they may not be such that all transmission standards for complete interconnection are met; nevertheless, most of the subsidiary standards will be met if the plant is so designed that *each part serves as economically as possible its major field of use.* The various local networks for instance (and these make up a very large

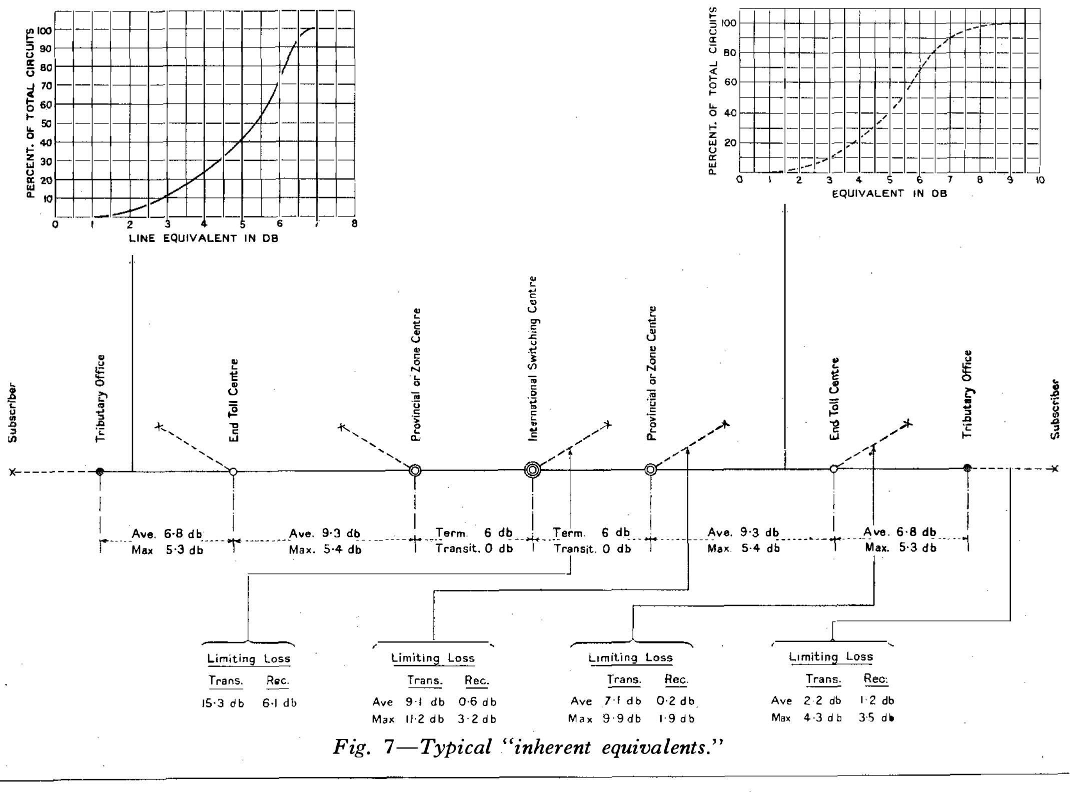


Fig. 7—Typical "inherent equivalents."

www.americanradiohistory.com

portion of the overall plant, as far as plant investment is concerned), will meet the local transmission standards. Likewise, the junction plant will be such that intra-group transmission standards will be met ; and both of these groups will have been engineered as economically as it is possible to design them, and still keep to the local transmission standards set. The same holds true of the provincial and the major long-distance networks.

The question now arises whether, if the plant should be designed in accordance with these inherent losses, the transmission on all types of built-up connections would be satisfactory, and if not, *what part of the plant can be up-graded with the least increase in overall costs.*

Taking again the Rumanian case as an illustration, we find that, having made the subsidiary studies already outlined, we can say that if we confine ourselves merely to the problem of meeting the transmission standards imposed by the major field of use of each type of facility, a problem which must, of course, be met, regardless of the rest of the plant, we shall have a condition illustrated in Fig. 7. We shall also have provided ourselves with a fund of subsidiary information as to the percentage of connections having various losses smaller than the maximum "inherent loss" as determined from the study. With such data available, plus the cost-vs-equivalent relationships already determined for each general class of plant, it is a relatively simple matter to balance the relative economies involved in limiting the loss of one or another type of plant in order to allow all connections to meet whatever overall standards have been set, and to assign definite design standards to each class of plant which will allow the plant extension engineers to carry out their work of rearranging the existing plant and providing new circuits to meet the year-by-year demands of the network.

The final step, from the international standpoint, will, of course, be a similar investigation of the various possible types of connections from the international standpoint, and a balancing of the relative economies involved in up-grading. In fact, this should go hand in hand with the final allocation of losses from a national standpoint, since, if some up-grading is necessary to meet the international standard, it should fit in as efficiently and economically as possible with the meeting of the national standards, and vice versa.

Important Post for A.T. & T. Vice-President

MR. W. H. HARRISON, Vice-President and Chief Engineer of the American Telephone and Telegraph Company, has been appointed Director of the Construction Division of the Production Department of the National Defence Advisory Commission of the United States of America.

Referring to this important appointment, *Telecommunications Reports* points out that it gives the communications industry its first major representation on the Defence Advisory Commission, and that in this new capacity Mr. Harrison will be called upon to handle many of the weightiest problems in the country's defence plans, including the planning, co-ordination and financing of plant construction and expansion on a nation-wide scale.

Because of his wide engineering experience and his knowledge of architectural and construction problems resulting from his general direction of Bell System construction activities in every State of the Union, Mr. Harrison is considered to be exceptionally well qualified for his important new post.

www.americanradiohistory.com

The Effect of Non-Linear Distortion in Multi-Channel Amplifiers

By B. B. JACOBSEN, B.Sc., A.C.G.I., D.I.C.,

Standard Telephones and Cables, Limited, London

This paper presents curves from which the power handling capacity of an amplifier carrying many speech channels can be accurately determined. Figures are given which enable the calculation to be based on the levels of harmonics produced by the amplifier when loaded with a sine wave of known power.

IT is well known that when the channels of a multi-channel carrier communication system are amplified by an amplifier common to the channels, distortion in the amplifier will cause new frequencies to be produced, and these may appear as noise in the channels.

This effect determines the maximum relative level to which a specified amplifier can raise the combined power of a specified number of channels. Or, conversely, this effect determines the properties required of an amplifier for a given system.

Speech currents from subscribers arrive at a carrier terminal with widely varying speech volumes, the variations being due partly to the different characteristics of the line or lines connecting the individual subscriber to the carrier terminal equipment, and partly to the loudness with which the subscriber speaks. Subscribers requiring the use of the carrier circuit are in general connected to individual channels quite at random, and all channels must therefore be designed alike and each capable of transmitting faithfully speech at any volume which is likely to occur at the point where a subscriber is connected to a carrier system. Also, the system as a whole must be capable of giving faithful transmission when all channels are available for the use of subscribers and are engaged for use to the extent and at speech volumes which are likely to be met with in practice.

The common amplifiers must, therefore, be able to handle, without overloading, any likely combination of speech volumes.

1. Curves are available showing the statistical distribution of subscriber speech volume at the point in a speech circuit at which the subscriber would be connected to a multi-channel carrier system. The paper is based on such a curve, and on the measured statistical properties of continuous speech at constant volume. By means of the results obtained, it is possible to calculate the requirements for an amplifier for use in a specified system.

The general method adopted is first to determine experimentally the long time mean power corresponding to continuous speech at reference volume, and then to calculate the distribution of long time mean combined power for a group of subscribers assumed each to speak half the time during the busy hour. The distribution of instantaneous voltage in the combined subscriber power is next calculated, and this distribution is used for calculating the total distortion produced in an amplifier. The total distortion according to an approximate method is assumed to be divided equally between the channels. According to a more exact and more laborious method, the second and third order distortion falling into a particular channel is calculated in detail by considering separately the contributions from all channels taken singly and in combinations. The effect of third order distortion on the transmission equivalent is also calculated.

The calculations applys only to single sideband systems.

As a matter of convenience in calculation, the present work draws a distinction between distortion caused by the near-linear part of the amplifier characteristic and that due to the discontinuity in the amplifier characteristic caused by anode current cut-off or grid current. This distinction is not as artificial as might at first appear. In an amplifier with negative feedback, the distortion due to the near-linear part of the valve characteristic can be reduced indefinitely by means of feedback, whereas the distortion due to the discontinuity (overloading) cannot be much improved by feedback.

www.americanradiohistory.com

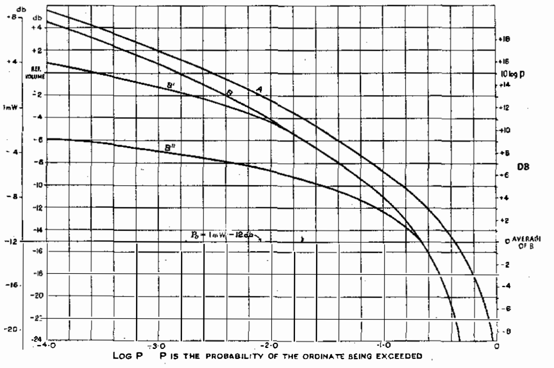


Fig. 1A—Statistical distribution of the mean power of a single subscriber.

A —Single subscriber, continuous speech.
B —Single subscriber, 50% *pause.*
B′ —Single subscriber, 50% *pause, but peak limited at 1 mW + 12 db.*
B″—Single subscriber, 50% *pause, but peak limited at 1 mW + 2 db.*
(Inst. Power.)

Holbrook and Dixon[1] have calculated the requirements for an amplifier in respect of the distortion due to overloading, their criterion being that only a negligible distortion should be produced. The present paper deals with both types of distortion, and the requirements calculated are for an amplifier to produce a specified amount of each type of distortion.

In an ideal case the overloading type of distortion determines the minimum size of the output valve of the amplifier ; this having been fixed, the distortion due to the near-linear part of the valve characteristic determines the amount of negative feedback necessary in order that the output valve may be fully loaded. The feedback required, and the overall gain of the amplifier with feedback, determine the number of stages of an ideal amplifier.

In practice it is sometimes necessary to compromise and to use less feedback than ideally required, and then to use a bigger output valve or reduce the speech level at the amplifier output. This compromise is only justifiable in the case of low power amplifiers in which the output valve is similar to the initial stages, and even for a small amplifier it is generally better to add an extra valve in front of the amplifier rather than in parallel to the output valve. When allowing for ageing of the valves it must be remembered that both the gain without feedback and the output power of the amplifier will decrease during the life of the valve.

2. Information regarding distribution of speech volumes is available in terms of "reference volume," an arbitrary unit of speech current strength as measured by a standard volume indicator.[2]

For the purpose of the present calculations it has been necessary to find a method of converting speech volume readings to another unit. A series of direct measurements has shown that continuous speech at reference volume has a long time mean power of 1 mW+3.1 db. (probable error of ±1.5 db.).*

It was further found that this equivalence holds good for speech of any volume that occurs in practice. Figure 1A, curve A, is the volume distribution assumed. The left-hand scales on the vertical axis are respectively the original scale in db. referred to reference volume and the converted scale in db. referred to 1 mW long time mean power.

2.1. The next step is to combine the long time mean power from a number of subscribers belonging to a group for which curve A, Fig. 1A, defines the distribution of long time mean speech power during speech periods only.

It is assumed that, owing to the two-way nature of telephone conversations, each channel is, on the average, actively engaged in continuous speech for half the time during periods of heavy traffic. This condition is perhaps too severe, but represents the highest limiting probability.[1] This assumption may be taken into account by a very simple modification of curve A, Fig. 1A. If the subscriber is silent half the time there is a 50% probability that the power will not exceed 0 and the original curve A must, therefore, be redrawn to half its former scale on the same graph. Curve B is the result.

2.2. The distribution curves for the combined volume due to R subscribers are shown in Fig. 1B for a number of values of R.† These curves were obtained by repeated integration of the frequency of occurrence curve corresponding to curve B. For the purpose of this integration

---

[1] For references see end of article.

* Holbrook and Dixon give a value of 1 mW + 2.2 db.

† For description of symbols used see end of article.

the power scale of curve B was converted into milliwatts and the linear probability axis divided into many equal sections. The mean ordinates of each section were then taken to be the ordinate for the whole section, whereby a stepped curve is obtained. Each value of power indicated by the ordinates of the stepped curve is equally likely to occur. These values are written down, uniformly spaced in a row and repeated in another row at right angles, as shown in Fig. 2 in which 50 sections were used. The frequency of occurrence of each power value shown is $\frac{1}{50}$. To find the power distribution of a combination of two independent sources, equi-occurrent power from one source must be added in turn to each equi-occurrent power from the other source. This combination is done very simply by means of Fig. 2.

In each little square is written the sum of the numbers in the corresponding positions on the initial vertical and horizontal rows. The relative frequency of occurrence of each particular value shown in the small squares is $\frac{1}{2\,500}$ and there are 2 500 squares. The figures in the squares are next arranged in order of magnitude. The number of terms which are bigger than a specified value, divided by the total number of terms, gives the probability that the specified value will be exceeded. In actual calculations more steps than 50 are in general necessary, but the steps can be graded in width according to the steepness of the original curve. The curves in Fig. 1B were calculated in this way, and are shown, each expressed in terms of its own mean. When using the curve for two combined, it is therefore necessary to add 3 db. to the values shown by the curve. For four combined, add 6 db., etc.

Figure 1B, therefore, shows the distribution of mean power for R subscribers combined, each assumed to be active on the average half the total time, and which, when speaking, speak at volumes distributed in accordance with Fig. 1A, curve A. The power summation assumes that no two sources produce the same frequency, but this condition is fully satisfied by actual systems at the point where channels are combined.

For a very large number of subscribers, each assumed to speak on the average half the time, the long time mean power divided by the num-

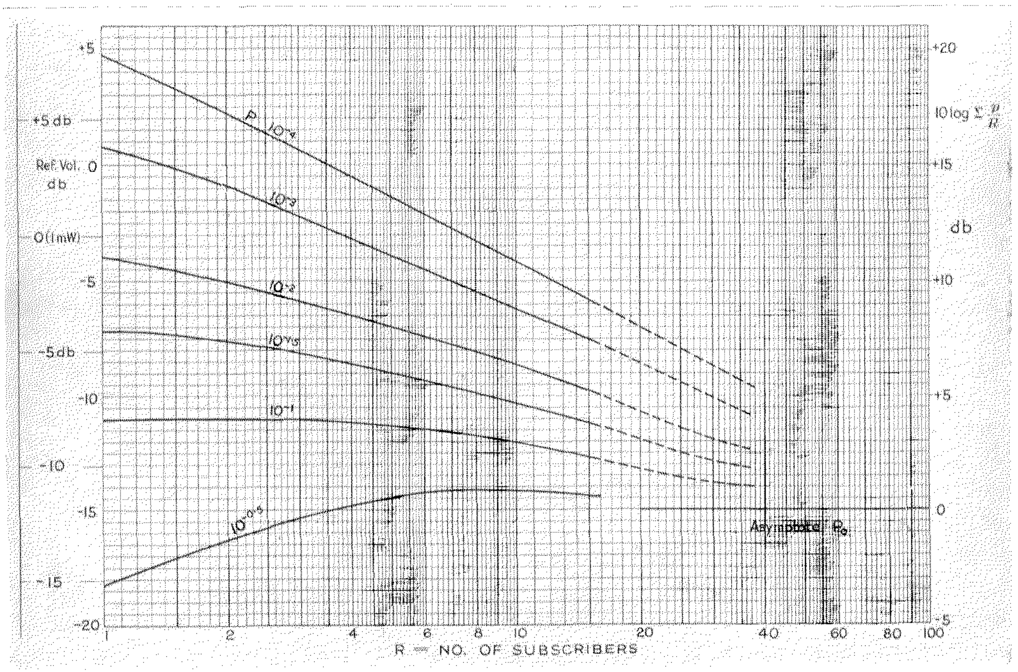


Fig. 1B—Deviation of the combined mean power of R subscribers, speaking half the time, from its long time mean value. No peak limiting.

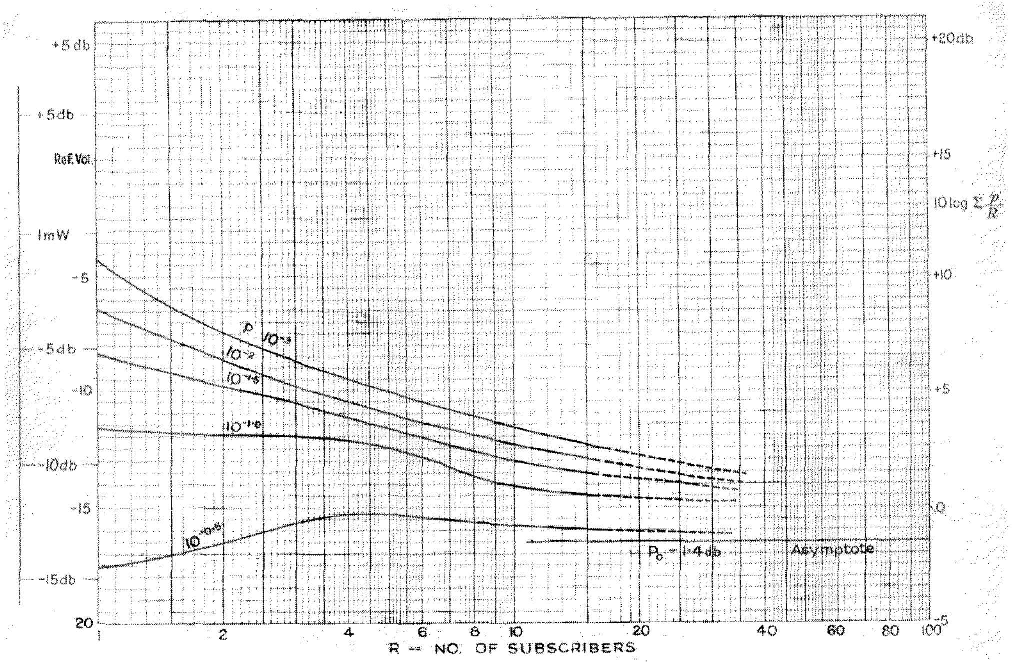


Fig. 1C—Deviation of the combined mean power of R subscribers, speaking half the time, from its long time mean value. Peak limiting at 1 mW + 6 db. inst. power.

ber of subscribers (channels) approaches the limiting value P_0 milliwatts. For the curve B, Fig. 1A, this power is 1 mW – 12 db. The right-hand scale shows db. deviation from P_0 and applies only to B curves.

3. *Distribution of instantaneous power in a single speech wave of known long time mean power*

There is some information available on this subject[3] but it was thought necessary to obtain more detailed information. Also it was noticed that the mean power calculated from Sivian's curve did not agree exactly with the expected value of unity.

The experimental method used was to obtain speech current at a definite volume, measured either by a volume indicator or by a very slow thermocouple, and to analyze the speech currents by means of a circuit which integrates the time during which a particular instantaneous voltage is exceeded. The speech currents, suitably amplified, are applied to a diode biased back by a known voltage. In series with the diode is a resistance, across which is an amplifier. High input voltages cause the diode to conduct, and the current, through the series resistance, to produce a voltage which is amplified. The amplifier is arranged to saturate on very small inputs and the output wave is a rectangular wave. Each pulse in the rectangular wave is of duration equal to the time during which the speech wave instantaneous voltage exceeded the bias voltage on the diode. The pulses are all of a fixed instantaneous current. These pulses are applied to a milliammeter which measures the average pulse current. This average current, expressed as a fraction of the instantaneous output current of the test apparatus, is an exact measure of the fraction of time during which the bias voltage is exceeded. Tests are made with various bias settings. The apparatus was tested on waves with known statistical properties, such as a sine wave and a thermal agitation wave, and was found to be very accurate. Both polarities of the wave were investigated and several speakers and sub-sets were tried. Experimental results for a speech wave are shown in Fig. 3 by the points near curve 1, and are expressed as db. ratio of instantaneous to long time mean power. All results were similar. The mean power was computed from the test results themselves, and in all tests on speech waves it was found that the long time mean power as measured with a thermocouple was about 1.5 db. smaller than the power calculated from the statistical measurements. This difference is approximately equal to that calculated for Sivian's curve, and is probably due to the difference between the integration methods of the thermocouple and the distribution measuring apparatus, and the uncertainty in defining speech volume over short periods.

In Fig. 3 the points shown near curve 4 represent the measured distribution for three voices speaking simultaneously but not in unison. Measurements were also made on single sideband waves in order to find if the peak distribution is changed by the process of modulation. It was found that in fact there was no noticeable change in the peak distribution.

4. *Peak distribution function for combined single sideband channels of equal volume*

Based on the single channel peak distribution just obtained, it should be possible to calculate the multi-channel peak distribution. Unfortunately, the single channel distribution function is not a simple analytical function, and the graphical method described in paragraph 1 is very laborious.

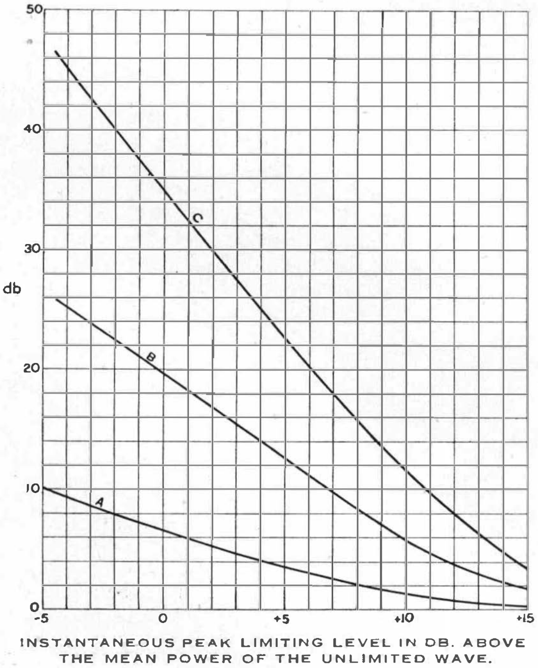
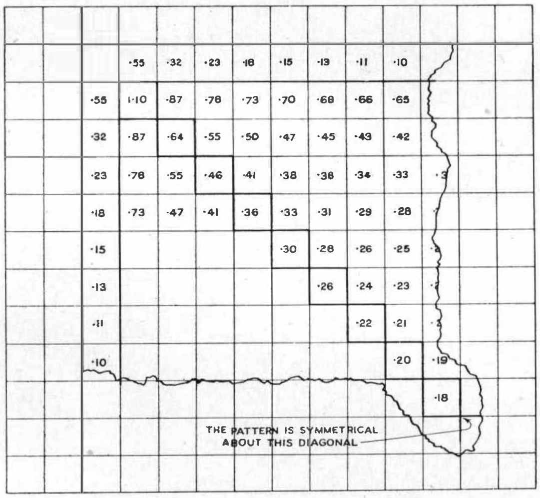


Fig. 1D—Effect of limiting on a "single speech" wave.

A—Reduction in mean power.
B—Reduction in second order distortion power.
C—Reduction in third order distortion power.



	·55	·32	·23	·18	·15	·13	·11	·10	
·55	1·10	·87	·78	·73	·70	·68	·66	·65	
·32	·87	·64	·55	·50	·47	·45	·43	·42	
·23	·78	·55	·46	·41	·38	·38	·34	·33	·3
·18	·73	·47	·41	·36	·33	·31	·29	·28	
·15					·30	·28	·26	·25	·2
·13						·26	·24	·23	·2
·11							·22	·21	·2
·10								·20	·19
									·18

Fig. 2—Part of a number pattern used to evaluate the integral giving the statistical power distribution of a number of subscribers.

The method used is as follows.

Consider a peak distribution of the form

$$P(|v|) = \varepsilon^{-\sqrt{2}\left|\frac{v}{v_0}\right|} \quad \ldots\ldots\ldots\ldots\ldots(1)$$

or

$$F(+v) = F(-v) = \frac{1}{\sqrt{2}\quad v_0}\ \varepsilon^{-\sqrt{2}\left|\frac{v}{v_0}\right|} \quad \ldots.(1a)$$

where $P(|v|)$ is the probability that the magnitude of an instantaneous voltage exceeds $|v|$ and v_0 is the R.M.S. voltage of the wave. $F(v)\,dv$ is the relative frequency of occurrence of a voltage in the range between v and $v+dv$. There is an equal probability of positive and negative voltages, and the functions are discontinuous at $v=0$.

An assumption similar to the present was used by Thierbach and Jacoby[4] who, however, assume that this formula shows the actual voltage distribution in speech, and appear to have overlooked the fact that the wave may assume both negative and positive voltage values; and in consequence the mean power of the combined wave by their method appears to be proportional to the square of the number of sources combined, whereas in fact it is directly proportional. Combination of two distributions of equation (1) gives the result:

$$F_2(+v) = \frac{1}{2\sqrt{2}\,v_0}\left[\sqrt{2}\left|\frac{v}{v_0}\right| + 1\right]^{-\sqrt{2}\left|\frac{v}{v_0}\right|} \quad .(2)$$

and for three combined:

$$F_3(+v) = \frac{1}{8\sqrt{2}v_0}$$

$$\left[2\frac{v^2}{{v_0}^2} + 3\sqrt{2}\left|\frac{v}{v_0}\right| + 3\right]\varepsilon^{-\sqrt{2}\left|\frac{v}{v_0}\right|} \quad ..(3)$$

Frequency functions of this type, and the corresponding probability functions, have been worked out for m waves combined, and the former are given in Appendix A. Figure 4 shows the distribution functions plotted as instantaneous to mean power ratio in db., the mean power in each case being the mean power of the combined wave. By a process of extrapolation a formula was obtained by means of which the family of curves derived from formula 1 may be extended to fractional values of m. It is found that the curve for $m = \frac{1}{4}$ corresponds fairly closely to the measured single channel data, and it has therefore been assumed that four speech waves of equal volume, when combined, will produce the peak distribution function of formula 1. Figure 3 shows that the distribution so calculated agrees fairly well with the measured values for a single speaker. Also the curve for $m = 1$ corresponds very nearly to either 3 or 4 active speakers, but 4 has been assumed for further work. Consequently, formulæ 2 and 3 may be taken to represent the distribution for eight and twelve combined equal-volume speech waves respectively. By extrapolating in the other direction towards an infinite number of sources of speech combined, a curve is obtained which differs very little from "Normal Distribution." Inspection of the curves shows that about 64 effective channels of equal volume give a distribution closely similar to the "Normal Distribution" which may, therefore, be assumed for large numbers. The results are in fair agreement with those obtained by Holbrook and Dixon[1]; the advantage of the present method is that most of the distribution curves are analytical functions, and this is of considerable value for the further work.

To sum up the foregoing:

1. The mean power due to the "average sub-subscriber" is $P_0 = 1$ mW − 12 db.
2. The mean power due to R subscribers is $P_0 \times p_R$. $\left(\frac{p_R}{R}\right)$ ma be obtained from Fig 1B right-hand scale.
3. The distribution o peak to mean powe for r subscribers a equal volume i shown by Fig. 4. I will be shown late that, at least for value of R above 60 channels, r may be take as $\frac{R}{3}$ (where r is th

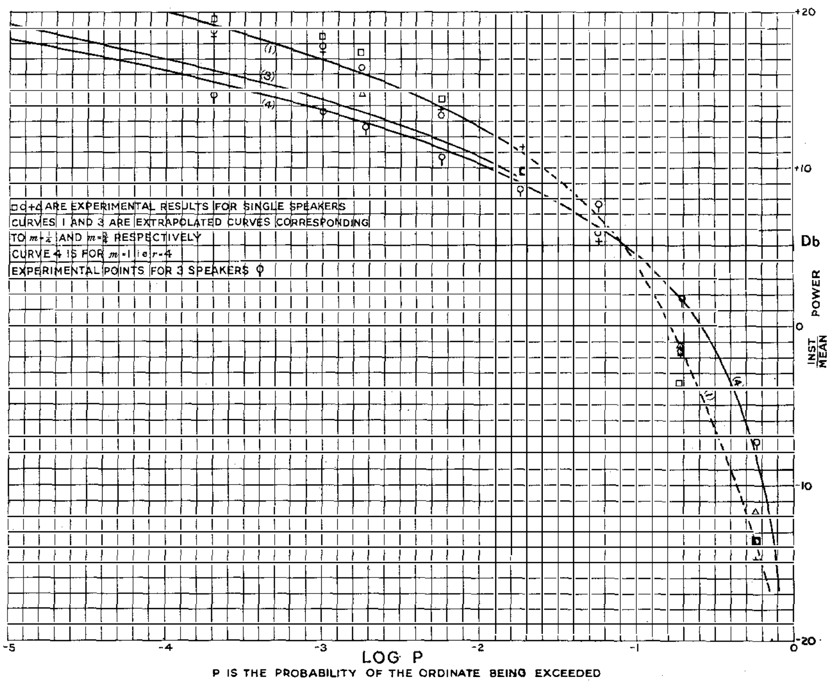


Fig. 3—Peak power distribution for various numbers of speakers.

number of channels of equal volume equivalent to R random channels.

5. *Distortion produced by a complex wave in an ideal amplifier of finite output capacity (overloading distortion)*

The amplifier is assumed to have an infinite negative feedback and, therefore, to be perfectly linear up to a certain instantaneous power, the instantaneous overload power. For inputs of higher instantaneous voltage the output instantaneous voltage is assumed not to exceed a value v_c. The wave to be amplified will be assumed to have the distributions already found. The distribution function is considered as a recurrent function. Figure 5 shows this function. The horizontal line at height v_c indicates that after amplification the waveform will be flat-topped. The flat-topped wave may be considered as the original wave minus another wave, the amplitude of which is given by the height of the original curve above v_c. This second wave will consist partly of new frequencies (intermodulation products) and partly of frequencies already present in the original wave ; these latter frequencies determine the transmission loss which the original frequencies suffer due to overloading of the amplifier.

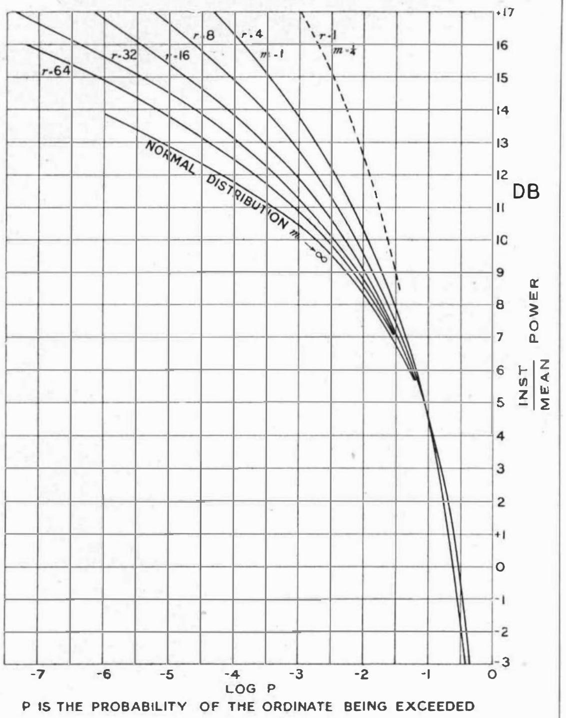


Fig. 4—Statistical peak power distributions.

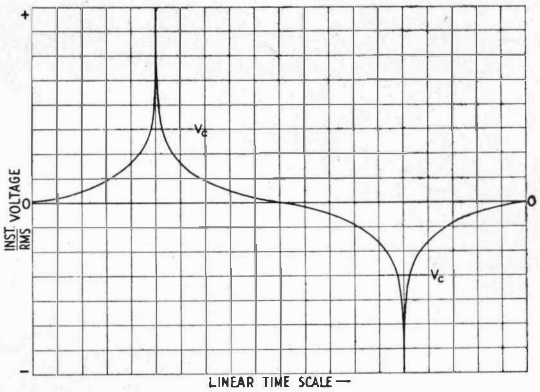


Fig. 5—Statistical peak power distribution curve drawn as a recurrent wave.

5.1. The assumption is now made that all frequencies present in the original wave are reduced by the same factor $(1 - a)$. This assumption is perhaps difficult to justify, but if it is made it is found that a is negligibly small in practical cases.

Let the power in the original wave be A where

$$A = \tfrac{1}{2} \sum q_v^2 \qquad (4)$$

where q_v is the amplitude of each frequency component of the wave. The power in the output wave is B.

$$B = \tfrac{1}{2} \sum q_v^2 (1 - a)^2 + D \qquad (5)$$

where D is the power at new frequencies or the distortion power.

Consider now the suppressed part of the wave as an independent wave of power C, then

$$C = \tfrac{1}{2} \sum q_v^2 a^2 + D \qquad (6)$$

Solving these equations

$$a = \frac{A - B + C}{2A} \qquad (7)$$

$$D = C - A a^2 \qquad (8)$$

Although this calculation has assumed a waveform as shown in Fig. 5, the validity is not restricted to this, but holds for any wave defined by a distribution function. A certain amount of the distortion power will fall outside the band of original frequencies, but it will be seen from the results later, that even if only one quarter of the distortion falls in the useful band, the error in the calculated overload power requirement is less than 1 db.

5.2. By using for the input wave the analytical multi-speech distribution functions found in para. 4, and expressing the distortion as db. ratio between A and D, the curves shown in Fig. 6 were obtained in which the distortion margin is shown as a function of K, the db. difference between the maximum possible instantaneous amplifier output power and the mean power of the amplified wave. The maximum possible instantaneous power may be measured in an actual amplifier by observation with a cathode-ray tube or by tests with a sine wave. It is important that the test should not take account of any cumulative effects, for instance, of grid current, since these will not occur to any great extent when the amplifier is dealing with waves in which the overload condition occurs only during a very small part of the time. When testing amplifiers liable to these cumulative effects it is therefore best to use a peaky test wave. In calculating D it was found that for all practical conditions the term Aa^2 is negligible; this fact makes unnecessary the assumption of equal reduction in original frequency components.

It should be noted that the parameter r is the number of active channels combined at equal volume.

The transmission loss caused by the removal of the peaks is on the average $10 \log (1-a)^2$ db. This loss is not important for a single repeater, but when many are joined in tandem it may become noticeable if the line or the attenuation equalizers have sufficient delay distortion to restore to some extent the lost peaks before another amplifier is reached. In systems of many channels this restoration of the peaks is more likely to occur than in systems with only a few channels.

The use of the curves in Figs. 6A and 6B is described in para. 8.

6. *Distortion produced by the near-linear part of the amplifier characteristic. 1st method*

When the instantaneous voltage of the wave to be amplified does not exceed the overload value, the amplifier output voltage may be represented by a few terms of the following equation:

$$V = \mu_1 v + \mu_2 v^2 + \mu_3 v^3 + \mu_p v^p + \ldots \quad (9)$$

where v and V are the instantaneous input and output voltages respectively, and μ_1, μ_2 etc., are parameters of the amplifier. The amplifier may be one using negative feedback.

If v is a sine wave voltage, the term $\mu_1 v$ will represent the desired output wave, while $\mu_2 v^2$, etc., represent distortion. The term $\mu_2 v^2$, for instance, consists of a second harmonic frequency and a direct current term, while $\mu_3 v^3$ contains a third harmonic and also a component of fundamental frequency.

The formula further indicates that the distortion power due to μ_2 varies as the square of fundamental output power, that due to μ^3 as the cube, etc. By making a sine wave test on an amplifier, curves may be obtained of the variation of each harmonic as a function of the fundamental output: such curves are shown for a particular amplifier in Fig. 7. The ordinate is the db. ratio between the power of the harmonic indicated on the curve and the power of the fundamental frequency, the abscissæ being output power in db. referred to 1 mW. The slope of each curve is seen to be equal to its harmonic order, less one. This is not the case for all amplifiers; for instance, if hysteresis in the magnetic core of the output transformer produces the chief part of the distortion, the third harmonic curve will be parallel to that of the second harmonic. This condition ought not to occur in amplifiers for frequencies used in multi-channel systems, and in what follows curves of the type shown in Fig. 7 will be assumed. The fact that these curves obtain is some proof that formula (9) is fulfilled by an amplifier.

6.1. To find now the distortion introduced by the amplifier when a multi-speech wave is amplified, consider the term $\mu_2 v^2$ when v is defined only by a distribution curve. The instantaneous distortion voltage of second order is $\mu_2 v^2$, the instantaneous power, therefore, $\mu_2^2 v^4$. The distortion power is therefore defined by another distribution curve. The distortion distribution curve is steeper than the corresponding multi-speech wave distribution curve, the more so the higher the order of distortion considered. The speech wave instantaneous power exceeds the mean power during 16% of the time, whereas the second order distortion instantaneous power will exceed the mean distortion power only 6% of the time. But when the distortion is due to a number of channels the mean distortion may safely be used in calculating noise.

As an example of the calculation of mean second order distortion power, consider the wave defined by formula (1*a*), which describes the distribution for four channels combined. The instantaneous second order distortion power is $\mu_2^2 v^4$ with a frequency of occurrence $dP = F(|v|)\,dv$.

The mean distortion power is therefore: for v positive (or negative),

$$\mu_2^2 \frac{\int_0^1 v^4\,dP}{\int_0^1 dP}$$

$$= \mu_2^2 \frac{\dfrac{1}{\sqrt{2}\,v_0}\displaystyle\int_0^\infty v^4\,\varepsilon^{-\sqrt{2}\left|\frac{v}{v_0}\right|}\,dv}{\dfrac{1}{\sqrt{2}\,v_0}\displaystyle\int_0^\infty \varepsilon^{-\sqrt{2}\left|\frac{v}{v_0}\right|}\,dv} = 6\mu_2^2 v_0^4 \quad \ldots.(10)$$

The mean output power is

$$\frac{\mu_1^2 \int_0^1 v^2\,dP}{\int_0^1 dP} = \mu_1^2 v_0^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots(11)$$

For a sine wave of mean power $\mu_1^2 v_0^2$ the input wave is $\sqrt{2}\,v_0 \sin \omega t$ and the second harmonic output power is

$$\tfrac{1}{2}\mu_2^2 v_0^4 .$$

For the same mean power linear output the complex wave produces a mean distortion power output twelve times higher than the sine wave second harmonic. The complex wave average distortion power may therefore be expressed as being twelve times, or 10.8 db. worse than, the second harmonic power produced by a sine wave of equal mean power.*

All the distributions shown by Fig. 4 have been integrated in this way, and the result is shown by Fig. 8. In general, only second and third order distortion is of sufficient importance.

This figure shows, for the various numbers of equal volume active channels "*r*," by how much the n^{th} order mean distortion power exceeds the n^{th} harmonic of a sine wave of power equal to the combined speech power.

These curves assume that the amplifier output never exceeds the instantaneous overloading power. In actual fact this power generally is exceeded, even if only for a very small fraction of time.

6.2. Formula (9) is only valid up to near the overload point. To be even approximately valid above this point many more μ terms would have to be included. These μ terms would be difficult to determine in practice and would, for instance, not be affected by feedback to the same extent as the other terms. It is, therefore, better to restrict the calculation of distortion to the near-linear part of the characteristic. The restriction is introduced very simply by changing the upper limit of the integral in formula (10). Instead of extending the integral to an infinite voltage it has been taken only to a voltage v_c, corresponding to an instantaneous power K db. above the combined mean speech power.

Figure 9 shows the result for the second and third orders of distortion for various values of K, and for any number of effective channels r. The ordinate is the reduction which should be made in Fig. 8. Suitable values of v_c may be found from Fig. 6A, by assuming the margin required. The curves in Fig. 9 have been calculated for the smallest and highest values of K likely to be useful in practice. The lower value of K corresponds, of course, to a low margin.

It will be noticed that for about twelve or more active channels the curves of Fig. 8 need no allowance. For the higher orders of distortion the allowance will be needed until a somewhat higher number of channels is reached. But in practice it will often be found unnecessary to make the special calculations, since the higher orders of distortion calculated without any allowance generally make only a negligible contribution to the total distortion, and the correction is one that reduces the calculated value.

6.3. Figures 8 and 9 will, therefore, be suffi-

---

[*] If an amplifier due to restricted bandwidth cannot transmit a wave and its harmonic, the harmonic power due to a sine wave can readily be evaluated by measuring the power of combination tones caused by the simultaneous application to the amplifier of two sine waves of known amplitude.

www.americanradiohistory.com

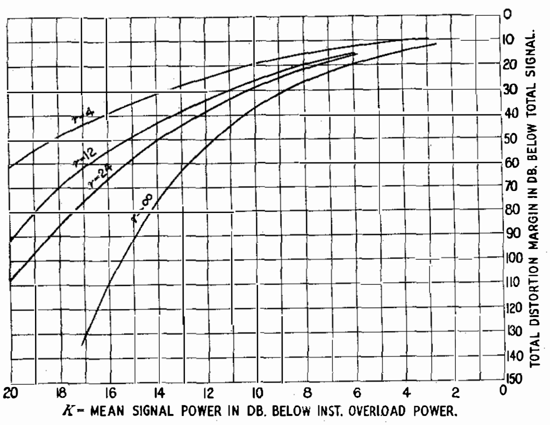
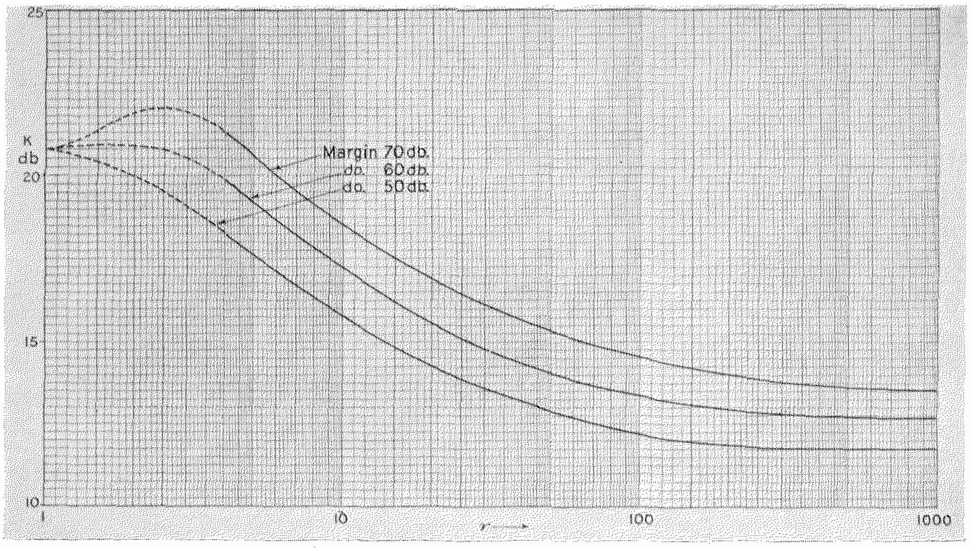


Fig. 6A—Overload distortion margin for various numbers of channels of equal volume. No peak limiting.

cient in most cases for the direct calculation of mean distortion power for any number of active channels of equal volume. Some modification will be introduced in the next paragraph to allow for the fact that not all the distortion produces noise. The curves in Fig. 8 are based on r channels of equal volume, but in an actual system the channels are not of equal volume and the channels are not active all the time. The average number of active channels has been assumed to be $R/2$. Only a fraction of the number of channels active at any particular instant will contribute materially to the total power. When the total power is high compared to the mean, the number of active channels will mostly be rather higher than the average, and it may be assumed that the larger part of the power is due to rather more than half the number of active channels. As a compromise it may be assumed that the number of effective channels is approximately equal to one-third the total number of channels. This holds only for numbers of channels exceeding 20 or 30.

7. It will now be interesting to approach the near-linear distortion problem from a qualitative point of view. Formula (9) has been discussed for v being a sine wave and a multi-speech wave voltage. If v instead consists of n sine waves of total power independent of n, i.e., each of amplitude proportional to $\sqrt{\frac{2}{n}}$, the second order distortion will consist of n terms of second harmonic frequency, each of relative mean power $\frac{\mu_2^2}{2n^2}$, and of $\frac{n(n-1)}{2}$ terms of frequencies equal to the sums of original frequencies in



NUMBER OF CHANNELS OF EQUAL VOLUME

Fig. 6B—"K" as a function of the number of channels of equal volume for different values of overload distortion margin.

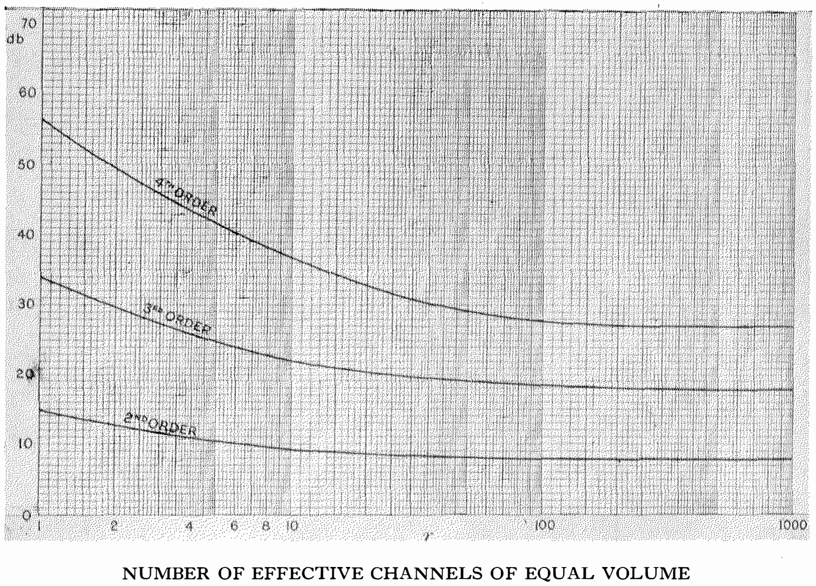


Fig. 8—*Average total non-linear distortion of a multi-channel speech wave in db. worse than the corresponding harmonic of a sine wave of the same mean power.*

pairs, and the same number of terms with frequency equal to differences of the original frequencies. These terms are each of relative power $\frac{2\mu_2^2}{n^2}$. The distortion also contains a D.C. term of relative power μ_2^2. The total distortion power is, therefore, assuming that no two terms are of the same frequency,

$$= \mu_2^2 \left[\frac{1}{2n} + \frac{2n^2 - n}{n^2} + 1\right].$$

The sum and difference frequency terms are seen to be the most important, both as regards their individual and their total power. When n is increased indefinitely the distortion power becomes $3\mu_2^2$ or $6 \times$ (7.8 db.) higher than the second harmonic of a sine wave of same power. It consists of $2\mu_2^2$ contained in sum and difference frequencies, and μ_2^2 in the direct current component. The magnitude agrees, as would be expected, with that found by integration of the "normal" distribution wave. The sine wave method shows that, for the "normal" distribution, practically all the distortion is contained in sum and difference frequency terms; this is true, even for simple sine wave combinations. It also shows that for the more complex sine wave combination, $\frac{1}{3}$ of the distortion power calculated is contained in the direct current term which is of no importance. The results for the "normal" wave may, therefore, be reduced by 1.78 db. For the third order terms, calculations similar to the above show that the distortion in the case of a wave consisting of a large number of sine waves resides in frequencies equal to sum and difference combinations of the original frequencies in groups of three different frequencies, and in the original frequencies themselves. The total distortion agrees with that calculated for a "normal" wave, but an allowance may be made of 4 db., since the exact original frequencies which are produced by third order distortion do not cause noise, but a change in the transmission efficiency. This change is readily calculated, and will be dealt with later. The harmful part of third order distortion of a "normal" wave is 13.8 db. higher than the third harmonic of a sine wave of the same mean power, and consists largely of combination terms containing three different frequencies.

7.1. Figure 1D gives a further set of auxiliary

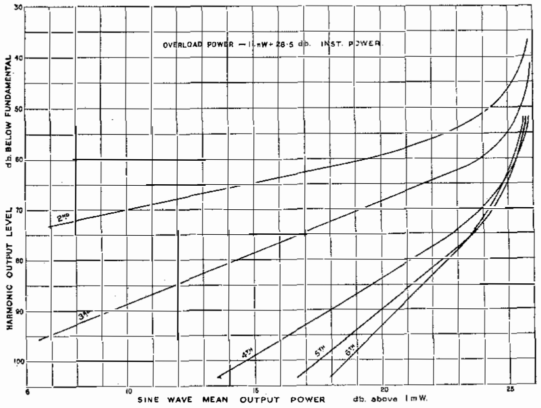


Fig. 7—*Example of amplifier harmonic curves.*

curves which are necessary when calculating the distortion due to a single channel in a system where the channels are equipped with peak limiters, or in which, for instance, the modulator has a peak limiting effect. The curves B and C show the db. reduction which should be applied to the results obtained for Fig. 8 for single channel second or third order distortion when the limiting (instantaneous) power exceeds the mean single channel power by the number of decibels shown by the abscissa. Curve A in the same figure shows the reduction in the mean power of the speech wave due to peak limiting. Curve A is required for calculating curves such as B′ and B″, Fig. 1A. These curves, when averaged, give the db. reduction in total mean speech power due to peak limiting in a system with 100 or more channels (see para. 8.4). Curves A, B and C were computed as described in para. 6.2. Curve A has been determined also by an experimental method which gave very nearly the calculated result.

The method of using the foregoing work will now be illustrated by an example for a system with 240 channels.

8. To find the overload power required at a point of zero relative level

Assume that the specified noise power may be exceeded on the average during one call in a thousand; from Fig. 1B for $P = 10^{-3}$ and $R = 240$, it can be estimated that $10 \log \sum \frac{p}{R}$ is approximately 2 db. The combined mean power due to 240 channels is, therefore, 10 log 240+2 db. above the average subscriber mean power P_0, or is 1 mW+13.8 db. at a point of zero relative level.

Assume next that the noise level is specified as z db. below 1 mW. If the relative level at the point where the noise is to be measured is $-q$, then the corresponding noise power at a point of zero relative level is $z-q$ db. below 1 mW per channel, or total noise is $z-q-23.8$ db. below 1 mW.

Assuming that only half the specified noise may be caused by overloading, the ratio of total signal power to total noise power becomes $+z-q-7$ db. (noise margin). In Fig. 6B find now the value of K required for this margin to be obtained. In order to use this curve, it is necessary to estimate what number of equal volume channels may be taken to represent the actual system with 240 channels. Assume $r = 80$ to be correct (the exact figure is of small importance in this case), and K can now be found. The smallest safe instantaneous overload power is K db. above the mean signal power, or is $13.8+K$ db. above 1 mW for an amplifier with reference level output. If the amplifier instantaneous overload power is known, by subtracting $13.8+K$ the maximum possible transmitting

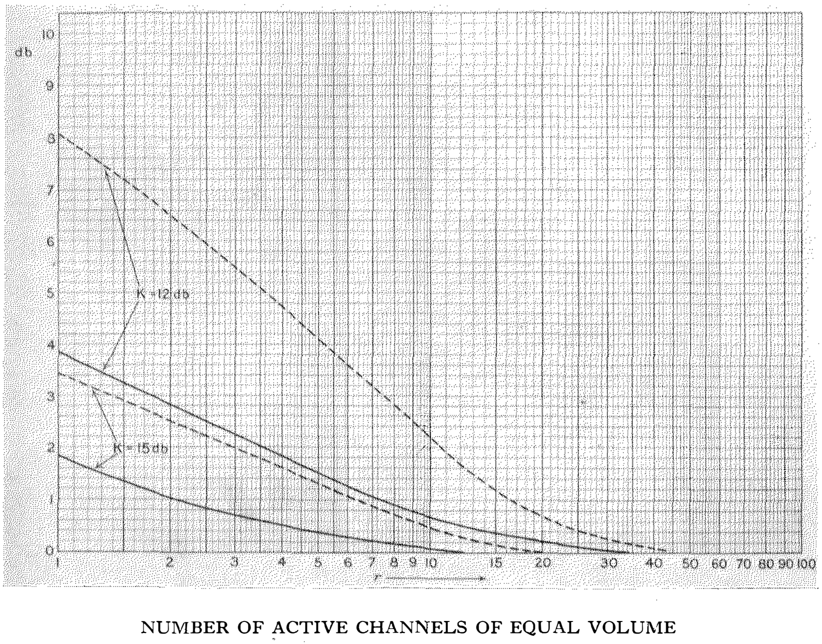


Fig. 9—Decrease of non-linear distortion obtained by considering voltages less than the overload point voltage (full curve—2nd order distortion, broken curve—3rd order distortion).

gain β_1 is obtained. This transmitting gain cannot necessarily be used in practice, but could be used if the amplifier were distortionless except for the finite maximum output power.

8.1. *To find for a given amplifier the maximum relative output level (transmitting gain) considering only distortion produced by the near-linear part of the amplifier characteristic*

Assuming again that 240 actual channels are equivalent to 80 equal volume channels, then from Fig. 8 it is found that the second (or third) order total distortion power is 8.0 (or 18) db. above the second (or third) harmonic of a sine wave with mean power equal to the combined channel power. Figure 9 shows that no correction will be needed on account of occasionally exceeding the overload point. But corrections may be made in respect of distortion power which is not harmful. For systems with a large number of channels these corrections have been shown to be 1.8 and 4 db. respectively. From harmonic measurements on the amplifier, plot curves of harmonic margin against output power (such as Fig. 7) and check that the curves are of correct slope. The second (or third) harmonic margin required at the working output power is $+z-q-7+6$ db. (or $+14$ db.), and the curve shows at what output power this margin is obtained. If both second and third order distortion are important, the working point is, of course, defined as that at which the power sum of second and third order distortion just reaches the margin permitted. The ratio between the power just found and the total signal power (1 mW + 13.8 db. in this case) expressed in decibels is the transmitting gain β_2 at which the distortion due to the near-linear part of the amplifier characteristic is just equal to half the specified distortion.

In an ideally proportioned amplifier, β_1 and β_2 would be equal. In practice the smaller value of β should be used. If β_2 is smaller than β_1 the amplifier would be improved by an increase in negative feedback.

The above calculations are for a single amplifier: when several are used in tandem the distortion due to the near-linear part of the characteristic will in general be increased by 10 log n, where n is the number of repeaters. Distortion due to overloading will not occur in every repeater except in special cases, and a reduction of one or two db. in β_1 will in general allow for 20–60 repeaters. The results obtained do not allow for reduction in performance during the life of the valves.

8.2. As a check on the value of β_2 it is necessary to consider the effect of a single channel producing second (or third) order noise into another channel. The assumption in the above that all the distortion is shared equally between the channels is obviously untrue, and in the case of a single disturbing channel the distortion falls mainly into a channel at twice (or three times) the frequency of the disturbing channel.

In the example, take again the probability $P = 10^{-3}$. Figure 1A, curve B, shows that a single channel may exceed the mean subscriber power by as much as 16 db. during, on the average, one call in a thousand. (The excess may be considerably reduced if volume limiting means are used.) From Fig. 8 it is found that for a single channel the second (or third) order distortion is 14.4 (or 23.5) db. higher than the second (or third) harmonic of a sine wave of power equal to the mean speech power. It will be shown that only a part of this distortion falls in the double (or treble) frequency range—the corrected figure is 9.6 (or 23.5) db. worse than the sine wave harmonic (see paras. 11.1 and 13.1).

The single channel signal mean power ($P = 10^{-3}$) without limiting is 1 mW $-12+16$ db., or 10 db. smaller than the combined signal power, and the sine wave harmonic power (not margin) will therefore be 20 (or 30) db. lower than the value found for all the channels, but the single speech channel distortion is 9.6 (or 23.5) db. worse than the equivalent sine wave harmonic, whereas for the 240 ch. the corresponding figures were 6 db. (or 14 db.). The distortion may be assumed to fall into a single other channel and will therefore on a relative scale be 10 log 240 db. higher.

The results of these considerations are that for the system considered (no peak limiting), the "single channel distortion" will be 7.4 db. (or 3.3 db.) above the average distortion noise falling into a channel. In the example chosen and for the probability considered, the distortion due to a single channel will therefore be the limiting factor and a new value of β_2 must be found which

www.americanradiohistory.com

will be 7.4 db. $\left(\text{or } \frac{3.3}{2} \text{ db.}\right)$ lower than the value determined above (depending on whether second or third order distortion determines β_2). Conversely, the negative feedback on the amplifier should be increased by 7.4 or 3.3 db.

8.3. The probability of 1/1 000 is, perhaps, rather too small for practical purposes. It is the probability that a particular channel should exceed reference volume by 1 db. or more. In most networks it is probably reasonable to assume that reference volume will never be exceeded, or even reached, at the point where subscriber's speech is applied to a carrier system. Assuming that calls last as long as three minutes, the probability of 1/1 000 means that during 50 busy hours a channel is liable, on the average, to be disturbed for a three-minute period. When it is further considered that, in reality, there is some chance that the disturbed channel will not be in use when the distortion exceeds the limit, that not all channels receive this type of distortion, and that the slightly higher distortion when it does occur will cause very little annoyance, it would appear to be justifiable to allow the single channel distortion to exceed the average distortion per channel by 5–10 db. Alternatively, the probability considered when calculating the single channel distortion might be taken rather lower than the overall, probability, for instance, at 1/100. Taking $P = 1/100$ for the single channel distortion in the above example, it will be found that the single channel distortion for second (or third) order will be 2.4 db. (or 11.5 db.) lower than the fraction of the total distortion which has been assumed to fall into each channel.

8.4. If, in this example, peak limiting is introduced such that the instantaneous power at the input to a channel cannot exceed 1 mW + 12 db. (or 1 mW + 2 db.), the distortion calculated without limiting can be corrected by subtracting the db. reductions shown in Fig. 1D, curves B and C.

For a single channel $P = 10^{-3}$ the mean power is 1 mW + 4 db. (curve B, Fig. 1A), the limiting power is therefore $12 - 4 = 8$ db. (or $2 - 4 = -2$ db.) above the mean power. From Fig. 1D the correction for second order distortion is 8.3 db. (or 22.3 db.). The corresponding figure for third order distortion reduction ($P = 10^{-3}$) is 15.7 db. (or 39.9 db.).

It is clear, therefore, that limiting, even at 1 mW + 12 db., will reduce the distortion due to a single channel to a value below the mean distortion per channel. The mean distortion per channel would, therefore, be the controlling factor. For smaller numbers of channels, the distortion due to a single channel is relatively more important, and limiting therefore relatively more worth while. Peak limiting will also reduce the general distortion, but to a much smaller extent. For a system with more than about 100 channels the effect may easily be accounted for by a reduction in the total signal power. For limiting at 1 mW + 12 db. the reduction is 0.3 db., while for limiting at 1 mW + 6 db. and + 2 db. the reductions are, respectively, 1.4 db. and 2.5 db. For smaller numbers of channels it is necessary to construct sets of curves similar to those on Fig. 1B, but based on curves such as B′ and B″ in Fig. 1A, and Fig. 1C was calculated for peak limiting at an instantaneous power of 1 mW + 6 db. at the input to each channel of the system. This figure may be used in the same way as Fig. 1B, and can be used in connection with Fig. 8. This latter figure does not strictly apply to a multi-channel speech wave formed from limited channels. To allow for limiting, take the number r of effective equal volume channels to be about $\frac{R}{2}$ or even higher (depending on the severity of the limiting), instead of the previous value of $\frac{R}{3}$.

9. The method just described is simple and easy to use, but has obvious defects, some of which cannot easily be corrected. For a system with a very large number of channels the main sources of error are due to the assumption that all the distortion of a particular order is harmful, and that the total is divided equally between all the channels. For the special case of a very large number of channels it has already been shown that the harmful part of the second order distortion is 1.8 db. less than the total second order distortion, and for third order it is 4 db. less. The distortion which remains after these corrections does not all occur at frequencies belonging to channels, and a further allowance must be made based on the frequency range actually used in the system and bearing in mind that, at

www.americanradiohistory.com

least for large numbers of channels, the most important distortion of any particular order occurs at frequencies equal to all possible sum and difference combinations of the original frequencies taken in groups of 2, 3, etc., for second, third, etc., order distortion. For the purpose of this calculation the energy in each channel may be assumed concentrated at one frequency.

For example, third order distortion in a system with many channels is largely due to frequencies equal to $r \pm q \pm s$ (four different results), r, q and s being frequencies or frequency ranges due to different channels. The number of sets of four such frequencies for a 12-channel system is

$$\frac{12\,!}{(12-3)\,!\,3\,!} = 220$$

corresponding to 880 different frequencies (or bands of frequencies). If the 12-channel system has a frequency range from 12–60 kc., not more than 36 such bands of frequencies will fall into any one channel (distortion falling into a channel which itself is part cause of the distortion has been disregarded). It will thus be seen that out of an average number of distortion frequencies or bands of frequencies of 73 per channel, not more than half fall into any one channel in the case considered. A further allowance of 3 db. might, therefore, be applied in this case on the third order distortion. For the same system the maximum number of terms of the type f_1+f_2 or f_1-f_2 falling into any one channel is 7, whereas the total number of terms is 132, corresponding to 11 per channel. A 2 db. allowance is justified in this case. With a different position in the frequency spectrum this allowance is different, and if, for instance, the channels are placed in a frequency band having a ratio between maximum and minimum frequency equal to or less than 2, no second order distortion will fall into any part of that frequency range.

For systems with a large number of channels, 60 or more, the method described is fairly accurate for the second and third order of distortion provided that the "single channel distortion" is taken into account.

When the number of channels is very small, say 12 or less, this method is inaccurate. It is not justifiable for such small numbers to assume that the mean distortion is shared equally between the channels: the distortion falling in a particular channel will fluctuate too much to justify averaging.

In spite of these difficulties and errors the method is still useful on account of the ease with which it can be applied.

The second method of calculating non-linear distortion described below is not subject to these difficulties. The results are accurate for any number of channels, but more work is required to obtain a result.

10. Second method of calculating noise due to non-linear distortion in an amplifier

In the following, it has again been assumed that the channels are active on the average half the time, and that when they are active the volume distribution follows curve A in Fig. 1A, and, further, that in continuous speech the distribution of instantaneous to long time mean power is defined by the curve 1, Fig. 3.

The subscriber mean power distribution may be expressed in terms of an "average subscriber," and a distribution p of deviation from the average subscriber condition. The average subscriber volume (50% active) is 15.1 db. below reference volume, and the long time mean power contributed by an average subscriber is 1 mW − 12.0 db. = P_0 mW.

The method is to determine the noise falling into a particular frequency band by adding the separate types of distortion products due to the other channels, singly or combined in groups of two or three, according to the type of distortion considered. The distortion due to any one cause or set of causes is averaged as regards the instantaneous to mean distribution, but is left expressed by a probability curve for the more slowly varying subscriber volume changes. When a number of similar sources of distortion are present they are combined on a statistical basis and give a new distribution curve. Such curves are obtained for each type of distortion, and these should again be combined on a statistical basis. In actual practice this last operation is generally unnecessary, since a particular type of distortion will predominate.

11. Second order distortion

Consider the term $\mu_2 v^2$ in formula (9); v is the instantaneous voltage due to a number of subscriber voltage distributions not necessarily at equal volume. The voltages due to separate subscribers are v_r, v_q, v_s. Consider, further, that the voltages each consist of frequencies in a band indicated by the suffix. These bands are of equal width, and correspond each to the sideband range of one channel. Now put $v_r = a_r \sqrt{P_0\ p_r}$, etc. where p_r is the deviation from mean subscriber power P_0 for channel r (see Fig. 1B (right-hand side)), and a_r is the ratio of instantaneous to the root of long time mean square volts in speech due to a single subscriber. (Figure 3 shows the distribution function for a_r^2.) On squaring v, two types of terms are obtained: $P_0\ p_r\ a_r^2$ and $2P_0 \sqrt{p_r\, p_q}\ a_r\ a_q$.

11.1. The term $P_0\ p_r\ a_r^2$ consists of direct current, of sum and difference frequencies produced by the components in the r waveband, and, further, of the second harmonics of each component in the original wave. The instantaneous power in this term is $P_0^2\ p_r^2\ a_r^4$. The frequencies in this term may be arranged into two groups, one which consists of frequencies falling into a double range at about twice the frequency, and another falling into a double range with 0 frequency as the middle of the range. This "0 range" or $r–r$ range generally falls outside the channel ranges.

The D.C. power is easily shown to be:

$$P_0^2\ p_r^2\ \overline{a_r^2} \text{ or equal to } P_0^2\ p_r^2$$

since the voltage distribution "a" has unity mean power. (The circuit resistance of 1 ohm has been assumed for convenience.)

The power at frequencies in the $r+r$ range can be shown to be $\frac{1}{3}$ of the total power or $\frac{1}{3}\ P_0^2\ p_r^2\ a_r^4$, while the power in the 0 frequency range or $(r-r)$ range is

$$P_o^2\ p_r^2 \left[\ \tfrac{2}{3}\ \overline{a_r^4} - 1\ \right] \text{ (exclusive of D.C.)}$$

The factor $\overline{a_r^4}$, the mean fourth power of instantaneous volts in a single voice wave with unity mean power, was worked out in connection with the first method, and is found in Fig. 8 to be 14.4 db. above what would be produced by a sine wave of unity mean power. For a sine wave the corresponding factor is $\frac{1}{2}$ or - 3 db, or $\overline{a_r^4}$ is 11.4 db. or 13.8. The power contained at frequencies equal to sums of the original frequencies is therefore (including now μ_2)

$$\tfrac{1}{3}\ \mu_2^2\ P_0^2\ p_r^2\ 13.8\ .$$

To simplify, compare this term to the power of the second harmonic of a sine wave of power $P_0 p_r$, which is

$$\tfrac{1}{2}\ \mu_2^2\ P_0^2\ p_r^2\ .$$

The sum frequency (or $r+r$) distortion power is therefore 9.2 times or 9.6 db. higher than the second harmonic of a sine wave of the same mean power $(P_0\ p_r)$.

Each channel in the system produces such a term. The factor p_r^2 is obtained from the subscriber mean power distribution curve B, Fig. 1, the right-hand ordinate, and, when substituted, gives the distribution of noise power in a range at double the frequency of the range causing the noise. It should be noted that Fig. 1A shows 10 log p—not p^2.

11.2. The term $2P_0\sqrt{p_r\, p_q}\ a_r\ a_q$ can only contain frequencies which are the sum and difference of one frequency in each band. The whole power in this term is equally divided between the sum and difference frequencies: the instantaneous power of either is, therefore, $2\mu_2^2\ P_0^2\ p_r\ p_q\ a_r^2\ a_q^2$. The mean distortion power is obtained by averaging the product $a_r^2\ a_q^2$; a_r and a_q are the same function, but the suffixes are used to indicate that the product must be extended over all values of a_r and a_q independently. The mean value of this product is 1. The second order sum and difference terms are, therefore, each 6 db. higher than the second harmonic of a sine wave of power $P_0 \sqrt{p_r\, p_q}$. The use of the mean value $\overline{a_r^2\ a^{\ 2}}$ is justified if the function satisfies the mean value over a short time of the order of 100–200 milliseconds. The power will eventually be appreciated by the ear, which will effect the real averaging.

The duration of syllables of speech is rather longer than the averaging time of the ear, but the time during which two subscribers each simultaneously produce a very loud syllable is, of course, in general very much shorter than the syllables themselves; the noise peaks, therefore, are many of short duration rather than a few of longer duration. Noise of the type being considered will, in general, come from many pairs of subscribers. In the combined noise wave

www.americanradiohistory.com

there is a much reduced probability of the short time mean power seriously exceeding the long time mean power. If, however, only a few pairs of channels are involved, it will be necessary to make an allowance for the peaky nature of this noise.

The factor $p_r p_q$ is the product of two deviation ratios, both defined by the distribution curve B, Fig. 1A. The ratios are between the actual mean power of a channel and the "average subscriber" power P_0. This product is expressed by a new distribution curve 1, Fig. 10, which shows the probability of the product $p_r p_q$ exceeding the values indicated by the abscissa. This curve has been calculated from the single subscriber curve B, Fig. 1A, which includes allowance for the channels being active only half the time. By substituting values obtained from this curve the distortion power due to the sum or difference between frequencies in two independent channels can be evaluated as a distribution curve. This curve has not been averaged, since the occurrences concerned are slowly varying.

11.3. When several pairs of frequency ranges produce noise which falls in a particular range under consideration, the separate noise power distributions due to each pair must be added together on a probability basis. This addition has been done graphically, and the result is shown on Fig. 10. The ordinates represent $\frac{1}{n}$ of the sum of n products such as $p_r\ p_q + p_s p_t + \ldots$ etc., expressed in decibels compared to unity, and the abscissa shows the logarithm of the probability that the ordinate will be exceeded. The numbers on the curves refer to the number n of pairs which have been combined. The pairs combined are assumed to be independent; this is not generally quite true, since two pairs may have, for instance, p_r in common, but no two pairs will have more than one such factor in common. When a very high number of pairs are combined, the distribution curves become flat and approach the abscissa. In using these curves, add to the ordinate 10 × logarithm of the number of pairs involved.

12. *Example for illustration*

To evaluate the total second order distortion in a particular channel, find how many terms of the types $r \pm q$ fall into the channel; then find if an $r+r$ type of term will be present.

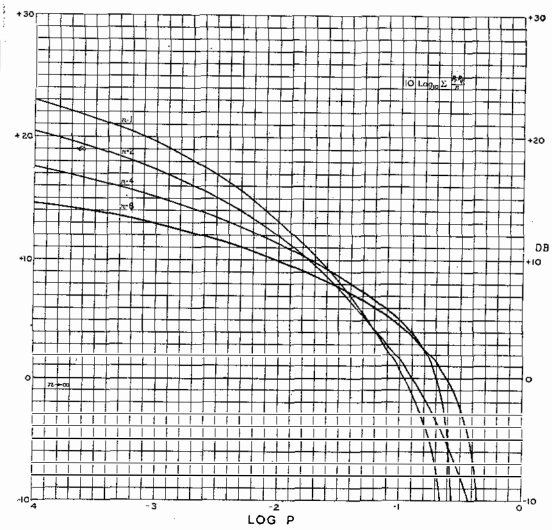


Fig. 10—*Distribution for sum of terms of type* $p_r p_q$.

If the channels are of equal frequency bands, divide the range of frequencies from 0 to the maximum channel frequency into ranges of channel bandwidth, and number these ranges beginning from 0 frequency. If the first of these frequency ranges, which is actually occupied by a channel, is assumed to carry the number F, and the last channel-space the number L, then the number $r+q$ terms falling into a channel carrying the number X is $\frac{1+X}{2} - F$ (fractions being disregarded).

Similarly, the number of $r-q$ type terms is approximately $L-F-X$.

The maximum number of $r \pm q$ terms falls into the lowest channel, for which $X = F$.

For a 12-channel system with channels between 12 and 60 kc, $L = 15$, $F = 4$ and the maximum number of terms $r \pm q$ into any one channel is 7.

If ${}^2H_0$ mW is the second harmonic output power caused by a sine wave output power P_0, then the total second order crosstalk of $r+q$ and $r-q$ type into the worst channel is $(10 \log {}^2H_0 + 6 + 13.0 + 10 \log 7)$ db. above 1 mW, or 27.5 db. above ${}^2H_0$ mW.

The 13.0 db. is the allowance obtained from Fig. 10 for a probability $\frac{1}{1\,000}$ of the calculated value being exceeded. If a probability of $\frac{1}{100}$ is considered the result is about 3 db. lower. The 6 db. addition is that calculated in para. 11.2 for $r \pm q$ type terms.

The lowest channel into which an $r+r$ type term falls is $X = 2F$. The power of this term for $P = \frac{1}{1\,000}$ is $+9.6$ db. $+ 32$ db. or is 41.6 db. above ${}^2H_0$ or for $P = \frac{1}{100}$ is $9.6 + 22$ db. or 31.6 db. above ${}^2H_0$.

The last figures in the sums are double the single channel deviation obtained from Fig. 1A, curve B, by reading the right-hand scale for $R = 1$. The 9.6 db. addition is that calculated in para. 11.1 for $r+r$ type terms.

The number of $r \pm q$ terms falling into the channel $X = 2F$ is 4 and for $P = \frac{1}{1\,000}$ (or $\frac{1}{100}$) the power is approximately $+27.0$ (or 23.3) db. above ${}^2H_0$. As regards second order distortion in the system considered, it is, therefore, clear that the $r+r$ term is the most important, but occurs only in some channels.

If the channels are equipped with peak limiters the $r+r$ term will be much reduced. If the limitation is at 1 mW+6 db. instantaneous power at the input to the channel, the $r+r$ term in the above example must be reduced by a factor obtained from Fig. 1D. This figure is described in para. 8.4. The reduction for $P = 10^{-3}$ is 16.8 db. (and for $P = 10^{-2}$, 9.7 db.) The corrected distortion will, therefore, be 24.8 db. (or 21.9 db.) above ${}^2H_0$. Terms of types $r \pm q$ will also be reduced by channel peak limiting, but to a much smaller extent. Other sets of curves, similar to Fig. 10, but based on curves such as B′ or B″, Fig. 1A, may be calculated and used for finding approximately the effect of limiting on terms of $r \pm q$ type: or else an allowance may be made for the reduction in total mean power. In both cases the results would be pessimistic for small numbers of channels, but tending to become correct for about 60 or more channels. According to the second method of correction with limiting at 1 mW+ 2 db., and, therefore, a loss of mean power (R large) of 2.5 db. (see para 8.4.), the second order $r+r$ term would be 5 db. smaller than calculated. With limiting at 1 mW+12 db. instantaneous power, the correction would be only 0.6 db.

13. *Third order distortion*

When v in formula (9) consists of a voltage such as $P_0^{\frac{1}{2}}\, p_n^{\frac{1}{2}}\, a_r + P_0^{\frac{1}{2}}\, p_q^{\frac{1}{2}}\, a_q$, etc., the term $\mu_3\, v^3$ will consist of terms of the following types:—
$P_0^{\frac{3}{2}}\, p_r^{\frac{3}{2}}\, a_r^3$, $3P_0^{\frac{3}{2}}\, p_r\, p_q^{\frac{1}{2}}\, a_r^2\, a_q$ and $6\, P_0^{\frac{3}{2}}\, p_r^{\frac{1}{2}}\, p_q^{\frac{1}{2}}\, p_s^{\frac{1}{2}}\, a_r\, a_q\, a_s$.

13.1. The first type of term consists of two ranges of frequencies, one in $r+r-r$, a range overlapping the r range, and another $r+r+r$ near the $3r$ range. The total power in a term of this type is $P_o{}^3\, p_r{}^3\, \overline{a_r{}^6}$; $\overline{a^6}$ has already been evaluated in connection with the first method as total third order distortion of a single channel speech wave. In Fig. 8 the value is 33.5 db. above the third harmonic of a sine wave of unit power; p_r may be obtained from Fig. 1A, curve B.

It can be shown that only $\frac{1}{10}$ of the total power in this term falls in the $r+r+r$ range; $\frac{9}{10}$ fall into the r range, and to some extent into the nearest adjacent ranges. If, actually, the main energy in a channel is contained in frequencies up to about 1 500 p:s, and if the channels are 4 kc wide, there will be a little noise into only one of the adjacent channels (depending on whether upper or lower sideband is used), and the noise will occur at frequencies above about 2 500 p:s where the psophometric allowance is more than 14 db. For small numbers of channels it is necessary to estimate how much of the term $r+r-r$ falls into the adjacent channels (i.e. $r+1$ and $r-1$). The actual amount depends on the channel filters and the frequency spacing of the channels. Since, in these adjacent channels, the majority of the noise will be at frequencies near the boundaries of the ranges, it is important to apply a psophometric allowance. The noise falling into the channel itself will be masked by the speech in the channel. The total power in the band near r is $+33.5$ db. $+10 \log p_r{}^3$ db. above ${}^3H_0$. ${}^3H_0$ is the third harmonic power due to a sine wave P_0. It is advisable in systems with only a few channels to check that this power is sufficiently small compared to the signal power 1 mW$+10 \log P_0\, p_r$. Noise, even when masked by speech, may reduce the intelligibility of the speech. This type of distortion contains some of the exact original frequencies, and these will cause a modification in the amplifier output which will be apparent as non-proportionality

www.americanradiohistory.com

between the input and output. This effect is not generally of sufficient magnitude to be important, particularly since it depends only on the channel itself.

In general the most important part of this term is, therefore, the $r+r+r$ range, for which the distortion is $+23.5+10\log p_r^3$ db. above $^3H_0$. If a channel limiting means is used, this distortion should be reduced by applying the correction from Fig. 1D, curve C (see para. 8.4). The procedure is similar to that for $r+r$ terms described in para. 12.

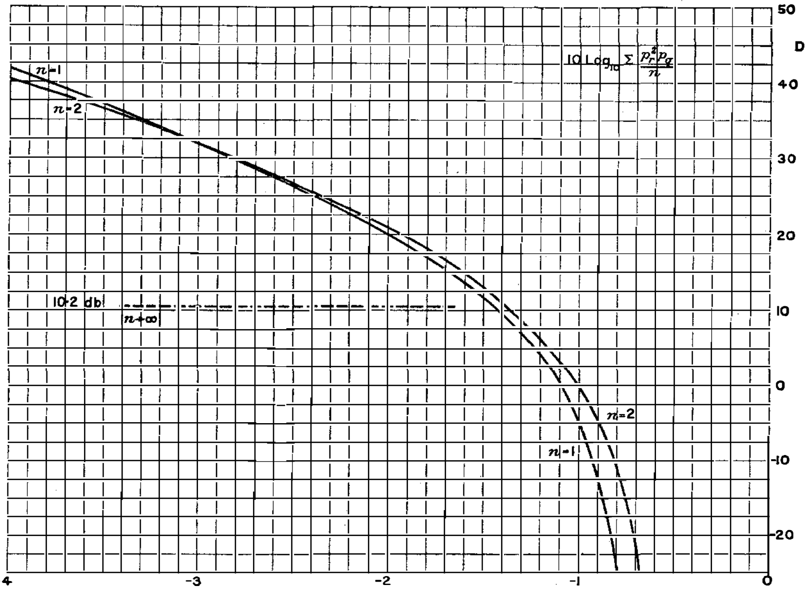


Fig. 11—*Distribution for sum of terms of type* $p_r^2 p_q$.

13.2. *Terms of type* $3P_0^{\frac{3}{2}}\, p_r\, p_q^{\frac{1}{2}}\, a_r^2\, a_q$

These terms contain frequencies in the ranges $r+r+q$, $r+r-q$ and $(r-r)\pm q$.

The total mean power of the term is $9\,\mu_3^2\, P_o^3\, p_r^2\, p_q\, \overline{a_r^4\, a_q^2}$. The factor $\overline{a_r^4\, a_q^2}$ has been calculated from curve 1, Fig. 3, by combining the distribution of the instantaneous to mean power ratio (a_q^2) with another similar, but independent, ratio squared (a_r^4). The average of the combined distribution is 14; it can be proved that $\frac{1}{6}$ of the total distortion power occurs in each of the bands $r+r+q$ and $r+r-q$ and $\frac{2}{3}$ in the band $(r-r)\pm q$. Some of the power in this latter band occurs at the exact input frequencies, and this part must be treated separately, since it combines with voltages due directly to the input. The distortion in the range $r+r+q$ is 19.2 db., that in $r+r-q$ is 19.2 db., and in $q\pm(r-r)$ is 25.2 db. above $^3H_0+10\log p_r^2\, p_q$ db. The factor $p_r^2\, p_q$ has been calculated as a distribution from curve B, Fig. 1A, right-hand scale, and is shown by curve 1, Fig. 11.

Distortion in the range $q\pm(r-r)$ falls into band q and the two nearest adjacent bands. If the power from the channels is concentrated at frequencies below 1 500 p : s, and the channel width is 4 000 p : s, a small fraction of the energy in the $q\pm(r-r)$ range will fall into one only of the adjacent ranges, and will occur in this channel at voice frequencies for which the psophometric allowance is high. This range, therefore, largely falls back into the channel itself. In any channel q this term occurs once for each of the other channels in the system, and the total power is $+25.2+10\log(\sum p_r^2\, p_q$ + etc.) db. above $^3H_0$. Noise which occurs in a channel only when it is active, and which is related to the channel voltage, is much less dangerous to intelligibility than is noise which is present independently of the channel. Noise which is related to the channel level should not be measured as power, but rather as ratio between useful signal and noise—this ratio in the present case being independent of the channel level. A value of 30 to 40 db. is quite adequate. The mean signal power in the channel is $10\log P_0+10\log p_q$ above 1 mW, and the db. margin between signal and noise is the difference between these quantities or

$$10\log\frac{P_0}{^3H_0}-25.2-10\log\sum p_r^2+p_s^2+p_t^2 + \ldots\ \text{db.}$$

$10\log\ \frac{1}{n}\sum\overline{p_r^2+p_s^2+}$ etc. can be shown to be +10.5 db., and this figure may be used when the number n of channels is large. If fuller information is required, distribution curves must be calculated similar to Figs. 10, 11 and 12.

13.3. The effect of the voltages at exact frequencies q which are produced by the term under discussion is to change the transmission of channel q. The change will in general be a reduction in gain. The voltage at the exact frequency of q is $3 \frac{\mu 3}{\mu 1} P_0 p_r$ times the output voltage due to q directly. The db. change in transmission is therefore approximately $26.1 \times \frac{\mu_3}{\mu_1} P_0 p_r$ due to channel r. But since ${}^3H_0 = \frac{1}{4} \frac{\mu_3^{\,2}}{\mu_1^{\,2}} P_0^{\,3}$, the db. change in gain is

$52.2 \times \left(\frac{{}^3H_0}{P_0}\right)^{\frac{1}{2}} \sum p_r + p_s + p_t \ldots$ db. due to channels r, s, t, etc.

This change in transmission is defined by the distribution of $\sum p_r + p_s + \ldots.$ which may be obtained from Fig. 1B for various numbers of channels. The gain change, therefore, fluctuates with the combined subscriber mean power condition. Of course, it also has a fluctuation due to the instantaneous to mean variation in each speech channel, but this fluctuation is more rapid, and should not be considered as fluctuation of transmission, but as noise, and thus constitutes the term $q \pm (r - r)$ where $(r - r)$ excludes 0. Unless many channels are present, the change given by the formula will fluctuate too much to permit averaging of $\sum p$.

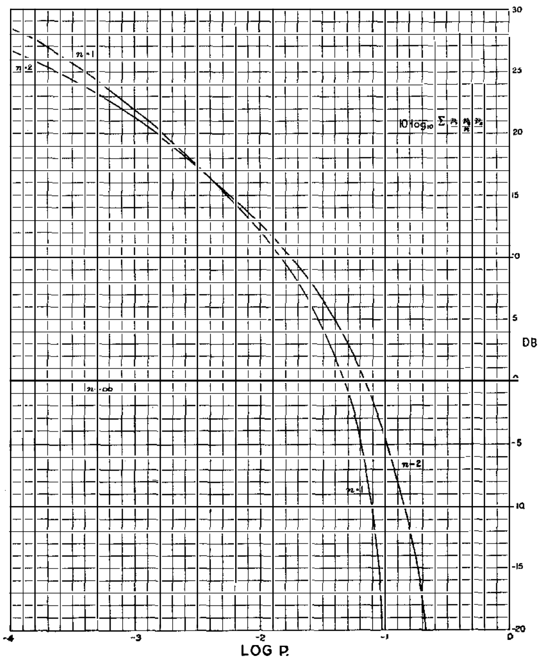


Fig. 12—*Distribution for sum of terms of type* $p_r p_q p_s$.

When repeaters are used in tandem, the db. gain reductions due to each repeater must be added. The voltages produced in the various repeaters, and which cause the gain reduction, will add in-phase, whereas the noise voltages at any one frequency produced in the various repeaters may, in general, be assumed to add at random phase. For a given overall third order noise the transmission change will, therefore, increase in proportion to the square-root of the number of repeaters.

13.4. Not all noise voltages produced in the various repeaters add with random phase, voltages in term $r \pm (r - r)$, for instance, tend to add in-phase. Terms which will add in-phase are the third order terms of form $r + r - r$ and second order terms of type $r - r$.

Other terms will, in general, add with random phase, or will add as powers. The minimum phase imperfection sufficient to produce the random phase condition for most terms is a phase intercept at 0 frequency of the phase versus frequency curve for a single section and a single repeater, but unless this intercept is of the order of 20 degrees the random phase condition will not be fulfilled except for very large numbers of repeaters. If the phase curve shows other imperfections, such as curvature or irregularities, the random condition will more readily be fulfilled. In an actual system the attenuation equalizers and the input and output transformers will provide sufficient phase distortion to ensure the random condition. But in a carefully phase-corrected circuit such as those used for television the random condition would never be fulfilled, and all distortion would add in-phase. But a phase intercept will not prevent terms of the types $r + r - r$, $r - r$, and $q \pm (r - r)$ from adding in-phase at the various amplifiers. These terms add with random phase only if the circuit has a very curved phase/frequency characteristic.

As the number of repeaters in tandem is increased, these in-phase terms become relatively more important and may constitute a limiting factor, but it is rather improbable that the phase curve of a very long system will be so nearly a straight line that these terms really do add strictly in phase.

13.5. Terms of type 6 $P_0^{\frac{3}{2}} p_r^{\frac{1}{2}} p_q^{\frac{1}{2}} p_s^{\frac{1}{2}} a_r a_q a_s$

For any three bands of frequencies r, q and s due to three independent channels, this term can be resolved into four bands of frequencies $r \pm q \pm s$, each containing $\frac{1}{4}$ of the total power of the term, or each being of power $\frac{1}{4}$ 36 $P_0{}^3 p_r p_q p_s \times a_r{}^2 a_q{}^2 a_s{}^2$. Evaluation of this factor shows that each of the four terms contains power equal to +15.6 db. + 10 log $p_r\ p_q\ p_s$ above ${}^3H_0$. Figure 12 shows the distribution of 10 log $p_r\ p_q\ p_s$: also the mean sum distribution of two such distributions. The mean sum distribution for a large number of groups of three approaches 0 db. as a limiting value.

14. To evaluate the total third order distortion falling into a particular channel, find the number of each type of term falling into the channel. Only one term of the type $r+r+r$ can fall into any one channel.

One term of the type $r+r-r$ falls into each channel, but only when the channel is active.

Terms of the type $r+r+q$ will, in general, be many; their number can be found in an actual system by counting the number of ways of obtaining a frequency in the channel in question as a sum of double one frequency+another different channel frequency, similarly for $2\,r-q$. It should be remembered when counting these latter terms that negative values for $r+r-q$ are as important as positive values. In both cases r and q must always be different channels. In general, terms $r+r-q$ producing either r or q should be disregarded.

The number of terms $r+q+s$ is easily counted, but care should be taken in counting $r+q\quad s$, and $r-q+s$ and $r-q-s$. These are most easily counted together without distinction; for instance, by counting the number of ways in which $(r+q)-s$ can be made equal to the band considered. The bracket indicates that permutations of $r+q$ must not be included. The maximum number of terms $r\pm q\pm s$ into any one channel of a system with many channels is approximately $\frac{R^2}{3}-R$.

14.1. Figure 13*a* is a tabulation of the number of third order terms of various types which fall into the channels of a 12-channel system. It is clear from this figure that channels such as numbers 11 and 14 will suffer the highest cross-talk. This statement assumes that ${}^3H_0$ is independent of frequency, which is not always true. In an actual amplifier, the gain and harmonic reduction due to feedback is generally dependent on frequency.

If ${}^3H_0$ is frequency dependent it will be necessary to consider several of the channels, and in connection with the appropriate value of ${}^3H_0$, but the method is very well adapted to allow this.

In the present case, consider only channel 14.

The distortion power from this channel is shown in Figs. 13*b* and 13*c*. The last three

DISTRIBUTION OF INTERMODULATION PRODUCTS $R=12$

Type of Term		Channel No.											
		4	5	6	7	8	9	10	11	12	13	14	15
2nd Order	$r+r$ ..					1		1		1		1	
	$r+q$ ..						1	1	2	2	3	3	4
	$r-q$ ..	7	6	5	4	4	3	2	1				
3rd Order	$r+r+r$ ..							←	— 1 —	→	←	— 1 —	→
	$r+r-r$ ..	1	1	1	1	1	1	1	1	1	1	1	1
	$r+r+q$ ..								1	2	1	3	3
	$r+r-q$ ..	7	6	7	5	5	5	5	5	5	5	5	5
	$q\pm(r-r)$ ..	11	11	11	11	11	11	11	11	11	11	11	11
	$r+q+s$ ..										1	1	2
	$r+q-s$ ..	27	31	34	36	35	35	35	35	35	33	29	25

Fig. 13*a*—*12-channel system,* 12–60 *kc/s upper sideband. All the terms represent bands of frequencies covering potentially two (second order) or three (third order) channel bands.*

Type of Term	No. of occurrences		db. above $^2H_0$ mW per term	Allowance for subscriber's mean power deviation in db.			Distn. power in db. above $^2H_0$ mW		
	No.	db.		$P=10^{-3\cdot0}$	$P=10^{-2\cdot0}$	$P=10^{1\cdot0}$	$P=10^{-3\cdot0}$	$P=10^{-2\cdot0}$	$P=10^{-1\cdot0}$
$r+q$	3	4.8	6	16	11.5	3	26.8	22.3	13.8
$r-q$	0								
$r+r$	1	0	9.6	32	22	8	41.6	31.6	17.6
If each channel is peak limited at 1 mW + 12 db. $r+r$	1	0	9.6 $P=10^{-1\cdot0}$ 6.6 $P=10^{-2\cdot0}$ 1.3 $P=10^{-3\cdot0}$	32	22	8	33.3	28.6	17.6
If each channel is peak limited at 1 mW + 6 db. $r+r$	1	0	7.4 $P=10^{-1\cdot0}$ −0.1 $P=10^{-2\cdot0}$ −7.2 $P=10^{-3\cdot0}$	32	22	8	24.8	21.9	15.4
If each channel is peak limited at 1 mW + 2 db. $r+r$	1	0	3.8 $P=10^{-1\cdot0}$ −5.8 $P=10^{-2\cdot0}$ −12.7 $P=10^{-3\cdot0}$	32	22	8	19.3	16.2	11.8

Fig. 13b—Calculation of 2nd order distortion falling into channel No. 14. A single repeater. 12-channel system 12–60 kc/s.

columns are the results for each important type of third order distortion. For a case of n repeaters in tandem, add 10 log n to each result shown except as explained in the note under Fig. 13*c*. Figure 14 is a table of both second and third order distortion for a system with 240 channels. In all these figures the total distortion must be found by adding together the distortion due to the separate terms. The term $q \pm (r-r)$, and other terms which tend to fall into the channel which produces the term, should not be included in this addition, except in so far as their frequency ranges spread into adjacent channels.

When only a small number of channels is present it cannot be assumed that the separate types of distortion are completely independent, and the separate contributions for each value of P should then be added as power. When many channels are present it is safe to assume independence, and the power should then, strictly speaking, be added on a statistical basis; but the extra work involved is not justified or even necessary. This also applies when second and third order distortions are being combined.

14.2. Figures 13*b* and 13*c* also show the effect of limiting on the distortion due to a single channel. For a 12-channel system it would appear that, in respect of third order distortion, little advantage would be gained by limiting at a level below 1 mW+8 db. inst., while, for second order, limiting down to 1 mW+2 db. would give an improvement.

The corresponding figures for a 240-channel system are, for third order distortion, 1 mW+9 db. (only of advantage for very rare peaks) and for second order, 1 mW+2 db. would help against the rare peaks while 1 mW+6 db. would probably be enough in practice.

The actual probability to be considered should be part of the requirements for the system. $P = 10^{-2}$ would be a reasonably strict requirement, while $P = 10^{-1}$ might be considered sufficient in some cases.

14.3. Calculation of the gain change for the 12-channel example

Assume that the amplifier has been designed to satisfy the third order noise requirements on the average for 99% of the busy period ($P = 10^{-2}$), and that third order noise due to more than one channel is the determining factor.

Assume, further, that the permitted noise power is 1 mW − 50 db. at the output of each channel at a point of 0 level relative to the input to the channel (this represents the lowest likely requirements). The noise for $P = 10^{-2}$ is 51.2 db. above $^3H_0$ mW, and since $P_0 = 1$ mW

– 12 db. the ratio $\left(\frac{^3H_0}{P_0}\right)^{\frac{1}{2}}$ will be $\frac{1}{29\,000}$ and the average gain change will be $\frac{52.2}{29\,000}$ 11 = 0.02 db. for a single repeater during the busy period. There is a $\frac{1}{100}$ (or $\frac{1}{1\,000}$) probability that the gain change will exceed the average busy period gain change by 4 times (7.0 times). The peak gain change for one repeater will therefore be 0.08 db. (or 0.14 db.). The increase depends on $\sum \frac{p_r + p_s + \ldots\ldots}{R}$ and has been read from Fig. 1B.

In a system with 100 repeaters the change will be 10 times greater, or there is a $\frac{1}{1\,000}$ probability that it will exceed 1.4 db. This change will in many cases not materialize, since the second order distortion (rather than third order) may be the determining factor ; the third order effects—including the gain reduction and fluctuation—will, of course, then be smaller than would have been the case had the third order been the limiting factor.

In the example of a 240-channel system the third order distortion is approximately 60 db. above $^3H_0$, and if the permissible third order noise power is again assumed to be 1 mW – 50 db. at a point of zero relative circuit level, the ratio $\left(\frac{^3H_0}{P_0}\right)^{\frac{1}{2}}$ becomes $\frac{1}{80\,000}$, and the average gain reduction in the busy period is 0.156 db. for a single repeater.

In this case, due to the large number of channels, there will be only a little fluctuation in the gain change during the busy hour, and the peak reduction ($P = 10^{-3}$) is very little larger than the average reduction. Outside the busy period the gain reduction will, of course, be smaller.

Although the above refers to the gain change as a reduction, it is possible, by special treatment of the amplifier, to obtain a gain increase with increasing power, at least up to a certain power. (This corresponds to a change in the sign of μ_3 in formula (9).)

In a single repeater the gain change is determined by the third order distortion, and can only be made 0 in an amplifier having no third order distortion. In a system with many repeaters it is possible to make the overall gain change zero or very small, but the overall distortion cannot be improved more than each repeater can be improved (except in systems

Type of Term	No. of occurrences		db. above $^3H_0$ mW per term	Allowance for subscriber's mean power deviation in db.			Distn. power in db. above $3H_0$ mW		
	No.	db.		$P=10^{-3\cdot0}$	$P=10^{-2\cdot0}$	$P=10^{-1\cdot0}$	$P=10^{-3\cdot0}$	$P=10^{-2\cdot0}$	$P=10^{-1\cdot0}$
$r+r\pm q$	8	9.0	19.2	28	23	10	56.2	51.2	38.2
$r+q\pm s$	30	14.8	15.6	14	10	6	44.4	40.4	36.4
$q\pm(r-r)$ ..	11	10.4	25.2	26	23	12	(61.6	58.6	47.6)*
$r+r+r$	1	0	23.5	48	33	12	71.5	56.5	35.5
If each channel is peak limited at 1 mW + 12 db. .. $r+r+r$	1	0	23.5 $P=10^{-1\cdot0}$ 17.2 $P=10^{-2\cdot0}$ 7.8 $P=10^{-3\cdot0}$	48	33	12	55.8	50.2	35.5
If each channel is peak limited at 1 mW + 6 db. .. $r+r+r$	1	0	18.7 $P=10^{-1\cdot0}$ 5.7 $P=10^{-2\cdot0}$ –6.3 $P=10^{-3\cdot0}$	48	33	12	41.7	38.7	30.7
If each channel is peak limited at 1 mW + 2 db. .. $r+r+r$	1	0	11.9 $P=10^{-1\cdot0}$ –3.8 $P=10^{-2\cdot0}$ –16.4 $P=10^{-3\cdot0}$	48	33	12	31.6	29.2	23.9

Fig. 13c—Calculation of 3rd order distortion falling into channel No. 14. 12 channels.

* This term largely falls into channel q itself. When n repeaters are used, add 20 log n. To other terms add 10 log n. The term $r+r-r$ falls largely into channel r itself, and is 10 db. higher than the corresponding value of the term $r+r+r$.

www.americanradiohistory.com

Type of Term	No. of occurrences		db. above $^2H_0$ mW per term	Allowance for subscriber's mean power deviation in db.			Distn. power above $^2H_0$ mW or $^3H_1$		
	No.	db.		$P=10^{-3\cdot 0}$	$P=10^{2-\cdot 0}$	$P=10^{-1\cdot 0}$	$P=10^{-3\cdot 0}$	$P=10^{-2\cdot 0}$	$P=10^{-1\cdot 0}$
$r+q$ .. .. $r-q$	49 110	22	6	2	1.5	1	30	29.5	29
$r+r$	1	0	9.6	32	22	8	41.6	31.6	17.6†
$r+r\pm q$ ..	208	23.2	19.2	12	11.5	11.0	54.4	53.9	52.4
$r+q\pm s$ ..	24 044	43.8	15.6	0	0	0	59.4	59.4	59.4
$q\pm(r-r)$ ..	254	24	25.2	11.5	11.0	10.5	(60.7	60.2	59.7)*
$r+r+r$ ..	1	0	23.5	48	33	12	71.5	56.5	35.5†

Fig. 14—*Distortion falling into channel No.* 130 *of a coaxial system containing* 240 *channels* (*Nos.* 16–255). *A single repeater.*

† The distortion due to the terms $r+r$, and $r+r+r$, is reduced by peak limiting as shown in Figs. 13*b* and *c*.

* This term falls largely into channel q itself. When n repeaters are used, add 20 log n. To other terms, add 10 log n.

with distortionless transmission, i.e., systems in which all distortion adds in-phase).

It appears, therefore, that the gain change due to third order distortion is not likely to become a limiting factor in systems with less than several hundred repeaters. If, however, the amplifiers are also carrying a photo-telegraphy or television channel it seems likely that gain fluctuation will be a limiting factor, since such channels are very sensitive to transmission fluctuation, but relatively insensitive to noise. In these special cases terms such as $q\pm(r-r)$ are more important than when the channels carry speech only.

14.4. To find what transmitting gain β can safely be used with a particular amplifier, express first the noise level permitted at a point in the circuit for which $\beta=0$.

For $\beta=0$ the mean power is P_0, and for this mean power the amplifier gives harmonic power $^2H_0$ (or $^3H_0$). If the mean power carried by the amplifier is now increased by β db. the harmonic power is increased by 2β (or 3β) db. But referred back to a point of 0 level the harmonic power is β (or 2β) db. above $^2H_0$ (or $^3H_0$). This power, plus the allowance from tables such as those in Figs. 13 and 14, gives the noise power due to speech, and by comparing to the specified noise power, β may be evaluated.

Overload distortion must, of course, be considered separately, and may be found to form the limiting factor. If overloading distortion is the limiting factor the repeater has an adequate or excessive negative feedback, and could be used with a higher gain. If, on the other hand, second or third order distortion determines β, the feedback is inadequate, and should be increased, in which case the repeater gain will, of course, be reduced.

The ideal case is that the values of β determined by near-linear and overloading distortion should be equal. The gain of the amplifier with the amount of negative feedback required for this condition should then be equal to the equivalent single section attenuation.

Although the present work has dealt with amplifiers, the method has been applied with little modification to problems involving distortion in multi-channel modulators.

Thanks are due to Standard Telephones and Cables, Limited, for permission to publish this paper, and to Mr. J. Paine and others in the S.T.C. Transmission Laboratory for assistance with the computations.

www.americanradiohistory.com

APPENDIX A

$$F_1\ (v)\ dv = \frac{1}{\sqrt{2}\,v_0}\,\varepsilon^{-\sqrt{2}\frac{|v|}{v_0}}\,dv$$

$$F_2\ (v)\ dv = \frac{1}{2\sqrt{2}\,v_0}\,\varepsilon^{-\sqrt{2}\frac{|v|}{v_0}}\left[\sqrt{2}\,\frac{|v|}{v_0} + 1\right] dv$$

$$F_3\ (v)\ dv = \frac{1}{8\sqrt{2}\,v_0}\,\varepsilon^{-\sqrt{2}\frac{|v|}{v_0}}\left[\frac{2v^2}{{v_0}^2} + 3\sqrt{2}\,\frac{|v|}{v_0} + 3\right] dv$$

FOR SIMPLIFICATION WRITE $\sqrt{2}\dfrac{|v|}{v_0} = x$

$$F_4\ (x)\ dx = \frac{1}{96}\,\varepsilon^{-x}\,[x^3 + 6\,x^2 + 15\,x + 15]\,dx$$

$$F_5\ (x)\ dx = \frac{1}{768}\,\varepsilon^{-x}\,[x^4 + 10\,x^3 + 45\,x^2 + 105\,x + 105]\,dx$$

$$F_6\ (x)\ dx = \frac{1}{7680}\,\varepsilon^{-x}\,[x^5 + 15\,x^4 + 105\,x^3 + 420\,x^2 + 945\,x + 945]\,dx$$

$$F_7\ (x)\ dx = \frac{1}{9.216 \times 10^4}\,\varepsilon^{-x}\,[x^6 + 21\,x^5 + 210\,x^4 + 1\,260\,x^3 + 4\,725\,x^2 + 1.039 \times 10^4\,x + 1.039 \times 10^4]\,dx$$

$$F_8\ (x)\ dx = \frac{1}{1.290 \times 10^6}\,\varepsilon^{-x}\,[x^7 + 28\,x^6 + 378\,x^5 + 3150\,x^4 + 1.733 \times 10^4\,x^3 + 6.237 \times 10^4\,x^2 + 1.351 \times 10^5\,x + 1.351 \times 10^5]\,dx$$

$$F_9\ (x)\ dx = \frac{1}{2.064 \times 10^7}\,\varepsilon^{-x}\,[x^8 + 36\,x^7 + 630\,x^6 + 6\,930\,x^5 + 5.198 \times 10^4\,x^4 + 2.703 \times 10^5\,x^3 + 9.459 \times 10^5\,x^2 + 2.027 \times 10^6\,x + 2.027 \times 10^6]\,dx$$

$$F_{10}\ (x)\ dx = \frac{1}{3.716 \times 10^8}\,\varepsilon^{-x}\,[x^9 + 45\,x^8 + 990\,x^7 + 1.386 \times 10^4\,x^6 + 1.351 \times 10^5\,x^5 + 9.459 \times 10^5\,x^4 + 4.730 \times 10^6\,x^3 + 1.622 \times 10^7\,x^2 + 3.446 \times 10^7\,x + 3.446 \times 10^7]\,dx$$

SYMBOLS

R.	Number of channels in the system, or the maximum number of subscribers which can occupy the system in one direction of transmission.
P_0.	The long time mean power of an "average subscriber" in a system where, on the average, half the channels are active (during the busy period).
p.	The long time mean power due to a particular channel divided by P_0. p is defined by a distribution function.
p_r, p_q, etc.	Values of p for independent calls on channels r, q, etc.
p_R.	The long time mean power sum due to R independent channels divided by P_0, p_R is also defined by a distribution function.
K.	Mean signal power in db. below amplifier instantaneous overload power.
β_1.	The transmitting gain of the system when the distortion produced by overloading is just equal to the permissible noise.
β_2.	The transmitting gain of the system when the distortion produced by the near linear part of the amplifier characteristic is just equal to the permissible noise.
a.	The ratio of instantaneous volts to the square root of the long time mean square volts in the speech wave of a single subscriber. a is defined by a distribution function.
a_r, a_q, a_s.	Refer to independent speech voltages in the channels r, q and s, each having the same distribution function.
n.	The number of sources of distortion of a particular type falling into a specified channel.

www.americanradiohistory.com

m.	Number of independent waves each with an exponential statistical distribution of voltage.
r.	Number of active channels of equal volume equivalent to R random channels.
$^2H_0$.	Second harmonic output in milliwatts when fundamental sine wave output is P_0.
$^3H_0$.	Third harmonic output in milliwatts when fundamental sine wave output is P_0.

REFERENCES

(1) "Load Rating Theory for Multi-channel Amplifiers," by B. D. Holbrook and J. T. Dixon, *Bell System Tech. Journ.*, October, 1939.

(2) *C.C.I.F. Proceedings*, Budapest, p. 490, Englis version.

(3) "Speech Power and Its Measurement," by L. J Sivian, *Bell System Tech. Journ.*, October, 192 p. 649.

(4) " Concerning the distribution of speech potential in transmission of multi-carrier frequency com munications," by D. Thierbach and H. Jacob *Zeitschrift für Technische Physik* 12, 1936, pp. 553 557.

Telephone Service in Great Britain*

THE number of telephone stations in service in the Post Office system of Great Britain and Northern Ireland at the end of March, 1939, was 3 235 498, the highest point yet reached. The increase for the year was 185 486 (6.1%), against 223 017 (7.9%) for the previous year.

The mean number of telephone stations in service during the year was about 3 142 755. Total conversations during the year were 2 236 017 000, giving 712 conversations per year per telephone station (based on mean number of stations for the year); the increase in the total conversations was 3.2%.

The ratio of Operating Revenue to Plant Investment was, at the end of the year, 16.2%.

Plant additions accounted for £17 320 773, equal to £93.4 per net added telephone station. The prime cost per telephone station was £77.7.

Depreciation for the year was at the rate of 4.48% of the plant investment at the end of the previous year. Five years ago the rate was 5.25% per annum.

The income was £11.[illegible]2 per mean telephone station.

The items of the Income and Expenditure Account are divided as follows :

	%
Administration and Traffic Expense ..	22.69
Maintenance	20.18
Accommodation (Rents)	7.77
Depreciation	25.20
Pension Liability	4.15
Interest on Capital and Surplus	20.01
	100.00

---

* Abstracted or deduced from the British Post Office Commercial Accounts for the year ended 31st March, 1939, and earlier.

Telephone and Telegraph Statistics of the World

Compiled by Chief Statistician's Division, American Telephone and Telegraph Company

Telephone Development of the World, by Countries
January 1, 1939

COUNTRIES	NUMBER OF TELEPHONES			Per Cent of Total World	Telephones Per 100 Population
	Government Systems	Private Companies	Total		
NORTH AMERICA:					
United States	—	19 953 263	19 953 263	48.56%	15.37
Canada	205 846	1 153 571	1 359 417	3.31%	12.13
Central America	13 131	17 999	31 130	0.07%	0.40
Mexico	1 337	157 232	158 569	0.39%	0.81
West Indies—					
Cuba	610	53 543	54 153	0.13%	1.29
Puerto Rico	531	15 170	15 701	0.04%	0.86
Other Places in the West Indies	9 042	18 838	27 880	0.07%	0.36
Other Places in North America	—	17 014	17 014	0.04%	4.40
Total	230 497	21 386 630	21 617 127	52.61%	11.85
SOUTH AMERICA:					
Argentina	—	405 474	405 474	0.99%	3.13
Bolivia	—	2 595	2 595	0.006%	0.08
Brazil	1 000	255 467	256 467	0.62%	0.59
Chile	—	78 119	78 119	0.19%	1.69
Colombia	8 500	30 333	38 833	0.10%	0.44
Ecuador	4 276	3 050	7 326	0.02%	0.29
Paraguay	—	3 339	3 339	0.01%	0.35
Peru	—	29 318	29 318	0.07%	0.43
Uruguay	34 810	11 846	46 656	0.11%	2.20
Venezuela	702	23 102	23 804	0.06%	0.67
Other Places in South America	3 018	—	3 018	0.007%	0.54
Total	52 306	842 643	894 949	2.18%	1.00
EUROPE:					
Belgium	415 522	—	415 522	1.01%	4.95
Bulgaria	29 576	—	29 576	0.07%	0.46
Denmark	18 607†	424 391	442 998	1.08%	11.61
Finland	7 720	177 736	185 456	0.45%	4.79
France	1 589 595	—	1 589 595	3.87%	3.79
Germany†	4 146 489	—	4 146 489	10.09%	5.20
Great Britain and Northern Ireland	3 220 241	—	3 220 241	7.84%	6.77
Greece	6 273	43 599	49 872	0.12%	0.71
Hungary	164 572	790	165 362	0.40%	1.64
Ireland (Eire)†	43 086	—	43 086	0.11%	1.47
Italy	—	611 254	611 254	1.49%	1.41
Latvia†	83 650	—	83 650	0.20%	4.20
Lithuania	26 591	—	26 591	0.06%	1.03
Netherlands	433 927	—	433 927	1.06%	4.97
Norway*	143 642	91 622	235 264	0.57%	8.03
Poland	160 251†	134 577	294 828	0.72%	0.84
Portugal	18 158	51 098	69 256	0.17%	0.91
Roumania	—	93 314	93 314	0.23%	0.47
Russia ¶	1 272 500	—	1 272 500	3.10%	0.75
Spain	—	300 000	300 000	0.73%	1.19
Sweden	801 562	1 666	803 228	1.95%	12.73
Switzerland	450 380	—	450 380	1.10%	10.72
Yugoslavia	67 588	—	67 588	0.16%	0.43
Other Places in Europe	275 482	—	275 482	0.67%	1.66
Total	13 375 412	1 930 047	15 305 459	37.25%	2.67
ASIA:					
British India†	31 878	51 500	83 378	0.20%	0.02
China	40 000	120 000	160 000	0.39%	0.04
Japan†	1 367 958	—	1 367 958	3.33%	1.89
Other Places in Asia	198 462	103 295	301 757	0.73%	0.15
Total	1 638 298	274 795	1 913 093	4.65%	0.18
AFRICA:					
Egypt	64 823	—	64 823	0.16%	0.29
Union of South Africa†	205 892	—	205 892	0.50%	2.03
Other Places in Africa	133 508	1 350	134 858	0.33%	0.11
Total	404 223	1 350	405 573	0.99%	0.26
OCEANIA:					
Australia*	630 175	—	630 175	1.54%	9.14
Hawaii	—	33 287	33 287	0.08%	8.10
Netherlands Indies	45 033	4 328	49 361	0.12%	0.07
New Zealand†	206 216	—	206 216	0.50%	12.69
Philippine Islands	1 263	28 579	29 842	0.07%	0.19
Other Places in Oceania	4 935	330	5 265	0.01%	0.24
Total	887 622	66 524	954 146	2.32%	0.99
TOTAL WORLD	16 588 358	24 501 989	41 090 347§	100.00%	1.91

* June 30, 1938. † March 31, 1939.

¶ U.S.S.R., including Siberia and Associated Republics.

§ Includes approximately 21 900 000 automatic or "dial" telephones, of which about 42% are in the United States.

www.americanradiohistory.com

Telephone and Telegraph Wire of the World, by Countries
January 1, 1939

Countries	Service Operated by (See Note)	Miles of Telephone Wire			Miles of Telegraph Wire		
		Number of Miles	Per Cent of Total World	Per 100 Population	Number of Miles	Per Cent of Total World	Per 100 Population
NORTH AMERICA:							
United States	P.	92 850 000	53.20%	71.53	2 300 000	34.17%	1.77
Canada	P.G.	5 397 000	3.09%	48.15	366 000	5.44%	3.27
Central America	P.G.	62 000	0.04%	0.81	22 000	0.33%	0.29
Mexico	P.	628 000	0.36%	3.22	100 000	1.49%	0.51
West Indies—							
Cuba	P.	278 000	0.16%	6.62	11 000	0.16%	0.26
Puerto Rico	P.	38 000	0.02%	2.08	2 000	0.03%	0.11
Other Places in the West Indies	P.G.	107 000	0.06%	1.36	7 500	0.11%	0.10
Other Places in North America	P.	22 000	0.01%	5.68	11 000	0.16%	2.85
Total		99 382 000	56.94%	54.47	2 819 500	41.89%	1.55
SOUTH AMERICA:							
Argentina	P.	1 583 000	0.91%	12.22	165 000	2.45%	1.27
Bolivia	P.	5 500	0.003%	0.17	5 000	0.07%	0.16
Brazil	P.	1 128 000	0.64%	2.58	110 000	1.63%	0.25
Chile	P.	310 000	0.18%	6.69	30 000	0.45%	0.65
Colombia	P.G.	137 000	0.08%	1.56	22 000	0.33%	0.25
Ecuador	P.G.	10 000	0.006%	0.40	4 500	0.07%	0.18
Paraguay	P.	7 500	0.004%	0.79	3 500	0.05%	0.37
Peru	P.	122 000	0.07%	1.80	13 000	0.19%	0.19
Uruguay	P.G.	160 000	0.09%	7.54	8 000	0.12%	0.38
Venezuela	P.	111 000	0.06%	3.13	8 000	0.12%	0.23
Other Places in South America	G.	6 000	0.003%	1.08	500	0.01%	0.09
Total		3 580 000	2.05%	3.99	369 500	5.49%	0.41
EUROPE:							
Belgium	G.	2 000 000	1.14%	23.85	35 000	0.52%	0.42
Bulgaria	G.	84 000	0.05%	1.31	6 000	0.09%	0.09
Denmark	P.	1 500 000	0.86%	39.30	7 500†	0.11%	0.20
Finland	P.	324 000	0.18%	8.37	23 000	0.34%	0.59
France	G.	6 018 000	3.45%	14.35	317 000	4.71%	0.76
Germany†	G.	18 045 000	10.34%	22.63	237 000	3.52%	0.30
Great Britain and Northern Ireland†	G.	15 172 000	8.69%	31.84	241 000	3.58%	0.51
Greece	P.G.	150 000	0.09%	2.13	37 000	0.55%	0.53
Hungary	G.	468 000	0.27%	4.63	53 000	0.79%	0.52
Ireland (Eire)†	G.	138 000	0.08%	4.70	22 000	0.33%	0.75
Italy	P.	1 736 000	0.99%	4.01	278 000	4.13%	0.64
Latvia†	G.	327 000	0.19%	16.43	4 500	0.07%	0.23
Lithuania	G.	82 000	0.05%	3.18	2 500	0.04%	0.10
Netherlands	G.	1 385 000	0.79%	15.87	9 000	0.13%	0.10
Norway*	P.G.	738 000	0.42%	25.19	22 000	0.33%	0.75
Poland	P.G.	1 068 000	0.61%	3.04	48 000	0.71%	0.14
Portugal	P.G.	188 000	0.11%	2.48	18 000	0.27%	0.24
Roumania	P.	403 000	0.23%	2.02	49 000	0.73%	0.24
Russia¶	G.	2 000 000	1.14%	1.17	600 000	8.91%	0.35
Spain	P.	1 500 000	0.86%	5.93	90 000	1.34%	0.36
Sweden	G.	3 105 000	1.79%	49.21	15 000	0.22%	0.24
Switzerland	G.	1 585 000	0.91%	37.74	12 000	0.18%	0.29
Yugoslavia	G.	153 000	0.09%	0.98	57 000	0.84%	0.36
Other Places in Europe	G.	864 000	0.49%	5.22	64 000	0.95%	0.39
Total		59 033 000	33.82%	10.31	2 247 500	33.39%	0.39
ASIA:							
British India†	P.G.	460 000	0.26%	0.13	366 000	5.44%	0.10
China	P.G.	600 000	0.34%	0.14	100 000	1.48%	0.02
Japan†	G.	4 864 000	2.79%	6.73	233 000	3.46%	0.32
Other Places in Asia	P.G.	976 000	0.56%	0.49	226 000	3.36%	0.11
Total		6 900 000	3.95%	0.66	925 000	13.74%	0.09
AFRICA:							
Egypt	G.	473 000	0.27%	2.14	27 000	0.40%	0.12
Union of South Africa†	G.	831 000	0.47%	8.18	31 000	0.46%	0.31
Other Places in Africa	G.	414 000	0.24%	0.33	149 000	2.22%	0.12
Total		1 718 000	0.98%	1.09	207 000	3.08%	0.13
OCEANIA:							
Australia*	G.	2 831 000	1.62%	41.07	107 000	1.59%	1.55
Hawaii	P.	113 000	0.07%	27.49	0	0.00%	0.00
Netherlands Indies	G.	254 000	0.15%	0.37	20 000	0.30%	0.03
New Zealand†	G.	647 000	0.37%	39.82	21 000	0.31%	1.29
Philippine Islands	P.	76 000	0.04%	0.48	10 000	0.15%	0.06
Other Places in Oceania	G.	14 000	0.01%	0.63	4 000	0.06%	0.18
Total		3 935 000	2.26%	4.07	162 000	2.41%	0.17
TOTAL WORLD		174 548 000	100.00%	8.11	6 730 500	100.00%	0.31

NOTE: Telegraph service is operated by Governments, except in the United States and Canada. In connection with telephone wire, P. indicates that the telephone service is wholly or predominantly operated by private companies, G. wholly or predominantly by the Government, and P.G. by both private companies and the Government. See preceding table.

* June 30, 1938. † March 31, 1939.

¶ U.S.S.R., including Siberia and Associated Republics. (Estimated.)

www.americanradiohistory.com

Telephone Development of Large and Small Communities—January 1, 1939

Country	Service Operated By (See Note)	Number of Telephones: In Communities of 50 000 Population and Over	Number of Telephones: In Communities of less than 50 000 Population	Telephones per 100 Population: In Communities of 50 000 Population and Over	Telephones per 100 Population: In Communities of less than 50 000 Population
Australia*	G.	390 700	239 475	11.66	6.76
Belgium‡	G.	278 411	115 117	7.70	2.42
Canada	P.G.	751 273	608 144	20.03	8.15
Denmark	P.	237 617	205 381	21.27	7.61
Finland	P.	70 532	114 924	13.31	3.44
France	G.	866 080	723 515	8.17	2.31
Germany†	G.	2 711 165	1 435 324	8.50	3.00
Great Britain and Northern Ireland†	G.	2 322 000	950 000	8.42	4.73
Hungary	G.	123 384	41 978	5.10	0.55
Japan†	G.	959 734	408 224	3.97	0.85
Netherlands	G.	273 747	160 180	7.37	3.20
New Zealand†	G.	88 079	118 137	15.24	11.28
Norway*	P.G.	97 781	137 483	17.18	5.82
Poland	P.G.	189 681	105 147	4.11	0.35
Sweden	G.	336 737	466 491	26.81	9.23
Switzerland	G.	218 620	231 760	22.70	7.16
Union of South Africa†	G.	128 133	77 759	8.69	0.90
United States	P.	11 15[illegible] 933	8 802 330	21.71	11.22

NOTE: P. indicates that the telephone service is wholly or predominantly operated by private companies, G. wholly or predominantly by the Government, and P.G. by both private companies and the Government. See first table.

* June 30, 1938. ‡ February 28, 1938. † March 31, 1939.

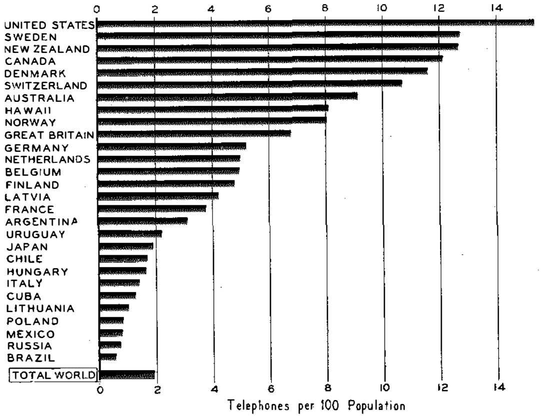
Telephone Conversations and Telegrams—Year 1938

Country	Number of Telephone Conversations	Number of Telegrams	Total Number of Wire Communications	Per Cent of Total Wire Communications: Telephone Conversations	Per Cent of Total Wire Communications: Telegrams	Wire Communications Per Capita: Telephone Conversations	Wire Communications Per Capita: Telegrams	Wire Communications Per Capita: Total
Australia	599 000 000	17 710 000	616 710 000	97.1	2.9	87.2	2.6	89.8
Belgium	320 000 000	5 900 000	325 900 000	98.2	1.8	38.5	0.7	39.2
Canada	2 623 000 000	11 958 000	2 634 958 000	99.5	0.5	235.0	1.1	236.1
Denmark	704 000 000	1 649 000	705 649 000	99.8	0.2	185.3	0.4	185.7
Finland	309 000 000	811 000	309 811 000	99.7	0.3	80.3	0.2	80.5
France	972 000 000	27 524 000	999 524 000	97.2	2.8	23.2	0.6	23.8
Germany	3 640 000 000	21 701 000	3 661 701 000	99.4	0.6	45.8	0.3	46.1
Gt. Britain and Northern Ireland	2 255 000 000	59 484 000	2 314 484 000	97.4	2.6	47.4	1.3	48.7
Hungary	187 000 000	2 439 000	189 439 000	98.7	1.3	19.5	0.3	19.8
Japan	5 339 000 000	68 475 000	5 407 475 000	98.7	1.3	74.2	0.9	75.1
Netherlands	468 000 000	3 588 000	471 588 000	99.2	0.8	53.9	0.4	54.3
Norway	281 000 000	3 489 000	284 489 000	98.8	1.2	96.1	1.2	97.3
Poland	621 000 000	4 161 000	625 161 000	99.3	0.7	17.8	0.1	17.9
Sweden	1 137 000 000	4 339 000	1 141 339 000	99.6	0.4	180.6	0.7	181.3
Switzerland	307 000 000	1 710 000	308 710 000	99.4	0.6	73.3	0.4	73 7
Union of South Africa	301 000 000	6 857 000	307 857 000	97.8	2.2	29.9	0.7	30.6
United States	28 800 000 000	190 000 000	28 990 000 000	99.3	0.7	222.6	1.5	224.1

NOTE: Telephone conversations represent completed local and toll or long-distance messages. Telegrams include inland and outgoing international messages.

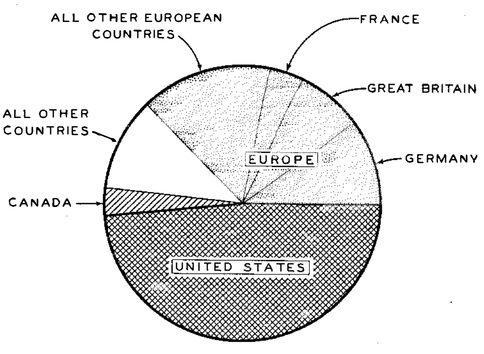
TELEPHONES PER 100 POPULATION

January 1, 1939



DISTRIBUTION OF THE WORLD'S TELEPHONES

January 1, 1939



Telephone Development of Large Cities
January 1, 1939

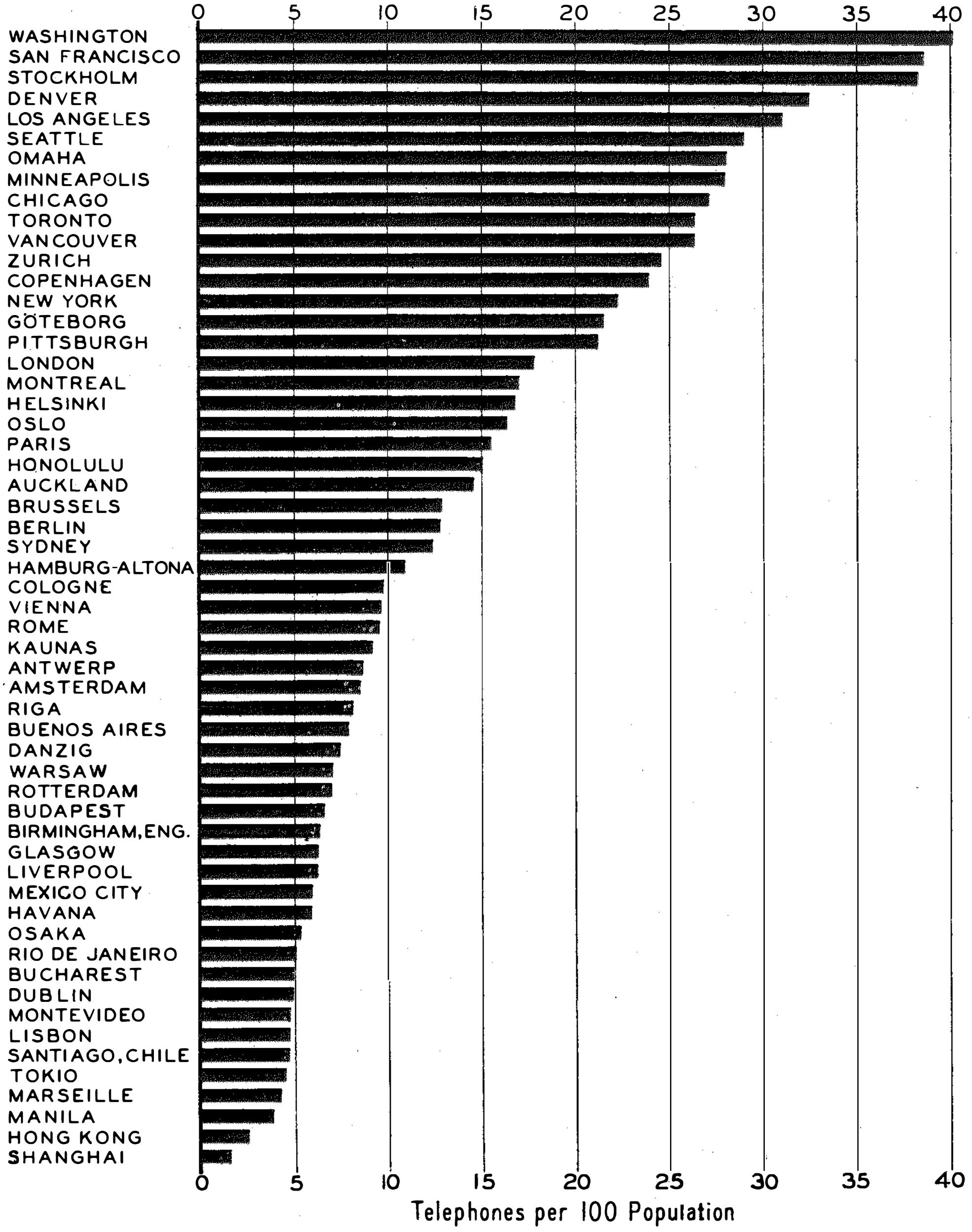
Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones Per 100 Population
ARGENTINA :			
Buenos Aires	3 200 000	252 400	7.89
AUSTRALIA :			
Adelaide	321 000	35 935	11.19
Brisbane	326 000	35 805	10.98
Melbourne	1 036 000	135 518	13.08
Sydney	1 289 000	159 825	12.40
BELGIUM :‡			
Antwerp	560 000	48 696	8.70
Brussels	991 000	127 639	12.88
Liege	433 000	29 885	6.90
BRAZIL :			
Rio de Janeiro	1 900 000	95 603	5.03
CANADA :			
Montreal	1 079 000	183 103	16.97
Ottawa	198 200	39 227	19.79
Toronto	803 300	211 601	26.34
Vancouver	286 100	75 354	26.34
CHILE :			
Santiago	850 000	40 109	4.72
CHINA :			
Hong Kong	800 000	20 322	2.54
Shanghai††	4 000 000	63 355	1.58
CUBA :			
Havana	724 000	42 937	5.93
DANZIG :			
Free City of Danzig	253 000	18 792	7.43
DENMARK :			
Copenhagen	883 000	211 156	23.91
FINLAND :			
Helsinki	305 000	51 328	16.83
FRANCE :			
Bordeaux	260 000	23 311	8.97
Lille	200 000	18 566	9.28
Lyons	650 000	39 369	6.06
Marseilles	915 000	38 801	4.24
Paris	2 830 000	437 139	15.45
GERMANY :†			
Berlin	4 339 000	599 911	13.83
Breslau	623 000	48 203	7.74
Cologne	771 000	75 393	9.78
Dresden	821 000	75 569	9.21
Dortmund	585 000	28 945	4.95
Essen	672 000	36 743	5.47
Frankfort-on-Main	647 000	68 112	10.52
Hamburg-Altona	1 724 000	188 861	10.96
Leipzig	767 000	73 959	9.64
Munich	866 000	97 215	11.23
Vienna	1 874 000	180 165	9.61
GREAT BRITAIN AND NO. IRELAND :†			
Belfast	415 000	23 336	5.62
Birmingham	1 259 000	79 847	6.34
Bristol	450 000	31 376	6.97
Edinburgh	465 000	47 066	10.12
Glasgow	1 150 000	72 359	6.29
Hull	359 000	25 134	7.00
Leeds	568 000	36 825	6.48
Liverpool	1 265 000	79 228	6.26
London—(City and County of London)	4 028 000	717 468	17.81
Manchester	1 015 000	68 191	6.72
Newcastle	482 000	28 167	5.84
Sheffield	522 000	28 776	5.51
HAWAII :			
Honolulu	153 000	22 994	15.03
HUNGARY :			
Budapest	1 635 000	107 906	6.60
Szeged	141 000	2 635	1.87
IRELAND (Eire) :†			
Dublin	482 000	23 928	4.96
ITALY :			
Bologna	315 000	14 738	4.68
Milan	1 206 000	109 168	9.05
Naples	920 000	31 373	3.41
Rome	1 280 000	122 442	9.57
Venice	284 000	10 209	3.59
JAPAN :†			
Kobe	989 000	46 265	4.68
Kyoto	1 160 000	51 457	4.44
Nagoya	1 224 000	46 122	3.77
Osaka	3 321 000	176 697	5.32
Tokio	6 458 000	290 510	4.50
LATVIA :†			
Riga	391 000	31 795	8.13
LITHUANIA :			
Kaunas	110 000	10 124	9.20
MEXICO :			
Mexico City	1 447 000	86 088	5.95
NETHERLANDS :			
Amsterdam	794 000	67 927	8.56
Haarlem	174 000	14 474	8.32
Rotterdam	635 000	44 145	6.95
The Hague	540 000	57 635	10.67
NEW ZEALAND :†			
Auckland	213 000	31 077	14.59
NORWAY :*			
Oslo	411 000	67 180	16.35
PHILIPPINE ISLANDS :			
Manila	620 000	24 035	3.88
POLAND :			
Lodz	670 000	19 048	2.84
Warsaw	1 270 000	90 627	7.03
PORTUGAL :			
Lisbon	697 000	32 988	4.73
ROUMANIA :			
Bucharest	900 000	44 617	4.96
SWEDEN :			
Göteborg	276 000	59 353	21.52
Mahnö	151 000	27 971	18.49
Stockholm	460 000	176 168	38.28
SWITZERLAND :			
Basel	155 000	38 191	24.64
Bern	116 000	30 174	26.01
Geneva	151 000	30 850	20.43
Zurich	287 000	70 573	24.59
URUGUAY :			
Montevideo	705 000	33 447	4.74
UNITED STATES : (See Note)			
New York	7 333 000	1 632 348	22.26
Chicago	3 550 000	962 351	27.11
Los Angeles	1 415 000	439 258	31.04
Pittsburgh	1 047 000	222 063	21.21
Total 7 cities over 1 000 000 Population	18 477 200	4 263 891	23.08
Milwaukee	798 000	157 437	19.73
San Francisco	732 000	282 008	38.53
Washington	597 000	239 668	40.14
Minneapolis	521 600	145 900	27.97
Total 13 cities with 500 000 to 1 000 000 Population	8 638 300	2 105 983	24.38
Seattle	427 500	123 752	28.94
Denver	321 000	104 156	32.44
Hartford	245 500	64 479	26.26
Omaha	237 800	66 762	28.08
Total 28 cities with 200 000 to 500 000 Population	8 921 500	1 872 574	20.99
Total 48 cities with more than 200 000 Population	36 037 000	8 242 448	22.87

NOTE: There are shown, for purposes of comparison with cities in other countries, the total development of all cities in the United States in certain population groups, and the development of certain representative cities within each of such groups.

* June 30, 1938. ‡ February 28, 1938. † March 31, 1939.

†† International Settlement and French Concession.

www.americanradiohistory.com



TELEPHONES PER 100 POPULATION OF LARGE CITIES

January 1, 1939

www.americanradiohistory.com

Meters in Telephone Exchanges

By L. SCHREIBER,

*Bell Telephone Manufacturing Company, Antwerp**

IN addition to meters for recording the number of telephone calls made by subscribers, automatic exchanges require meters for such purposes as recording traffic statistics in general; the number of cycles of operations of routine testing gear; recording the number of incoming inter-urban or toll connection tickets in centres where automatic ticketing is in use; and indicating the charge in local currency of a connection, where used in conjunction with public toll coin service with visual tariff control by the operator.

Special service meters recently developed are of the automatic re-setting type, and are provided with two electro-magnets, one for stepping, the other for re-setting.

A well-known meter re-setting method consists in providing each drum with a heart-shaped steel cam, against which a lever can be pressed by hand or under the control of a re-setting electro-magnet. As, in this arrangement, the drum teeth must be disengaged from their pinions, the latter must be made to be swung away from the drums during the re-setting period. A disadvantage of this arrangement is that the effort to cause the drums to re-set may have to be large owing to friction on the cam surface and re-setting pawls. Further, proper centring of the drum figures requires great precision in the shape of the cams, and the swinging away of the pinions requires some feature to prevent the pinion teeth from moving out of relative position and failing to mesh again properly with the drum gear.

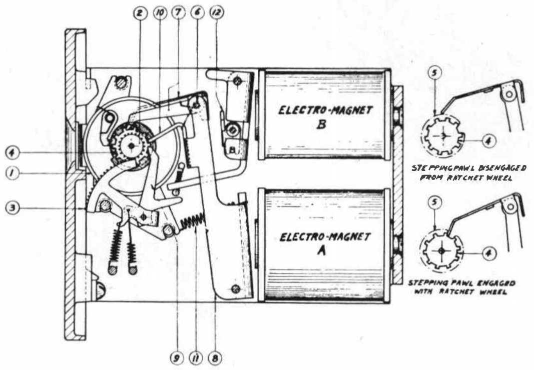


Fig. 1—Schematic of automatic re-setting meter.

The new automatic re-setting meter developed by the Bell Telephone Manufacturing Company, Antwerp, is illustrated schematically in Fig. 1. It will be noted that this meter has no pinions. Each drum (1) is independent of the others and is provided with a gear which meshes with a toothed segment (3). This segment is associated with a spiral spring which always tends to pull the drum to its home position. Each drum is also provided at the one side with a ratchet wheel (4) with 10 indentations; at the opposite side it has a disc (5) with only one indentation corresponding to position 0.

The armature extension arms carry a spindle (6) on which pivot the individual stepping pawls (7). The first pawl rests on the ratchet wheel (4) of the units drum, and at each release of the armature (8) of the electro-magnet A, the units drum will move one position. The second pawl rests on the disc (5) which has one indentation of the units drum (1) and does not engage with the ratchet wheel (4) of the tens drum until the units drum has been stepped to position 9.

At the attraction of the stepping armature (8), the second pawl falls into the indentation of the disc (5) on the units drum, and in consequence engages with the teeth of the ratchet wheel (4) on the tens drum. At the release of the armature, both drums will move one position simultaneously. At the next attraction of the armature, the second pawl has cleared the indentation of the disc (5) on the units drum, and is dis-

---

* Manuscript received 9th March, 1940.

www.americanradiohistory.com

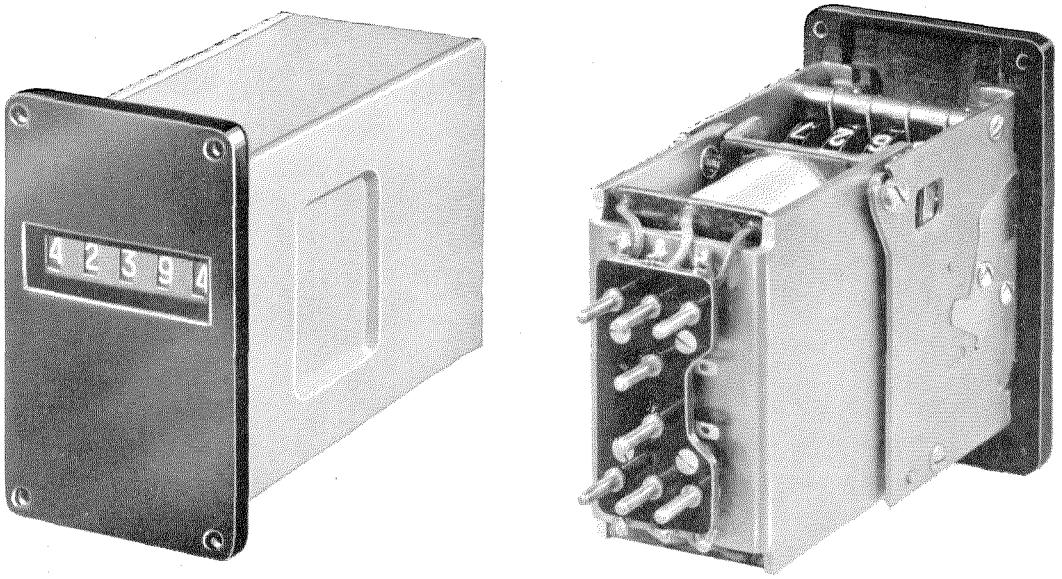


Fig. 2—Front and rear views of the 5-figure meter.

engaged from the ratchet wheel (4) of the tens drum.

The units drum will again have to move 10 positions before the second pawl will fall in for the following step of the tens drum. Since all the drums are alike, at every 10 steps of a drum the next one will move one step forward.

Individual retaining pawls (9) are provided to prevent the return of the drums to their home position during the period of attraction of the armature (8).

A common blocking pawl (10) is also provided to prevent overstepping of the drums owing to the shock caused by the sudden release of the armature (8) due to the retractive effect of the spiral spring (11).

Re-setting of the Meter

To re-set the meter, both electro-magnets, A and B, are operated simultaneously. Electro-magnet B pulls back the retaining pawls (9), thereby freeing the drums, and it lifts by means of lever (12) the stepping pawls (7) out of the indentations of the ratchet wheels. Electro-magnet A is operated at the same time, in order to disengage the blocking pawls (10) from the ratchet wheels and also to allow the action of lever (12) on the stepping pawls. The ratchet wheels being cleared from their pawls, the drums return to their zero position under the tension of the spiral spring, pulling back the toothed segment (3).

The automatic re-setting meters are manufactured with 3, 4, 5 and 6 drums, with decimal divisions. They will read : 000–999, 0000–9999, 00000–99999, 000000–999999.

Figure 2 illustrates the complete 5-figure meter, which is provided with plug connection to facilitate removal for inspection. The dimensions of this meter are : $2\frac{3}{8}$ in. × $3\frac{15}{16}$ in. × $5\frac{1}{8}$ in. (60 × 100 × 130 mm).

The meter is composed of two units : (*a*) the clutch unit, (*b*) the unit containing drums, armature and pawls. Figure 2 shows how the two units fit one into the other ; they are secured by two screws.

Tariff Indicator

Along the same line of development is the tariff indicator with electric re-setting. This indicator, illustrated in Fig. 3, is for mounting on a vertical panel, and is used on operator's positions for multi-coin type, and in public pay stations for local and inter-urban service.

www.americanradiohistory.com

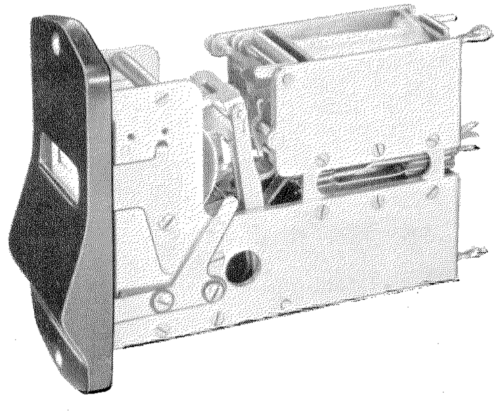


Fig. 3—Tariff indicator with electric re-setting.

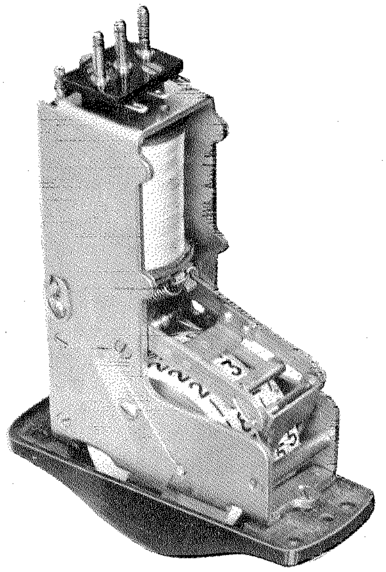


Fig. 4—Electric clock for toll operating positions.

The type built for use in Belgium indicates values varying from 0.00 to 11.75 Frs. in steps of 0.25 Fr. This meter has only two drums and one stepping pawl. The first drum is numbered 3 times 00, 25, 50, 75, and the second drum is numbered 0 to 11.

Both drums are provided with a ratchet wheel with 12 indentations. The ratchet wheel of the second drum is smaller in diameter than that of the first drum, but it has 3 deeper indentations corresponding with the depth of the indentations on the second wheel.

Only the first drum is moved until the pawl enters one of the deeper indentations; in this case, the pawl also engages the ratchet wheel of the second drum, and both drums are advanced simultaneously on each fourth step of the first drum.

The re-setting mechanism is similar in design to that of the meter described above.

Electric Clock

An electric clock, Fig. 4, of a similar design to the tariff indicator, but without re-setting mechanism, has been designed for use at toll operating positions. It reads from 00–00 to 23 hours, 59 minutes, and is controlled from a master clock to make one step every minute. The number drums are of large diameter so that the figures exposed have a height of $\frac{7}{32}$ in. (5.5 mm); the figures are black on a white ground. The minutes drum is numbered 0–9 twice per circumference, the second drum 4 times 0–5, and the third drum is numbered 00 to 23.

The drums are advanced by a double stepping pawl, as described for the tariff indicator.

Although the above-described apparatus was designed originally for use in telephone equipments, it is probable that these instruments may find other industrial applications.

www.americanradiohistory.com

Telephone Development in the U.S.A.

The Annual Report of the American Telephone and Telegraph Company is always of great interest. The latest Report, from which the following items are abstracted, records continued progress, and shows how hostilities in Europe have affected transatlantic telephone communication services.

Telephone Service.—The number of telephones in service in the Bell System at the end of 1939 was 16 536 000. This is the highest point yet reached and is approximately 1 350 000 higher than in 1930, which had the peak of the pre-slump period. The total number of telephones in the United States at the end of 1939 was about 20 750 000, equal to 15.9 telephones per 100 population.

The increase for 1939 was 775 000 telephones, against 430 000 in 1938, and the rate of increase was 4.92% for the year. The average number of telephones for 1939 was about 16 148 450, and the daily conversations averaged 4.57 conversations per telephone per day.

* * *

War Crisis increases Domestic Traffic.—At the time of the war crisis in Europe, early in September, 1939, a sudden great increase in telephone use took place in the United States. Practically overnight, the number of long-distance calls increased 30%, and passed all previous records. Because of advanced planning and close co-operation between the various units of the Bell System which made possible fast action under pressure, this emergency was met with distinction. The ability and capacity of the System to cope successfully with such sudden large increases in the demand for telephone service is evidence of the preparedness of the System to meet the needs of national defence.

* * *

Operating Companies.—The Bell System consists of the A.T. & T. Co., 24 principal subsidiary telephone companies, the Western Electric and the Bell Laboratories. Of the 24 operating telephone companies, seven range between 1 and 2¾ million telephones, averaging 1½ million telephones per company; 17 have less than a million and have an average of about 400 000 telephones. There are also about 6 500 independently-owned telephone companies and many rural lines which connect to the Bell System.

* * *

Progress in Automatization.—56% of the telephones are now on a dial basis and some tens of thousands are being served by the new type of cross-bar dial office. Telephones giving improved transmission are being installed, and by the end of 1939 were in use on about half the telephone lines of the Bell System.

* * *

Coaxial Cable Installation.—A 200-mile toll line from Steven's Point, Wisconsin, to Minneapolis (among other extensions) is under way, and will be the first commercial installation of coaxial cable in the United States.

* * *

Transatlantic Telephony and the War.—During the latter part of August, due to the war emergency, the number of transatlantic telephone messages increased to three times normal. By the end of August, however, England and France had established a censorship limiting calls to official messages. Since telephone messages to other countries in Europe were routed at that time through England, transatlantic telephone service was practically suspended. Service to Europe was restored by the establishment of direct circuits to Italy and to the Netherlands. Through these new terminals, connection is furnished to practically all countries of Europe other than England and France, and the volume of transatlantic telephone service, notwithstanding censorship restrictions imposed by England, France and Germany, developed again to about one-half its normal level just before the war.

* * *

Alternative Raw Materials.—Possible serious reactions on raw material supplies as a result of

www.americanradiohistory.com

war have necessitated an intensive scrutiny of alternatives and substitutes. As a result of this work, and of the research and development work done previously, it now seems certain that designs of apparatus can be changed, if necessary, to offset shortages or soaring prices of raw materials which can be obtained only from other countries.

* * *

Employees.—The number of employees of the A.T. & T. Co. and its principal operating companies was 259 900, equal to 15.7 employees per one thousand telephones at the end of the year. Approximately one-quarter of the Bell System employees own a financial interest in the Company. The number of employees having less than one year's service is less than 7%.

* * *

Federal Communications Commission.—During the year the Federal Communications Commission reported to Congress on the Special Telephone Investigation on which it had been engaged for 4½ years, and for which $1 500 000 had been appropriated. The Company's Report says that while the report recommended certain additions to the authority of the Commission, the Company believes that, as a whole, the amendments recommended would tend neither to improve telephone service nor to reduce costs to the user.

* * *

Speedy Long-distance Service.—Reduction in the average time to establish long-distance telephone connection continues. The service is so fast, averaging rather less than two minutes, that spectacular improvement cannot be expected.

Finance.—Total Plant Capital per Telephone is $278. Net plant additions during the year cost $101 432 000, equivalent to $131 per net added telephone. The most noticeable thing about the revenue and expense accounts is the continued growth of taxation; since 1920, each year with two exceptions, the amount of taxes per telephone has increased. The increase during the 19 years is about $6.50, and the amount is now $9.84 per telephone per year. They are about the same in total as the provision for depreciation, which works out at the rate of 3.56% of the investment as at the end of 1938.

* * *

General Policy.—Two very interesting items of general policy mentioned in the Report are reproduced below:—

> "The ideal and aim of the American Telephone and Telegraph Company and its Associated Companies is a telephone service for the nation, free, so far as humanly possible, from imperfections, errors or delays, and enabling anyone anywhere to pick up a telephone and talk to anyone else anywhere else, clearly, quickly and at a reasonable cost."
>
> "The present organization of business and social life in this country is such that the telephone is an integral and necessary part of it. This is strikingly so in emergencies. Good telephone service, therefore, involves plant facilities and organization adequate not only to take care of every-day needs of the nation, but also to meet sudden and perhaps unprecedented surges of demand for telephone connections."

www.americanradiohistory.com

Recent Telecommunication Developments

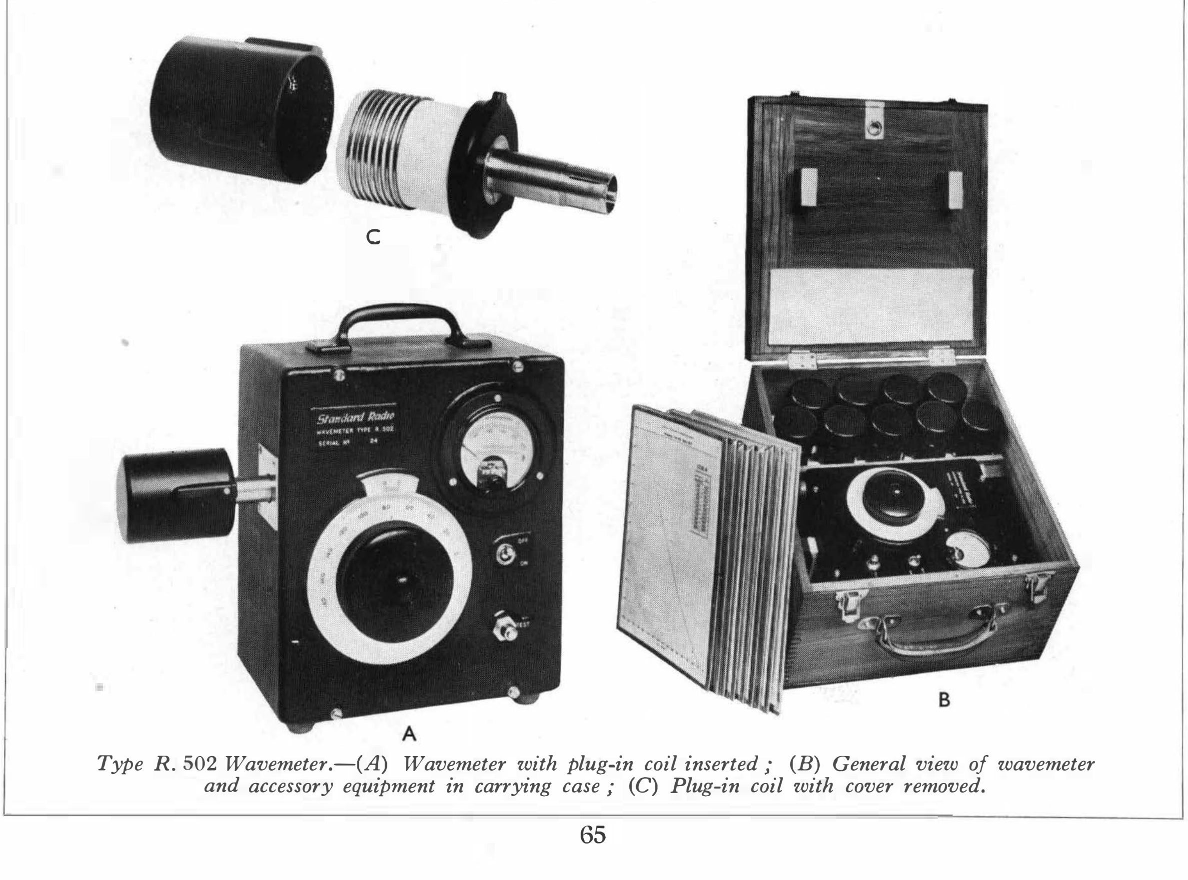
Wavemeter, Type R.502.—A new wavemeter for use under general shop and laboratory conditions has recently been developed by Standard Telephones and Cables, Limited, London. The wavemeter is of the absorption type, employing a diode rectifier, and with a moving-coil micro-ammeter as indicator ; the equipment has been designed for routine wavelength measurements between 6.5 and 3 000 metres (46 Mc to 100 kc).

This extensive range of wavelengths is covered by a series of 9 plug-in coils, each coil having a coverage ratio of just under 2 to 1. This makes it possible to avoid the use of the extreme ends of the condenser scale where non-linearity of the wavelength characteristic is unavoidable. A slow motion drive in conjunction with a 180° dial and fixed vernier scale enables readings to $\frac{1}{10}$th of a scale division to be obtained. The guaranteed accuracy of calibration at any point throughout the range exceeds 0.15 per cent. A special feature of the design is the use of a coaxial plug-socket for the coil connections. This arrangement ensures that the inductance coils give improved accuracy and performance, especially at the higher frequencies.

The power supply for the wavemeter is taken from a large capacity single-cell dry battery. The weight of the instrument in its carrying case, including all coils and calibration charts, is only 16 lb. (7.25 kg).

• • •

Type HS Commercial Radio Transmitters.—Two tuneable transmitters for fixed or mobile commercial radio services, known as types HS.1



Type R. 502 *Wavemeter.—(A) Wavemeter with plug-in coil inserted ; (B) General view of wavemeter and accessory equipment in carrying case ; (C) Plug-in coil with cover removed.*

www.americanradiohistory.com

and HS.2, have been developed by Standard Telephones and Cables Limited, London, to supplement their series of spot-wave transmitters. They can also be used where the special facilities of the spot-wave transmitters are not required. These new commercial radio transmitters are designed for C.W., M.C.W., and telephony, and for operation over a frequency range of 2.5 – 20 Mc or, alternatively, 1.5 – 4.4 Mc.

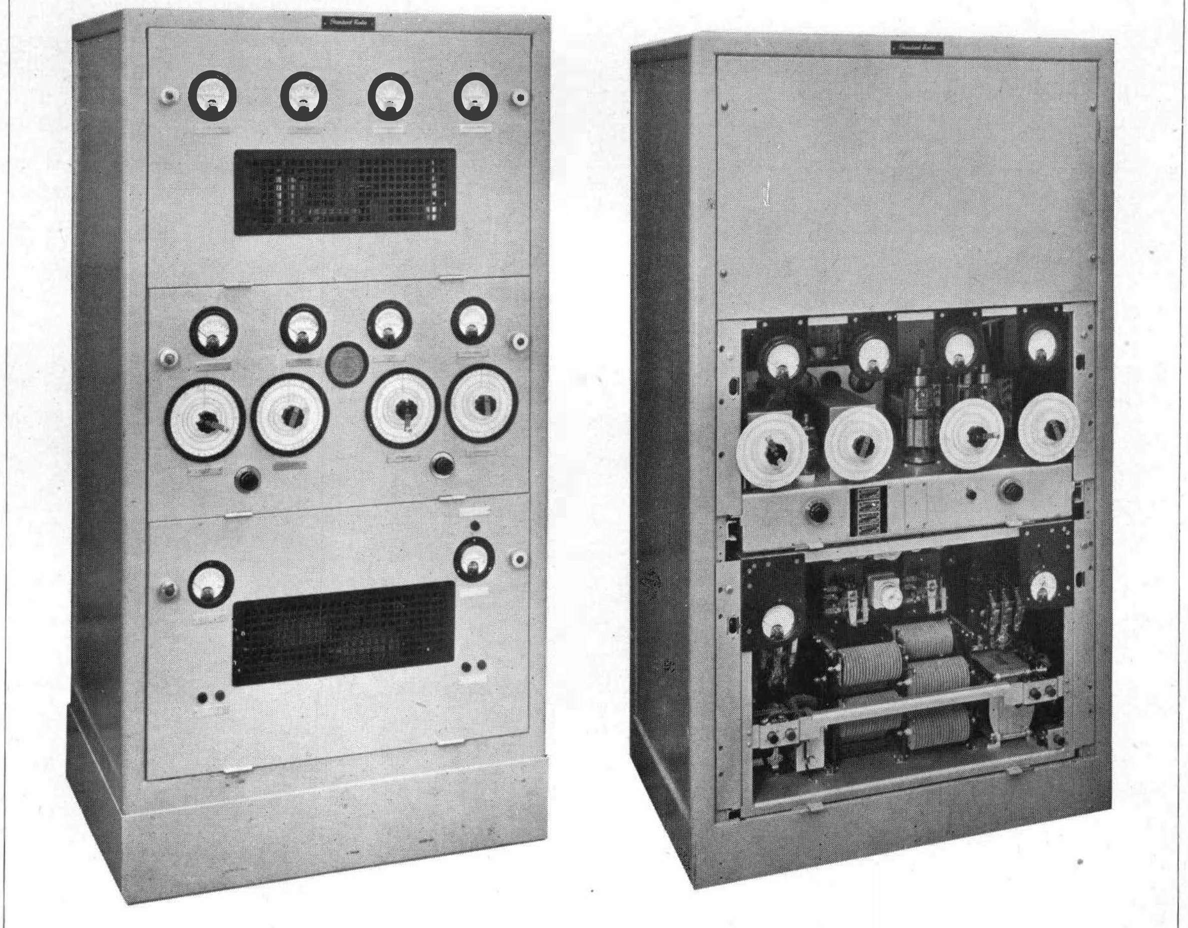
Tuning may be either continuously variable over the entire frequency range or selected from four crystal-controlled spot frequencies, the frequency being maintained within less than ± 0.05 per cent. in the case of auto operation and within ± 0.005 per cent. in the case of crystal operation.

The type HS.1 transmitter is rated at 250 watts continuously on C.W. and 250 watts in the carrier on M.C.W. and telephony, the corresponding ratings being 300 watts and 100 watts for the type HS.2 transmitter, with a keyed rating of 450 watts on C.W. The low-frequency system consists of a 3-stage speech amplifier which, in the case of the type HS.2, modulates the auxiliary grid circuit of the power amplifier stage.

In the case of the type HS.1, the speech amplifier drives a Class B modulator which anode-modulates the power amplifier valves.

• • •

Transportable Testing Equipment for 12-Channel Carrier-on-Cable Systems.—A test trolley designed for the complete maintenance of 12-channel carrier-on-cable systems is a



(Left) : Type HS.1 Transmitter. (Right) : Type HS.2 Transmitter (with front panels removed).

recent production of Standard Telephones and Cables, Limited, London. The design and dimensions of this trolley are such that it may readily be wheeled between the rows of bays, and tests on any particular piece of apparatus or system may thus be made without the use of long cords or office trunks. In this way, not only have the difficulties been eliminated which frequently arise when making high frequency measurements using long test connections, but also, a considerably greater degree of flexibility in the use of a systems maintenance equipment is obtained.

The following testing equipment is mounted on the trolley :—

(1) *A Voice Frequency Heterodyne Oscillator* continuously variable over the frequency range 30–10 000 p : s to provide a source of voice frequency test tone.

(2) *A Carrier Frequency Oscillator* providing a number of fixed frequencies suitable for checking the performance of filters and line amplifiers.

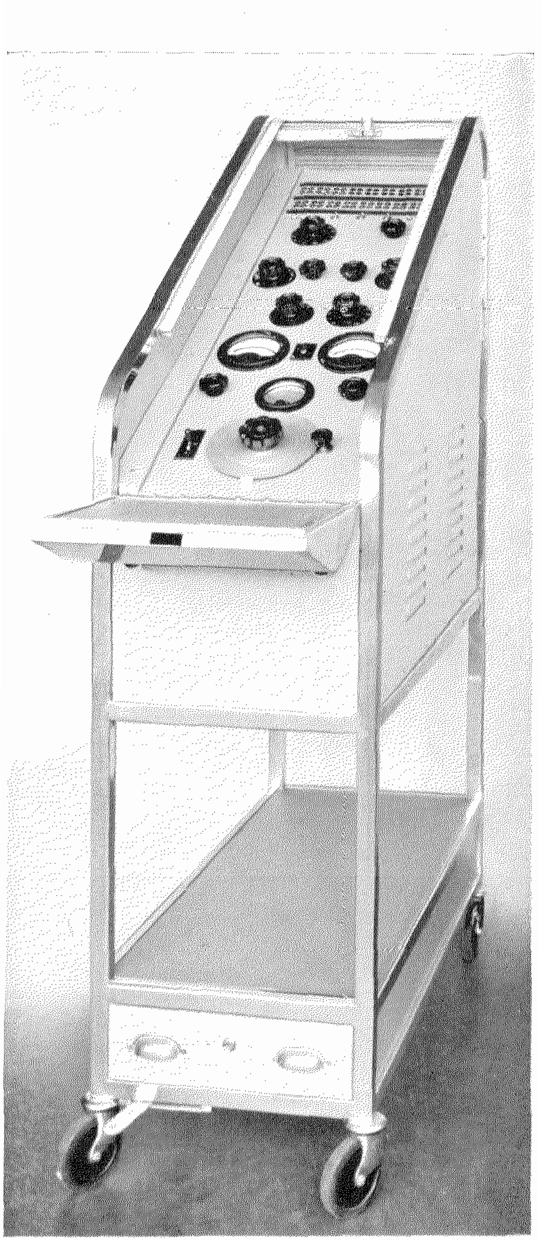
(3) *A Transmission Measuring Set* which is direct reading, and which enables loss, and level measurements to be made over the frequency band 30 p : s to 150 kc at any level within the range + 30 to − 35 db. referred to 1 mW. The set is provided with suitable terminations for making measurements at various points in the system, and is also provided with a sending circuit capable of delivering a suitable range of levels.

(4) *Harmonic Measuring Filters* enabling the level of harmonics generated in the line amplifiers to be measured in conjunction with the other testing equipment which is provided on the trolley.

(5) *Miscellaneous Panels* mounting U-links for making the necessary test connections, and fuses and protective resistances through which power is fed to the trolley from the normal station batteries by means of a cord and plug patched into supply sockets provided at suitable points on the system bays.

In addition to the equipment already mentioned, the trolley is arranged to accommodate a valve test set for making routine tests on the valves used in the system, and also a small and portable level meter for making the simpler check measurements on the system.

By means of the equipment provided, the complete range of voice and carrier frequency measurements may be made on the system, including overall equivalents and qualities, transmitting and receiving gains and qualities, amplifier gains, filter losses, carrier supply voltages and levels, etc.

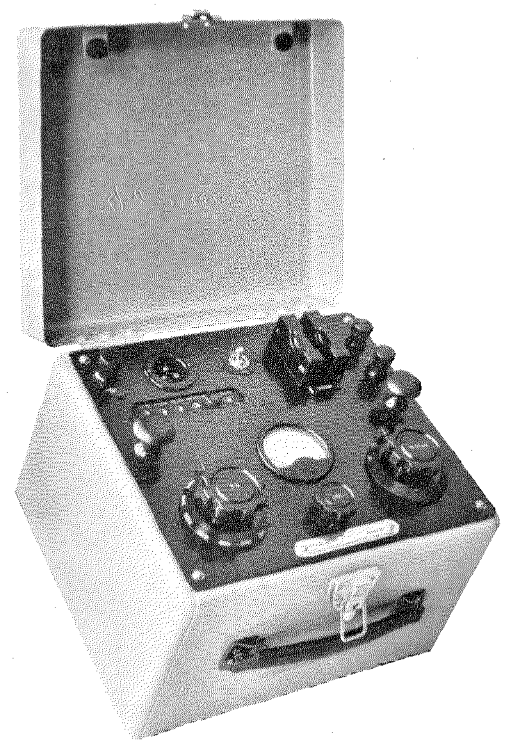


Transportable testing equipment for 12*-channel carrier-on-cable system.*

● ● ●

12-Frequency Oscillator.—A recent development of Standard Telephones and Cables,

www.americanradiohistory.com



12-*Frequency Oscillator.*

Limited, London, is an oscillator which gives 12 spot frequencies of 300, 400, 500, 600, 800, 1 000, 1 200, 1 400, 1 600, 2 000, 2 400 and 2 800 cycles.

It is a small portable mains-operated oscillator designed for general use with simple transmission measuring sets, and is particularly suitable for use with the 74105 A and C Transmission Measuring Sets.

The oscillator consists essentially of three circuits :—

(*a*) A mains supply circuit suitable for any A.C. supply between 100 and 150 volts or 200 and 250 volts.

(*b*) An oscillator circuit providing the 12 spot frequencies with an accuracy of approximately ± 2% and an harmonic content of less than 5%.

(*c*) A variable sending circuit with associated meter. Powers of + 10, + 5, 0, –5 and –10 db. (referred to 1 mW into 600 ohms) can be sent into 600-ohm circuits.

The total weight of the set is 24 lb. (11 kg). It is also available in rack-mounted form (19 in. × 5¼ in.).