INTERNATIONAL TELEPHONE CONSULTATIVE COMMITTEE

(C.C.I.F.)

XVII^th PLENARY ASSEMBLY

Geneva, 4th to 12th October, 1954

ANNEXES TO VOLUME III

LINE TRANSMISSION
MEASUREMENTS ON LINES

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PART ONE

ANNEXES TO THE C.C.I.F. RECOMMENDATIONS APPEARING IN VOLUME III OF THE GREEN BOOK

ANNEX 1

CALCULATION OF THE EFFECTS OF THE ECHO AND STABILITY FOR A TRUNK/TOLL CIRCUIT *

The methods of calculation given in this annex may be used:

1° to determine if a given circuit, used with a given equivalent (excluding variations with time of the transmission characteristics of the circuit) between the switchboard jacks at the two ends of this circuit, will give satisfactory results as regards echo and stability;

2° to determine the type of circuit to be used so that, with a given value of equivalent between the switchboard jacks, there are satisfactory results as regards echo and stability (excluding variations with time of the transmission characteristics of the circuit).

The nominal minimum admissible equivalent in service for a trunk/toll circuit is obtained by calculating:

1° the minimum value of the equivalent admissible as regards echo (for the speaker);

2° the minimum value of the equivalent admissible as regards stability (singing margin).

The higher of the two minimum values of the equivalents, determined by considering respectively echo and stability, is the value below which the equivalent of the circuit must not fall at any time.

Consequently, the nominal value in service is obtained by adding to the above value the expected variations of the equivalent as a function of time.

To simplify the calculations, some assumptions which are not always realised in practice, have been made; these are given below. For example, only attenuations

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* To calculate the minimum admissible equivalent for a trunk/toll circuit, not only echo and stability should be considered but also noise and intelligible crosstalk. Nevertheless, as experience in Europe has shewn, up to the present, that echo and instability are above all to be feared, the C.C.I.F. Study Group for the General Interconnection Plan has deferred examination of the need for taking noise and crosstalk equally into account.

and gains at 800 c/s have been considered, although the values which occur in practice for echo and stability may differ more or less from the values corresponding to 800 c/s. Nevertheless experience shews that in practice these methods of calculation suffice.

A. Echo

The effects of echos returning towards the speaker, from the point of view of the limitation of the minimum equivalent at which a trunk/toll circuit or combination of such circuits may be operated, have already been determined by means of various appreciation tests made by Administrations and Private Telephone Companies. These tests have shewn that these effects increase with the transmission time of the circuit (or the whole of the connection). Echo suppressors may however be used on four-wire or two-wire circuits to block the echo, and, as a result, greatly reduce the echo effects.

As a result of these appreciation tests, agreement was reached for circuits *without echo suppressors*, on the question of the admissible minimum value for the echo attenuation in terms of the total propagation time on the echo path; this curve is shewn in figure 1.

It was also agreed provisionally to use the curve of figure 2 (page 9) to determine the minimum admissible value for echo attenuation for circuits fitted *with echo suppressors* having a sensitivity or 30 db referred to zero relative level.

By means of the basic curves (fig. 1 and 2), the minimum admissible equivalent as regards echo for a trunk/toll circuit, or a connection made up of several such circuits, may be calculated by the following method.

Note 1. — The curve of figure 1 corresponds to the effects of echo on circuits when subscribers' telephone instruments without anti-sidetone circuits are used: however this type of telephone instrument is tending to disappear, so that this curve should be replaced by a new one. For a telephone instrument with anti-sidetone circuits, the masking effect produced by the vocal sounds of the person using this instrument is reduced, so that the conditions (from the point of view of talker echo) are more severe. Nevertheless, as a result of conversation tests carried out in Sweden, the difference between the minimum admissible values for echo attenuation, for telephone instruments with and without anti-sidetone circuits, is only in the region of 0.2 N. There are however greater differences between the curves used or proposed in various countries to determine the minimum admissible echo attenuation, as a function of the total propagation time on the echo path, for circuits without echo suppressors and using subscribers' instruments with anti-sidetone circuits.

It is therefore recommended that, provisionally the curve of figure 1 be used irrespective of whether the type of subscriber's instrument employed has or has not an anti-sidetone circuit.

Note 2. — The curve of figure 2 is adopted provisionally until general agreement is reached on a curve giving the minimum admissible value for echo attenuation, as a function of total transmission time on the echo path, on a circuit *fitted with echo suppressors* (sensitivity referred to zero relative level; 30 db).

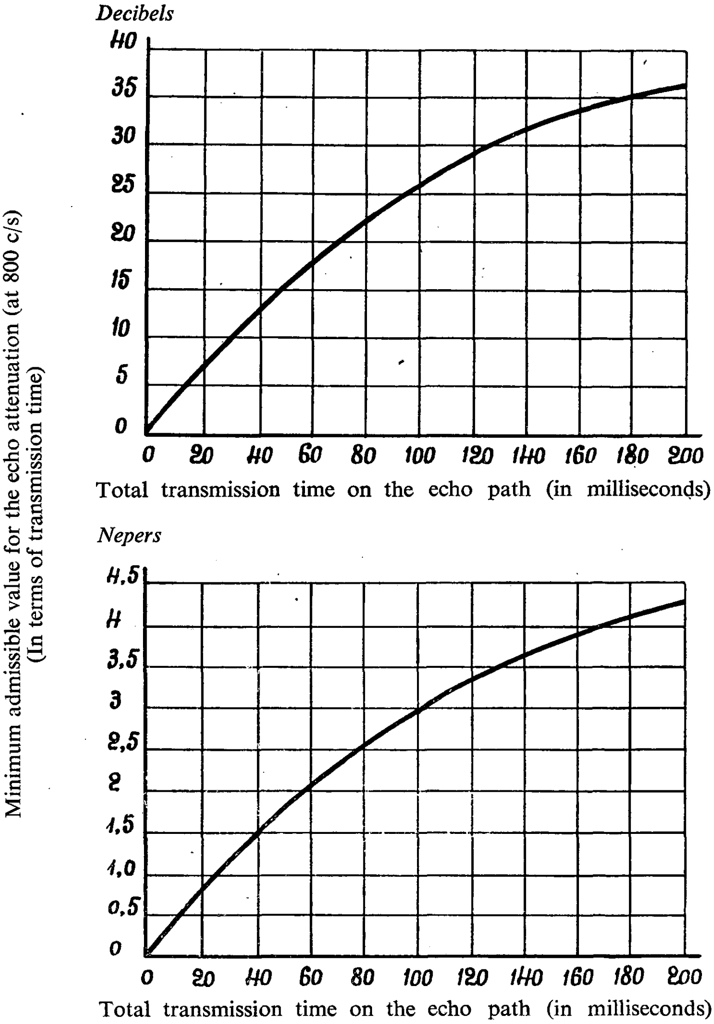


FIGURE 1. — *Curve giving the minimum admissible value for echo attenuation for circuits without echo suppressors, as a function of total transmission time on the echo path*

Note. — The above curve has been determined using old-type subscribers' instruments, without anti-sidetone circuits. It is provisionally recommended it should also be used for modern-type subscribers' instruments, with anti-sidetone circuits.

1. NUMERICAL VALUES NEEDED FOR THE CALCULATION

(a) *Return loss at the far end of the circuit.* — This is the return loss between the impedance of the circuit considered (looking towards the speaker and measured at the end of the circuit remote from the speaker) on the one hand, and the impedance of the extension line terminating at the telephone of the person listening, on the other hand. The return loss to be used in the calculation is equal to 6db (0.69 N).

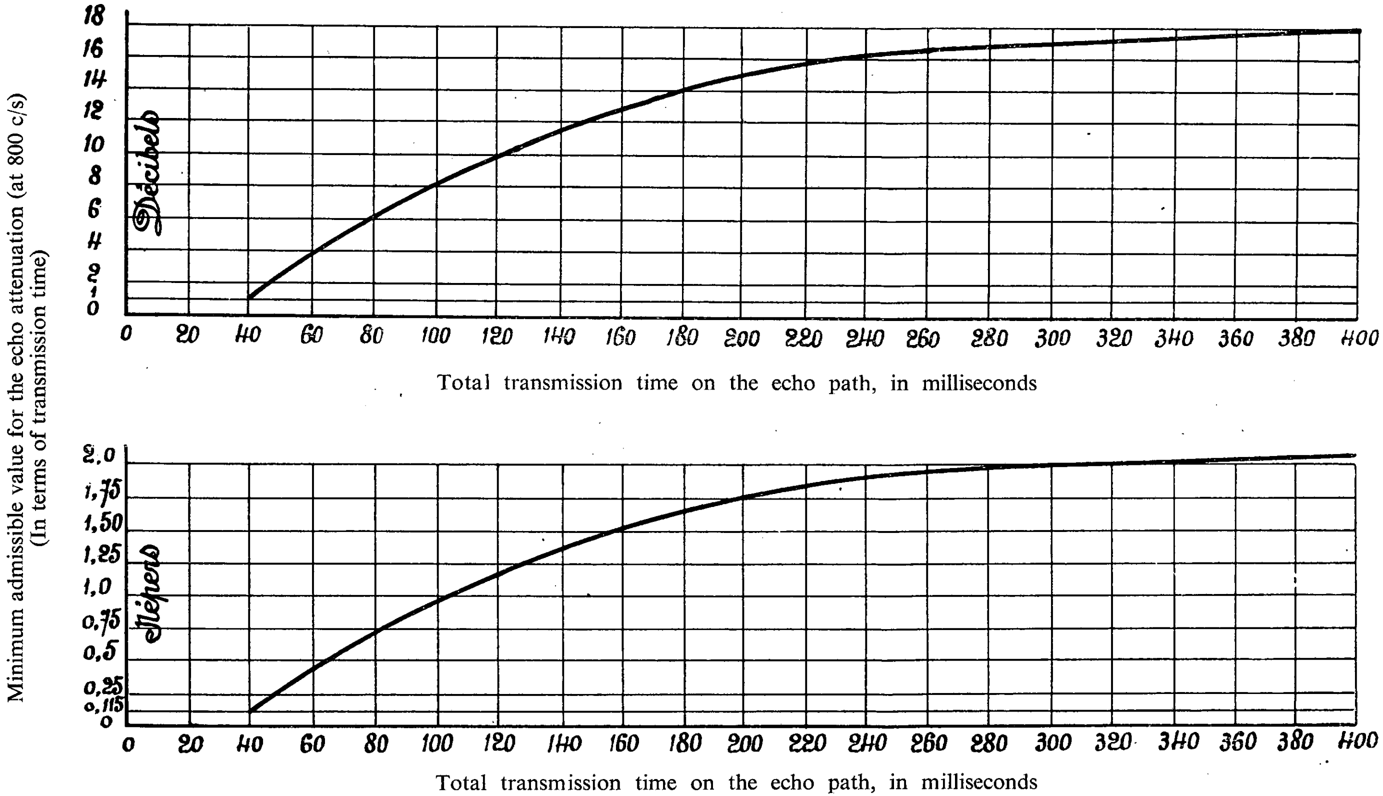


FIGURE 2. — *Curve giving the minimum admissible value for the zero attenuation for circuits fitted with echo suppressors (sensitivity referred to écho relative level: 30 db)*

(b) *Balance return loss of a repeater section.* — For the first applications of the method of calculation in question and until additional information is available, in order to calculate the minimum admissible equivalent as regards echo for a two-wire circuit or for a combination of two-wire and four-wire sections, the following balance return loss values for a repeater section, will be used:

Diameter of the conductors of the circuit in millimetres	Type of loading			Balance return loss of the repeater section			
	Inductance of side circuit loading coils in millihenr es	Inductance of phantom circuit loading coils in millihenries	Loading coil spacing, in metres	in decibels		in nepers	
				Side Circuits	Phantom Circuits	Side Circuits	Phantom Circuits
0·9	172	63	1 830	28	30	3·2	3·4
0·9	88	50	1 830	28	28	3·2	3·2
1·3	172	63	1 830	26	28	3·0	3·2
1·3	44	25	1 830	34	34	3·9	3·9
0·9	140	56	1 700	32	32	3·7	3·7
1·4	140	56	1 700	32	32	3·7	3·7

When it is a question of a type of circuit other than those shewn in the table above, it is better to use balance return loss values for the repeater sections corresponding to this particular type of circuit, if they are known; a value must be taken which will be exceeded in 63% of the cases in practice, which corresponds to an average distribution of the irregularities along the circuit (calculation of probability).

(c) *Balance return loss at the junction between a two-wire and a four-wire section.* — Assume that a transit telephone connection comprises, from the speaker at A, to the listener at D, a two-wire section AB, a four-wire section BC and a two-wire section CD. The balance return loss at point B depends on the relation between the impedance of the two-wire circuit AB seen from point B and the impedance of the four-wire circuit BC seen from the two-wire terminals of the terminating set situated at point B. The balance return loss at point C depends on the relation between, on the one hand, the impedance of the compromise balance of the four-wire circuit BC connected to the terminating set at point C, and on the other hand the impedance of the two-wire circuit CD.

Consequently, the balance return loss at the junction between a four-wire section and a two-wire section in a transit connection depends on the relation between the impedance of the two-wire section seen from the junction point and the impedance of the compromise balance connected to the terminating set of the four-wire section situated at this junction point. If a compromise balance is used, the value of the balance return loss to be used for the various types of two-wire circuit is given in the table below.

When a special balance is used and not a compromise balance, it is necessary to take for the balance return loss at the junction between the two-wire circuit and

Diameter of the two-wire circuit conductors in millimetres	Type of loading of the two-wire circuit			Balance return loss at the junction between the two-wire circuit and a four-wire circuit fitted with a compromise balance			
	Inductance of side circuit loading coils in millihenries	Inductance of phantom circuit loading coils in millihenries	Loading coil spacing in metres	in decibels		in nepers	
				Side circuits	Phantom circuits	Side circuits	Phantom circuits
0·9	172	63	1 830	16	18	1·8	2·1
0·9	88	50	1 830	18	20	2·1	2·3
1·3	172	63	1 830	14	16	1·6	2·8
1·3	44	·25	1 830	20	20	2·3	2·3

a four-wire circuit, the values given in the table on page 11 for the balance return loss of a repeater section.

When it is a question of a type of circuit other than those shewn in the table above, it is better to use suitable balance return loss values corresponding to this type of circuit, if these values are known; a value which will be exceeded in 63% of cases must be taken; if, at the transit centre, devices to match the impedances of the interconnected circuits are used, account must be taken of this.

(d) *Transmission time.* — In calculations of the transmission time for the various echo paths, the steady state velocity of a sinusoidal current of 800 c/s on the type of long-distance circuit in question, must be used.

2. Method of calculation

The method of calculation recommended by the International Telephone Consultative Committee for the calculation of the minimum admissible equivalent as regards echo, is summarised below:

(a) *Circuits not fitted with echo suppressors*

1. Assume a hypothetical value for the equivalent for the whole of the circuit (for which the minimum admissible equivalent as regards echo is to be calculated) and allot losses to the various sections of line and gains to the various repeaters, compatible with this hypothetical value of the equivalent of the whole of the circuit considered.

2. Choose for each intermediate two-wire repeater, or for each junction point between a two-wire circuit and a four-wire circuit, a suitable value of balance return loss (see above). For the return loss at the remote end of the circuit a value of 6 decibels (0.69 N) will be taken.

3. Calculate the equivalent for each path followed by the currents which, reflected at the various intermediate points of the circuit, return towards the speaker —including the path of the current reflected at the end of the circuit. It is assumed

that the reflection from any intermediate repeater is due to the balance return loss between the balance network of the repeater and the corresponding section of line, beyond the repeater (remote from the speaker); the equivalent for a given path is therefore obtained by adding to the balance return loss selected, the algebraic sum of the losses at 800 c/s of the various sections of line and the gains at 800 c/s of the various repeaters on the path considered; the result thus obtained is called the " equivalent at 800 c/s " of the path considered, although it should be noted that the balance return loss may in fact correspond to any frequency in the band 500-2 000 c/s. For the reflection at the end of the circuit, the value of 6 db (0.69 N) will be taken as the value of the return loss.

4. The equivalent at 800 c/s for the various paths having been calculated, a " weighting " corresponding to its total transmission time is allotted to each of them. For this, from the value of the equivalent at 800 c/s calculated for a given path, a " transmission time correction " is deducted, this being equal to the minimum admissible equivalent as regards echo for a circuit having the same transmission time as the particular path considered. This correction is read off the curve of figure 1 above.

5. The various reflected currents should then be combined on a square law basis (square root of the sum of the squares) *. To do this, the power ratios corresponding to the values (in decibels) of the equivalents at 800 c/s calculated for the various paths are added together, after deducting the appropriate " transmission time corrections " (weighted equivalents) — (See fig. 3 below giving the relation between numbers of decibels or nepers and power ratios, voltage ratios or current ratios).

6. The resulting power (obtained as in paragraph 5 above) corresponds to the echo actually produced and this could be expressed as a percentage of the maximum admissible echo for a circuit of this length. If this percentage is equal to 100% the echo actually produced is the maximum tolerable.

If this percentage is less than 100% the calculations are begun again with a smaller hypothetical value of the equivalent of the whole of the circuit considered; if, on the other hand, this percentage is greater than 100% the calculations are begun afresh with a higher hypothetical value of the equivalent of the whole of the circuits. After various successive approximations of this kind, the hypothetical value of the total equivalent of the circuit for which the percentage (calculated as shewn in paragraph 5 above) is precisely equal to 100%, is found.

Notes. — 1. When the transmission time relating to a particular path is determined, it is necessary to take into account that, for a given unbalance between the line and the balance network of a certain repeater, there are small reflected currents due to irregularities at various points between the repeater considered and the next repeater along the circuit. To take account of this effect in the calculation of the transmission time, it is assumed that the irregularity is concentrated in the middle of the repeater section. In other words, each echo path passes exactly

* Recent tests have confirmed that the effect on the ear of a number of echos, having transmission times and volumes as generally found in practice, may be calculated by adding the power rations corresponding to the " weighted equivalents " of the paths of these various echos.

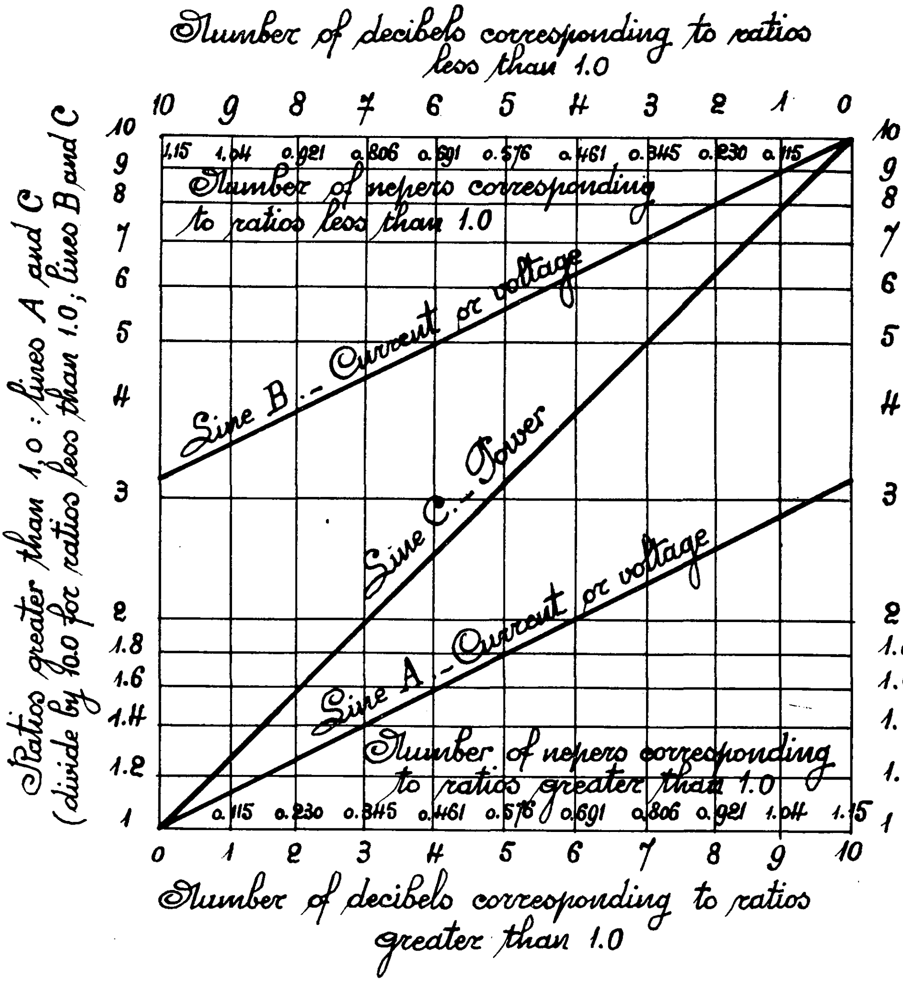


FIGURE 3. — *Diagram of relation between the numbers of decibels or nepers (between 0 and 10 decibels or between 0 and 1·15 nepers) and the ratios of power, voltage or current.*

through the middle of the repeater section situated beyond the last repeater considered. Only the last path passes exactly through the end of the circuit.

2. So as to establish a basis for choosing the types of lines to be used for a given telephone communication, the calculations given above may be repeated for each type of cable and for different circuit lengths, and finally the curve traced having as abscissa the circuit length (of the given type) and as ordinate the minimum admissible equivalent as regards echo.

(b) *Circuits fitted with echo suppressors*

Assume that the echo suppressors are adjusted to have a sensitivity (referred to zero relative level) equal to 30 db (3·45 N) (value recommended by the C.C.I.F.); otherwise account must be taken of the ratio, with respect to this nominal value, of the actual sensitivity of the echo suppressor.

Figure 4 shews echo paths in a typical connection having two two-wire circuits and a four-wire circuit, this latter being fitted with an echo suppressor.

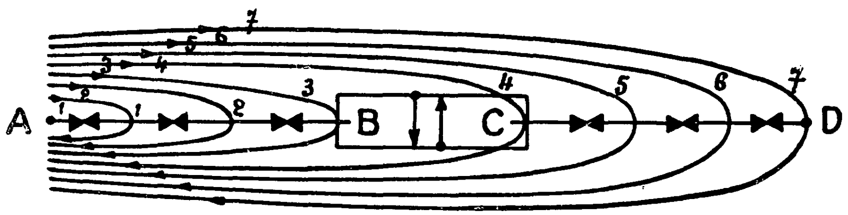


FIGURE 4

Assume that the balance return loss values at each repeater, as well as at points B and C, which are junctions between a two-wire section and a four-wire section (see above), are known; for the return loss at the far end (point D) the provisional value is 6 decibels (0·69 N).

It should be noted that, as far as the speaker at A is concerned, echo 1, 2 and 3 are independent of the operation of the echo suppressor while echos 4 to 7 are dependent on the echo suppressor characteristics. These two groups of echo are treated differently for the following reasons:

(a) when the speaking level is sufficient to completely operate the echo suppressor, echos 4 to 7 are eliminated. For these high volumes, the only echos reflected towards the speaker are 1, 2 and 3.

(b) when the speaking level is too low to completely operate the echo suppressor, or if certain syllables are too weak, echos 4 to 7 are reflected towards the speaker. Although, in these conditions, echos 1, 2 and 3 will continue to be reflected, their effects will be very reduced because of the low speaking level of the speaker. Further, echos 4 to 7 will ordinarily arrive with a greater delay than echos 1, 2 and 3. For these reasons, in order to simplify the calculations, it is assumed that for low speaking levels, the echos following the paths between the speaker and echo suppressor may be ignored if these paths do not give excessive echos when the level of speech is sufficiently high to cause the echo suppressors to operate completely. Similarly, for high speaking levels, it is sufficient to consider echos 1, 2 and 3, echos 4 to 7 being ignored.

The detailed method, based on these assumptions, for calculating the minimum admissible equivalent as regards echo for a circuit consisting of two-wire sections and one four-wire section (with an echo suppressor on the four-wire section) is as follows:

1. assume a value of equivalent for the circuit (or combination of circuits) for which it is desired to calculate the minimum admissible equivalent as regards echo, and allot to the various repeater sections and repeaters, losses and gains which will give this assumed value of equivalent.

2. calculate the equivalent of each path by which an echo produced at an intermediate point of the circuit is reflected towards the speaker, including the path which passes through the end of the circuit. In each case, the reflection at an intermediate repeater corresponds to the active balance return loss of this repeater (balance return loss relating to the section of the circuit beyond the repeater with respect to the speaker and the corresponding balance network). To obtain the equivalent of each path, the balance return loss is added to the algebraic sum of the gains and losses at 800 c/s in the particular path considered. The equivalent at 800 c/s of this path is thus obtained although, in practice, the balance return loss corresponds to any frequency between 500 and 2 000 c/s. In the case of the path passing through the far end of the circuit, 6 db (0·7 N) is taken for the balance return loss at this point.

3. when the equivalents of the various echo paths have thus been determined, a " transmission time correction " must be applied to each of them. This " transmission time correction ", equal to the minimum equivalent which the path may have for the corresponding transmission time whilst still being satisfactory as regards echo, is reduced by the equivalent at 800 c/s of the path considered. For paths 1,2 and 3, this " transmission time correction " is read off the curve of figure 1.

4. The echoes returning towards the speaker by paths 1,2 and 3 should be combined by adding the sum of the power ratios corresponding respectively to the equivalents at 800 c/s reduced by the " transmission time corrections " relating to the various paths quoted (weighted equivalents); this will result in the combining of the echos on a square law basis.

5. the resulting power ratio, obtained as shewn under 4., gives a fraction characterising the relation between the echo actually returning and the echo admissible for these particular paths. If this fraction is less than one, the echos returning by paths 1,2 and 3 may be considered as satisfactory. If, on the contrary, this fraction is greater than one, the assumed value of the equivalent in 1. should be increased and the calculations must be re-made until the assumed equivalent value results in a power ratio equal to or less than one.

6. the echos returning by paths 4 to 7 should then be combined by adding the power ratios corresponding to the equivalents at 800 c/s of these various paths, reduced by the " transmission time corrections ". In this case the " transmission time correction " is read on the curve of figure 2—which corresponds to circuits fitted with echo suppressors having a sensitivity, referred to zero relative level, of 30 db (about 3·5 N). This will result in the combining of the echos on a square law basis.

7. the resulting power ratio obtained under 6. gives a fraction corresponding to the relation between the total echo which returns by paths 4 to 7 and the echo admissible for the particular circuit considered. If this fraction is equal to one, the echo which reflects is equal to the maximum admissible. If this fraction is less than one, a lower hypothetical value is taken for the equivalent of the circuit, and the calculation shewn under 6. above is again made. If this fraction is greater than one,

a higher hypothetical value of the equivalent is taken and the calculation is again made until a value is obtained giving a fraction, calculated as shewn under 6., equal to one.

8. after having obtained a hypothetical value of the equivalent which satisfies the conditions set out under 7., it will be necessary to proceed once more as in 3., 4. and 5., so as to check that the echo conditions for paths 1, 2 and 3, for this value of the equivalent, are satisfactory. For most ordinary circuits it has been found that the effects of paths 4 to 7 preponderate; a value of the equivalent which gives satisfactory conditions for paths 4 to 7 generally gives a very large margin for paths 1,2 and 3, included between the speaker and the echo suppressor. Should this not be the case, it would be necessary to carry on again as shewn under 3., 4. and 5. above for various assumed values of the equivalent until a value satisfying echo conditions for paths 1, 2 and 3, has been found. The minimum admissible equivalent as regards echo for the circuit is the higher of the two values obtained respectively as shewn under 5. and 7.

Note. — In the application of the above method of calculation for a transit telephone connection having, from the speaker to the listener, a two-wire circuit, a four-wire circuit fitted with an echo suppressor (of which the sensitivity referred to the origin of the four-wire circuit in terminal service is 30 db (3·45 N) and another two-wire circuit, the correction for transmission time of the paths of the echo currents traversing the echo suppressor is the ordinate read off the curve relating to circuits fitted with echo suppressors of which the sensitivity referred to zero relative level is equal to 30 db (3·45 N). This is not strictly correct as, in the transit telephone connection considered, the point of zero relative level is the origin of the two-wire circuit situated at the speaker end and not the origin of the four-wire circuit. For the time being, it is not necessary to take account of this point.

B. Stability

Numerical values needed and method of calculating stability

It is first necessary to complete the two tables below, and then to proceed to calculate the stability as follows:

Diameter of the conductors of the circuit in millimeters	Type of loading			Balance return loss of the repeater section			
	Inductance of side circuit loading coils in millihenries	Inductance of phantom circuit loading coils in millihenries	Loading coil spacing in metres	in decibels		in nepers	
				Side circuits	Phantom circuits	Side circuits	Phantom circuits

Diameter of the conductors of the two-wire circuit in millimeters	Type of loading of the two-wire circuit			Balance return loss of the section between the two-wire circuit and a repeater section			
				in decibels		in nepers	
	Inductance of side c.rcuit load ng coils in millihenries	Inductance of phantom circuit loading coils in millihenries	Loading coil spacing in metres	Side circuit	Phantom circuit	Side circuit	Phantom circuit

The calculation of the minimum admissible equivalent as regards the " singing point " is carried out as follows:

(a) *A single four-wire circuit.* — The stability being determined with the ends " open ", the value of the return loss at each of the two ends which should be taken in the calculation (A_a) is zero.

To calculate the stability, it is necessary to take not only the equivalent at 800 c/s, but the minimum equivalent of the circuit in the frequency band effectively transmitted. It may happen that, for a particular frequency effectively transmitted, the equivalent is lower by 1·74 db (0·2 N), at the most, than the value at 800 c/s. In such a case, to obtain a given stability (K_s), the equivalent calculated at 800 c/s should be increased by a quantity (α) to be determined.

If q represents the minimum admissible equivalent from the point of view of " singing point " (desired stability equal to K_s):

$$q = K_s - A_a + \alpha$$

Making $K_s = 0{\cdot}2$ N and $A_a = 0$ N:

$$q = 0{\cdot}2 + \alpha$$

or $q = 0{\cdot}2$ N (if α is ignored, which is the general practice at the moment).

Note. — When the subscribers are connected at the two ends of the circuit, the balance return loss A_a to be used in the above formula is *the minimum return loss measured for any frequency within the band of frequencies effectively transmitted* by the circuit and for all impedance values of the circuit termination under service conditions.

Measurements suggest that it is desirable to take

$$A_a = 0{\cdot}2 \text{ N}.$$

On the other hand, for circuits without echo suppressors (in order to avoid near singing distorsion), K should be equal to 3·47 db (0·4 N). This again results in a minimum admissible value of the equivalent as regards stability equal to $q = 0{\cdot}2$ N (ignoring α).

(b) *Connections including both four-wire and two-wire sections.* — The principle of the above method should be followed, but it is essential to examine separately:

1. the stability of each four-wire circuit;

2. the stability of each two-wire repeater.

For this the active balance return losses at the input and output of each four-wire circuit or at each two-wire repeater are calculated. In this calculation it is assumed that the ends of the connection are open' at each terminal trunk/toll exchange.

To determine these active balance return losses, account is taken of all the reflection currents and they are added one to another; if q_1, q_2, q_3 ... represent the equivalents calculated respectively for the various reflected current paths, the resultant active balance return loss A is given by the formula:

$$e^{-A} = e^{-q_1} + e^{-q_2} + e^{-q_3} + \ldots$$

The values of the balance return loss and return loss at the ends of the circuit (connected to the subscribers) to be used in this calculation are not generally the same as those which are used in the calculation relating to echos, as *it is necessary to consider here the minimum values in the whole of the frequency band transmitted.*

In the above calculation, not only the equivalent at 800 c/s must be taken but *the minimum equivalent of the circuit in the band of frequencies effectively transmitted.* It may therefore be necessary in this case also, for the equivalent calculated at 800 c/s to be increased by a quantity to be determined.

C. Variations of the equivalent as a function of time

When the minimum admissible equivalents *in service* for the trunk/toll circuits, as regards echo and " singing ", are being determined, it is necessary to take account of the fact that the equivalent of the circuit will vary as a function of time.

The " overall variation of the equivalent " (overall net loss variation) of a telephone circuit, in each direction of transmission, is the difference between the equivalent at 800 c/s in the direction of transmission considered, and the nominal equivalent.

Causes of variation. — The most common causes of variation of the equivalent of a trunk/toll telephone circuit are the following:

(a) the effects of temperature which, by changing the resistance of the conductors, change the equivalent of the circuit. On very long cable circuits, it is possible to compensate for these effects by means of pilot wire transmission regulators these regulators make this correction in finite steps. Also, because of the delay between the operation of the regulator and the variation of the temperature of the cable conductors, and also because of the differences between the individual pairs of the cable conductors and the pilot pair which controls the operation of the regulator, there are individual small differences in the equivalent of the circuit considered.

(b) the effect, on the repeater gains, of variations of battery voltages.

(c) the effect, on the insertion loss of the internal cabling, of variations of humidity and also the effect of weather conditions (rain, frost, show, etc.), on the loss of open-wire lines.

(d) Errors due to the mean equivalent of a circuit not being exactly equal to the nominal value. These errors arise because the accuracy of the initial line-up

is necessarily limited and because of changes made to the line-up during routine maintenance tests, etc.

(e) The effect of faulty contacts in the circuit.

For a chain of interconnected trunk/toll circuits, the total variation is calculated by taking the square root of the sum of the squares of the variations corresponding to each circuit.

For the calculation of the total variation of the equivalent as a function of time, the following method is used: it is assumed that, for each circuit maintained as an entity and whatever its length, the difference Δ of the equivalent with respect to the nominal value does not exceed 1·7 db (0·2 N). It follows that if there are n independent, interconnected circuits, the total variation of the equivalent is, according to the theory of probability, $1{\cdot}7\sqrt{n}$ db ($0{\cdot}2\sqrt{n}$ N).

After having calculated the total variation of the chain of n circuits, each maintained as an entity, by the formula $0{\cdot}2\sqrt{n}$ N, this total variation is divided into equal parts between the circuits considered, so that the variation appropriate to each individual circuit is:

$$\Delta' = \frac{0{\cdot}2\sqrt{n}}{n}$$

The variation appropriate to a two-wire circuits is allocated entirely to the repeaters; it is usually divided into equal parts between the intermediate two-wire repeaters, the two-wire terminal repeaters if any and the cord circuit repeaters (two-wire) which may be inserted after the four-wire part of the connection.

In other words, a cord circuit repeater is considered as being part of the two-wire section of the connection if it is inserted between a four-wire circuit and a two-wire circuit, and as part of one of the two-wire sections of the connection if it is inserted between two two-wire circuits.

For an unamplified underground cable circuit, the variation is generally negligible.

The calculation of the individual variations may be readily verified in service by means of recording devices using a sinusoidal current with a frequency of about 800 c/s. Such a device, if it is connected to a circuit for long enough to give typical values for each individual variation, enables the accuracy of the calculations to be checked.

Table giving the allocation of the total variation of equivalent, as a function of time, of a chain of circuits

Number of circuits maintained as entities n	Total variation for the chain of circuit: $0{\cdot}2\sqrt{n}$ (nepers)	The part Δ' allocated to each circuit $\left(\frac{0{\cdot}2\sqrt{n}}{n}\right)$ (nepers)
2	0·28	0·14
3	0·36	0·12
4	0·40	0·10
5	0·45	0·09
6	0·48	0·08

Loss (nepers)	1·1	—2·04	1·55	0·15	0	0·6	—1·2	0·9	
1. Stability of the chain of four-wire circuits									
Balance return loss or return loss	← 0	← 3·2		← 2·0		→ 3·7	→ 3·5		→ 0
2. Stability of the cord circuit repeater at Allenstein									
Balance return loss or return loss	← 0	← 3·2		← 2·0		→ 3·7	→ 3·5		→ 0
3. Stability of the Les Abrets two-wire repeater									
Balance return loss or return loss	← 0	← 3·2	← 3·2	← 2·0		→ 3·7	→ 3·5		→ 0

FIGURE 5. — *Data for the calculation of the stability of a chain of circuits between terminal trunk/toll exchanges (ends open)*

The " total variations " defined and calculated as shewn above are used to calculate the minimum admissible equivalent *in service*, for a trunk/toll circuit as regards either echo or stability.

To facilitate the application of this method, the above table entitled "Table giving the allocation of the total variation of equivalent, as a function of time, of a chain of circuits " gives the parts Δ′ allocated to each circuit, for combinations of 2, 3, 4, 5 or 6 circuits.

D. Example of the calculation of echo and stability for a chain of trunk/toll and international circuits

An example is given below of calculations made to find if a communication set up in accordance with the present switching plan satisfies the standards laid down for the transmission quality (as regards speaker echo and near singing distortion). (See tables of fig. 5 and 6.)

Calculation of the stability of the chain of circuits between terminal trunk/toll exchanges (ends ' open ')

A. *Using nominal values of the equivalents*

1. Stability of the chain of four-wire circuits.

Active balance return loss at Allenstein, Hohenstein side:

$$e^{-A} = e^{-3\cdot7} + e^{-(3\cdot5-2\times1\cdot2)} + e^{-(2\times0\cdot9-2\times1\cdot2)} \qquad A = -\,0\cdot78\ N.$$

Active balance return loss at Lyon, Grenoble side:

$$e^{-A'} = e^{-2\cdot0} + e^{-[2(0\cdot15+1\cdot55-2\cdot04)+3\cdot2]} + e^{-2[0\cdot15+1\cdot55-2\cdot04+1\cdot1]} \qquad A' = 0\cdot83\ N$$

$$\frac{A+A'}{2} = \frac{0\cdot83 - 0\cdot78}{2} = 0\cdot03\ N$$

Stability $0\cdot6 + 0\cdot03 = 0\cdot63$ N

2. Stability of the cord circuit repeater at Allenstein: Balance return loss at Allenstein, Hohenstein side:

$$e^{-A} = e^{-3\cdot5} + e^{-2\times0\cdot9} \qquad A = 1\cdot63\ N$$

Balance return loss at Allenstein, Grenoble side:

$$e^{-A'} = e^{-3\cdot7} + e^{-[2\times0\cdot6+2\cdot0]} + e^{-[2(0\cdot6+0\cdot15+1\cdot55-2\cdot04)+3\cdot2]} + e^{-[2(0\cdot6+0\cdot15+1\cdot55-2\cdot04+1\cdot1)]}$$

$$\frac{A+A'}{2} = \frac{1\cdot63 + 1\cdot86}{2} = 1\cdot75 \qquad A' = 1\cdot86\ N$$

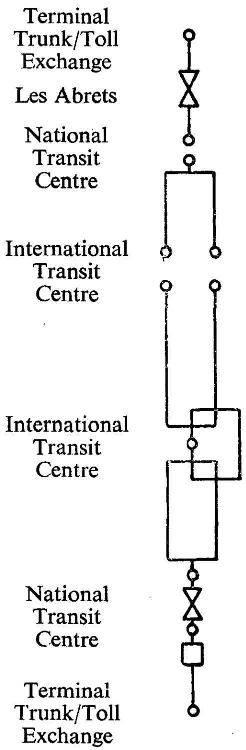
Stability $1\cdot75 - 1\cdot2 = 0\cdot55$ N

3. Stability of the two-wire repeater at Les Abrets:

Balance return loss at Les Abrets, Hohenstein side:

$$e^{-A} = e^{-3\cdot2} + e^{-(2\times1\cdot55+2\cdot0)} + e^{-[2(1\cdot55+0\cdot15+0\cdot6)+3\cdot7]} + e^{-[2(1\cdot55+0\cdot15+0\cdot6-1\cdot2)+3\cdot5]} + e^{-[2(1\cdot55+0\cdot15+0\cdot6-1\cdot2+0\cdot9)]} \qquad A = 2\cdot70\ N$$

FIGURE 6. — *Calculation of stability and echo for a connection between France and Germany. Normal routing Paris-Berlin*



Exchange	Length kilometers	Constitution	Transmission Time (one way) (mill seconds)	Losses (in nepers) Nominal values	Variation as function of time	
					Q	Q[1]
Grenoble . . .	47	0·9 mm, 177 mH, 1 830 meters	3	1·1	$\Delta_1 = \pm 0{\cdot}2$	$\Delta'_1 = \pm 0{\cdot}09$
Les Abrets . .				— 2·04		
	69	0·9 mm, 177 mH, 1 830 m	4	1·55		
Lyon				0·15		
	465	0·9 mm, 44 mH, 1 830 meters	14·5	0	$\Delta_2 = \pm 0{\cdot}2$	$\Delta'_2 = \pm 0{\cdot}09$
Paris.				0		
	1 170	0·9 mm, 44 mH, 1 830 meters / 0·9 mm, 30 mH, 1 700 meters	31·6	0	$\Delta_3 = \pm 0{\cdot}2$	$\Delta'_3 = \pm 0{\cdot}09$
Berlin				0		
	810	0·9 mm, 30 mH, 1 700 meters / 0·9 mm, 140 mH, 1 700 meters	25	0·60	$_4 = \pm 0{\cdot}2$	$\Delta'_4 = \pm 0{\cdot}09$
Allenstein . .				— 1·2	$\Delta_5 = \pm 0{\cdot}2$	$\Delta'_5 = \pm 0{\cdot}09$
Hohenstein . .	40	1·2 mm, 140 mH, 1 700 meters	2	0·3 0·6		
		Total	80·1	1·05		

Balance return loss at Les Abrets, Grenoble side:

$$e^{-A'} = e^{-3\cdot2} + e^{-2\times1\cdot1} \qquad A' = 1\cdot89\ \text{N}$$

$$\frac{A + A'}{2} = \frac{2\cdot70 + 1\cdot89}{2} = 2\cdot30 \qquad \textit{Stability}\ 2\cdot30 - 2\cdot04 = 0\cdot26\ \text{N}$$

Thus the stability of the whole of the connection between the terminal trunk/toll exchanges, Grenoble and Hohenstein, is 0·26 N.

B. *Taking account of the variations of the equivalents as a function of time*

In the table in figure 6 the values of the variations Δ' as a function of time are shown. In the example $\Delta' = 0\cdot09$ N.

In this example only the stability of the two-wire repeater at Les Abrets, has been calculated:

Balance return loss at Les Abrets, Hohenstein side:

$$\begin{aligned} e^{-A} = e^{-3\cdot2} &+ e^{-[2\times1\cdot55 + 2\cdot0]} \\ &+ e^{-[2(1\cdot55 + 0\cdot15 + 0\cdot6 - 3\times0\cdot09) + 3\cdot7]} \\ &+ e^{-[2(1\cdot55 + 0\cdot15 + 0\cdot6 - 1\cdot2 - 4\times0\cdot09) + 3\cdot5]} \\ &+ e^{-[2(1\cdot55 + 0\cdot15 + 0\cdot6 - 1\cdot2 + 0\cdot9 - 4\times0\cdot09)]} \end{aligned}$$

$$A = 2\cdot34\ \text{N}$$

Active balance return loss at Les Abrets, Grenoble side:

$$e^{-A'} = e^{-3\cdot2} + e^{-2\times1\cdot1}$$

$$A' = 1\cdot89\ \text{N}$$

$$\frac{A + A'}{2} = \frac{2\cdot34 + 1\cdot89}{2} = 2\cdot13 \qquad \textit{Stability}\ 2\cdot13\text{-}2\cdot13 = 0\cdot0\ \text{N}$$

Calculation of the effects of echo

Echo paths (for the Hohenstein subscriber when speaking):

No. 1. Hohenstein-Lyon-Hohenstein.
No. 2. Hohenstein-Les Abrets-Hohenstein.
No. 3. Hohenstein-Grenoble-Hohenstein.

A. *Using nominal values of the equivalents*

Active balance return loss at: { Lyon, Grenoble side A = 2·0 N; Les Abrets, Grenoble side A = 3·2 N }
Return loss: Grenoble, subscriber's side A = 0·7 N

Echo path number	Equivalent at 800 c/s of the echo path (nepers)	Total transmission time on the echo path (millisec.)	Correction for transmission time (nepers)	Weighted equivalent of the echo path (nepers)	Power ratio corresponding to the weighted equivalent
1	2·6	150	1·43	1·17	0·096
2	3·1	157	1·47	1·63	0·038
3	2·80	160	1·50	1·30	0·074
				Total	0·208

B. *Taking account of the variation of the equivalents as a function of time*

Echo path number	Equivalent at 800 c/s of the echo path		Total transmission time on the echo path	Correction for transmission time		Weighted equivalent of the echo path		Power ratio corresponding to the weighted equivalent
	N.	db.	(millisec.)	N.	db.	N.	db.	
1	1·88		150	1·45		0·45		0·407
3	2·20		157	1·47		0·73		0·232
3	1·90		160	1·50		0·40		0·449
							Total	1·088

Notes. — 1. In the example given above, the following method has been used to take account of the losses of the cord circuits in the transit centres:

It has been assumed:

(a) that because of the method of switching used in international transit centres, the insertion losses of the cord circuits at Paris and Berlin are included in the equivalents of the circuits,

(b) that the insertion loss of the cord circuit at the transit centre at Lyon, at the junction of the four-wire circuit and the two-wire circuit, is included in the equivalent of the two-wire circuit Grenoble-Lyon;

(c) that the losses of the two cord circuits at the Allenstein transit centre are included in the gain of the cord circuit repeater inserted at this national transit centre.

2. It has been assumed in the above example that the value of 2·0 N appearing in the table of balance return losses (page 12) represents the balance return loss between the impedance of the compromise balance of the terminating unit at Lyon and the impedance of the two-wire circuit Lyon-Grenoble seen through the cord circuit of the Lyon transit centre.

Similarly, the value of 3·7 N (on the table on page 13) represents the balance return loss between the input impedance of the cord circuit repeater at Allenstein, including the cord circuit, and the impedance of the compromise balance of the terminating unit at Allenstein.

3. In the above example of the calculation of the effects of echo, it has been assumed that the values of the balance return loss in the two tables quoted above, define the true return current, and it has been assumed that this return current has a transmission time corresponding to the path which would pass through the middle of the repeater section (see note 1 on page 13).

ANNEX 2

CABLING OF RACKS FOR CARRIER SYSTEMS AS USED BY THE CUBAN TELEPHONE COMPANY

The rack consists of cable runways which descend on the two sides of the rack. The cables on the left hand side (seen from the front of the rack) contain low level transmission circuits and also the alternating current power supplies if these are not taken through flow chases. The cables on the right hand side contain the power feeds to the individual panels and the transmission circuits from the panels to terminal strips mounted at the top of the rack.

ANNEX 3

NOTE BY THE FRENCH TELEPHONE ADMINISTRATION ON CABLING OF STANDARD "44 TYPE" APPARATUS RACKS

The cabling of standard " 44 type " apparatus racks is designed to allow the rack to be fitted with apparatus operating from very low frequencies, of the order of some tens of cycles per second (programme circuit repeaters), up to the highest frequencies used for 12 or 24 channel carrier systems (120 kc/s).

All the cables, including those used for power supplies, are in the form of screened pairs.

To avoid crosstalk between pairs carrying signals at very different levels, the low level pairs are located in cable forms on the left hand upright of the rack, while high-level pairs are on the right hand side, that is about 60 cm away.

However, the racks being double-sided, the low-level pairs on the front are on the same up right as the high-level pairs on the rear. These pairs are in different forms spaced at least 50 mm apart. It has not been necessary to make provision for an additional sereen (crosstalk better than 15 N at 129 kc/s).

The pairs having the same level are grouped in several cable forms with screens insulated each from the others and earthed at one point only, on a tagblock at the top of the rack.

The screens of pairs carrying heavy currents (ringing) are connected to an earth different from that used for the " telephone " pairs.

All the " telephone " pairs are connected to three tagblocks at the top of the rack. There is one tagblock for low-level pairs, another for high-level pairs and a third for auxiliary circuits.

Because of the precautions taken in making the cable forms the crosstalk is determined only by the values obtainable between adjacent tags on the same connection strip.

For tags connected to different tagblocks a crosstalk attenuation better than 15 N is obtained (cross talk between high level and low level pairs).

For pairs connected to the same tagblock a value of 9 N is obtained for tags " in line " (crosstalk between two pairs associated with one piece of apparatus) and 10 N for tags side-by-side (crosstalk between two pairs of the same type but connected to different pieces of apparatus).

These crosstalk values are adequate for the following reasons:

15 N is great enough to need no explanation.

9 N is adequate for pairs connected to the same piece of apparatus (repeater, modulator). These pairs, having the same level, generally are used for either the two directions of transmission of a repeater or of a modulator, or different frequencies in the case of a modulator.

10 N is adequate for pairs of the same type connected to different pieces of apparatus. Moreover it can be critical only for racks of 24 circuit repeaters because it fixes the crosstalk between two different circuits passing through the repeaters.

In the case of racks for carrier terminals, 10 N is more than adequate because these pairs are used for either audio frequencies (in which case the crosstalk attenuation will be much better than 10 db) or for high frequencies in which case the frequencies will be different and often the pairs are connected in parallel.

All the crosstalk attenuation values quoted are at the highest frequency used (120 kc/s). For lower frequencies the attenuation values clearly will be higher.

ANNEX 4

ARRANGEMENT OF CABLING TO REDUCE CROSSTALK ON APPARATUS RACKS USED FOR CARRIER SYSTEMS BY THE BRITISH TELEPHONE ADMINISTRATION

The arrangement of the cabling on apparatus racks for carrier systems on unloaded symmetrical pair cables or on coaxial cables used by the British Telephone Administration is as follows:

The whole width of the rack is used for the cable forms. The practice normally followed is to have separate cable forms for sending and receiving and sometimes for distribution of carrier and power supplies. Also, in certain cases, the cable forms for sending and receiving are subdivided in order to separate groups of pairs carrying signals having appreciably different levels. The individual cable forms are spaced across the full width of the rack; they are kept in place by tying them to closely spaced transverse bars.

It has been found that these simple precautions are adequate, the worst residual crosstalk being due to other causes arising within the equipments themselves, such as common carrier frequency supplies.

ANNEX 5

METHOD USED BY THE BRITISH TELEPHONE ADMINISTRATION FOR BALANCING NEW UNLOADED SYMMETRICAL-PAIR CABLES DESIGNED TO BE USED FOR 24-CHANNEL CARRIER TELEPHONE SYSTEMS

This annex describes a method of crosstalk balancing of carrier cables which the British Administration has used. This method is not necessarily the method used by contractors to the Administration and it could probably be improved, but it is an indication of one method of balancing the cable on the assumption that far-end crosstalk within the cable will be further reduced by the aid of networks.

A. Crosstalk in symmetrical-pair cables designed to be used for 24-channel carrier telephone systems

General

Crosstalk on 24-channel carrier cables can be divided into the following broad classes:—

(a) Near-end crosstalk between cables,

(b) Far-end crosstalk within cable. This class may be further subdivided as follows:—

(i) Direct,

(ii) Reflected,

(iii) Indirect.

Points in connexion with each of these classes are set out below.

NEAR-END CROSSTALK BETWEEN CABLES
(Fig. 1)

The near-end crosstalk attenuation between pairs transmitting in opposite directions must be very high, to allow for the big difference in levels at the ends of the repeater sections. For this reason, two entirely separate cables are provided, one for each direction of transmission. With this arrangement, the two lead cable-sheaths act as electromagnetic and electrostatic screens and reduce the crosstalk to a sufficiently low level.

For a sheath to be effective as an electromagnetic screen it is essential for it to be electrically continuous, and, to ensure this, any insulating gaps fitted to 24-channel carrier cables must be bridged with condensers. A condenser suitable for this purpose is now being developed.

FAR-END CROSSTALK WITHIN CABLE

(a) *Direct* (Fig. 2). — This type of crosstalk is due to mutual-capacity and mutual-inductance couplings between the pairs in each cable. The conditions differ from those in an audio cable on account of the lower impedance of the circuits, which results in a reduction of the effects of capacity unbalance and a corresponding increase in the effects of magnetic unbalance.

1. Capacity-unbalance couplings between non-adjacent quads are generally small, as the intermediate conductors are effective as electrostatic screens. The presence of the intermediate conductor does not, however, reduce magnetic couplings appreciably, and for this reason a different length of lay is used for each quad in a standard 24-channel carrier cable.

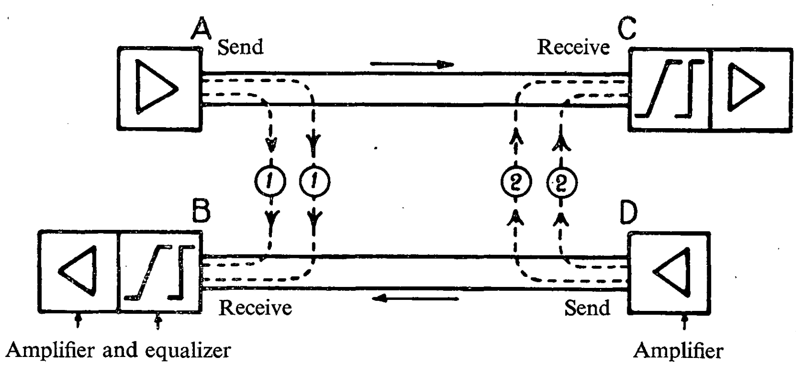


FIGURE 1. — *Near-end crosstalk between cables*

Note. — AC is a pair in one cable transmitting in one direction; BD is a pair in another cable transmitting in the opposite direction; Path 1 indicates two near-end crosstalk paths between A and B; Path 2 indicates two near-end crosstalk paths between D and C.

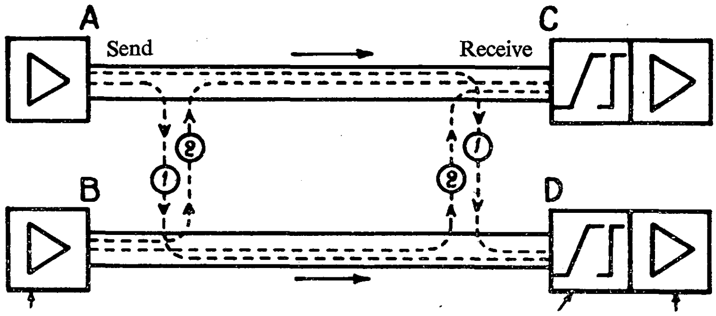


FIGURE 2. — *Far-end crosstalk within cable*

Note. — AC and BD are pairs in one cable transmitting in the same direction; Path 1 indicates far-end crosstalk between A and D; Path 2 indicates far-end crosstalk between B and C.

2. Providing the cable pairs are electrically similar, far-end crosstalk can be balanced out by means of networks fitted at one point in each repeater section, as the length of cable in each crosstalk path and in the correcting crosstalk path is the same. To correct the crosstalk between two pairs at all frequencies, it would be necessary to introduce a network consisting of capacity and inductance couplings equal to the residual unbalances between the cable pairs concerned. In practice, it is necessary only to consider the higher frequencies and, as the characteristic impedance is then substantially non-reactive and does not vary with frequency, it is possible to use simple correcting networks consisting of condensers only. Exceptionally, more-complicated networks consisting of condensers and resistances are used.

3. In all cases the networks are fitted in special frames, which in early installations were installed in huts at the centre point of repeater sections but are now located in the repeater station at the receiving end of the cables.

(b) *Reflected far-end crosstalk* (Fig. 3). — Far-end crosstalk may appear as the result of:—

(i) Reflexion of near-end crosstalk due to the balancing network from the input impedance of the equalizer at the receiving end of the repeater section (Path 2).

(ii) Reflexion of near-end within-cable crosstalk from the output impedance of the amplifier at the sending end of the repeater section (Path 3).

(iii) Reflexion of near-end within-cable crosstalk from the input impedance of the equalizer at the receiving end of the repeater section (Path 4).

Whilst the specifications for the repeater apparatus specify the coefficient of reflexion between the apparatus input and output impedances and the nominal cable impedance, it is not possible to obtain sufficiently low values to enable near-end crosstalk within cable to be neglected.

(c) *Indirect far-end crosstalk* (Fig. 4). — Far-end crosstalk between two pairs of a 24-channel carrier cable may result from couplings to a third circuit. This third circuit may have many forms. It may, for example, be an earthed circuit or a phantom circuit. If the phase-change per unit length in the third circuit is different from that in the normal cable pairs, it is not possible to correct this type of crosstalk over a range of frequencies by means of terminal networks.

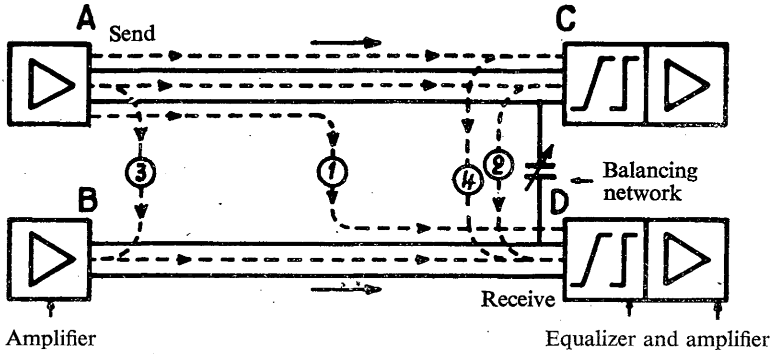


FIGURE 3. — *Reflected far-end crosstalk*

Note. — AC and BD are pairs in one cable transmitting in the same direction; Path 1 indicates ordinary far-end within-cable crosstalk as in figure 2; path 2 indicates crosstalk transmitted through the balancing network as a result of reflexion from the mismatch between the cable and equaliser impedances at C; path 3 indicates near-end crosstalk between A and B reflected as a result of mismatch between the cable and amplifier impedances at B; path 4 indicates energy reflected as a result of mismatch between the cable and amplifier impedances at C passing through the near-end crosstalk path between C and D; all the paths 1, 2, 3 and 4 contribute to far-end crosstalk between pairs AC and BD.

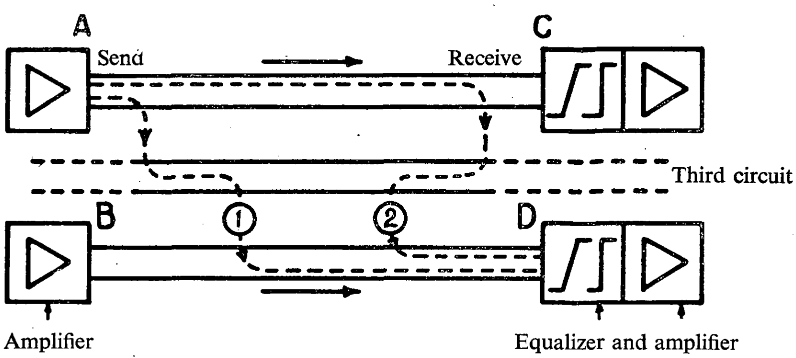


FIGURE 4. — *Indirect far-end crosstalk*

Note. — AC and BD are pairs in one cable transmitting in the same direction; paths 1 and 2 indicate indirect far-end crosstalk between the two pairs.

Field balancing

In the balancing of 24-channel carrier cables in the field, consideration must be given to the following aspects of the problem:—

(a) *Near-end crosstalk between cables.* — The lead sheaths are relied upon to reduce the crosstalk to a sufficiently low value, and no special steps need be taken in the field.

(b) *Direct far-end crosstalk within cables.* — To avoid the necessity for fitting in the balancing networks large values of capacity which would give rise to high reflected crosstalk, test-selected joints are made in the field to reduce unbalances to reasonable values.

(c) *Near-end crosstalk within cable.* — On account of the very short wave-length of the high-frequency signals to be transmitted, it is not possible to compensate for high unbalances in one length of cable by means of similar high unbalances in an adjacent length. All that can be done is to select for the lengths of cable situated near the repeater stations those which, from the factory test results, are known to have no high capacity or magnetic couplings.

(d) *Side-to-phantom and side-to-earth unbalances.* — To reduce the value of indirect far-end crosstalk which cannot be corrected by balancing networks, side-to-phantom and side-to-earth capacity unbalances should be reduced in the normal way.

(e) *Uniformity of electrical characteristics.* — To avoid reflexions at the repeater apparatus input and output impedances, the cable lengths must be so selected that the characteristic impedance/frequency curve is smooth and similar for all pairs. This can be done by equalizing the mutual capacity of the pairs in adjacent lengths of cable. This action also tends to equalize the attenuation and phase constants of all the cable pairs, which is essential for good results to be achieved from network balancing.

B. Field Balancing of a Carrier Cable

General

In carrier systems, crosstalk between cable pairs of widely differing power levels is normally kept small by utilizing separate cables for the opposite directions of transmission, and the balancing of carrier cables is therefore directed to the reduction of far-end within-cable crosstalk only. Such balancing is effected in two ways:—

(a) by selected jointing in the field, to reduce unbalances;

(b) by the use of balancing networks, which are normally fitted at one point in each repeater section.

Scope of Instruction

This Instruction describes the procedure for the balancing (in the field) of a repeater section. The procedure is largely experimental and may be modified as further experience is gained.

Indirect crosstalk between pairs is not readily balanced out by networks, and, in field balancing therefore, efforts should be made to reduce this type of crosstalk as much as possible. To this end, special attention should be given to the neutralizing of phantom-to-side and side-to-earth unbalances. It is important that unbalances which reduce one another should not be widely separated; if possible, they should be in adjacent lengths.

Balancing section

For the sake of uniformity with balancing methods employed on audio cables, a balancing section will be considered as approximately 2,000 yards. It will thus normally contain approximately twelve standard cable-lengths, as indicated in Figure 5.

Testing frequency

All measurements should be made at audio frequency, with the exception of those described in the paragraph below entitled " Joints T5 ".

Layout of cable

So far as is possible, factory figures will be obtained for each length of cable and, from an examination of these, the lengths with the largest unbalances (capacity and magnetic) will be allocated to the centre of the repeater section. It is particularly desirable that unbalances between pairs in lengths near the ends of a repeater section should be small.

Selecting and jointing procedure

Every joint made in a carrier cable will be selected. When the cable has been drawn-in, the single lengths will be jointed in groups of two (see Fig. 5).

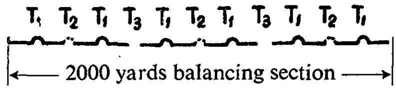


FIGURE 5

Joint T1 are made so that quads arranged in ascending order of magnitude of mutual capacity in one length are joined to quads arranged in descending order of magnitude of mutual capacity in the next length. In addition, within-quad crosses will be introduced for the reduction so far as is possible of $p - q$, $p + q + \frac{1}{2} u$, $r + s + \frac{1}{2} v$, u and v *, greatest attention being given to the reduction of phantom-to-side and side-to-earth unbalances.

Joints T2. — The two-length groups will each be tested, and selected joints made at T2 for the reduction of $p - q$, $p + q + \frac{1}{2} u$, $r + s + \frac{1}{2} v$, u and v, greatest attention being given to the reduction of phantom-to-side and side-to-earth unbalances.

Joints T3. — The four-length groups will next be tested, and a triple selection made for the reduction of $p - q$ (30), $p + q$ $\frac{1}{2} u$ (100), $r + s + \frac{1}{2} v$ (100), u (100) and v (100). Joints T3 will be made at this stage. The figures shown in brackets after the quantities named are the maximum unbalance values, in micro-micro-farads, which should be regarded as permissible in a 2 000 yards balancing section.

Tests on balancing section. — On each completed balancing section the tests specified and in addition pair-to-pair capacity-unbalance tests between each pair and every other pair in the cable, will be taken.

Joints T4. — The balancing sections will be joined together in groups of two, the joints T4 (Fig. 6) being selected to reduce any high side-to-side and pair-to-pair capacity unbalances.

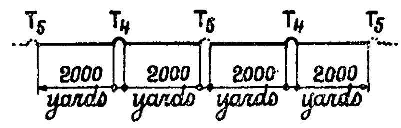


FIGURE 6

Joints T5 will be made either:—

(a) to reduce far-end crosstalk in accordance with the results of switching tests made at or near 60 kc/s, *or*

(b) to reduce admittance unbalance values measured at or near 60 kc.

Straightening-out joints. — In each repeater section, straightening-out will be effected at the joint between the main cable and the test-tablet tails at the Down Station.

* *Note.* — The symbols in these annexes refer to capacitances within a quad and are defined as follows:—

w, x, y, z	are the direct capacitances between wires not in the same pair.
m, n	are the direct capacitances between wires in the same pair.
a, b, c, d	are the capacitances of the four wires to all the other wires in the cable and to the cable sheath or earth.

$$\left.\begin{array}{l} p = w - x \\ q = z - y \\ r = w - z \\ s = x - y \end{array}\right\} \text{wire-to-wire capacitance unbalances;}$$

$$\left.\begin{array}{l} u = a - b \\ v = c - d \end{array}\right\} \text{wire-to-earth unbalances.}$$

ANNEX 6

METHODS USED IN THE NETHERLANDS FOR BALANCING NEW UNLOADED SYMMETRICAL PAIR CABLES DESIGNED TO PROVIDE 48 CARRIER TELEPHONE CHANNELS

The factory lengths of cables used in the Netherlands are about 500 metres. The far-end crosstalk at a frequency of 50 kc/s between the different side circuits is rarely less than 9·5 N. For at least 50% of side-side within group combinations and also between adjacent groups and between the centre and the surrounding layer, the far-end crosstalk attenuation exceeds 11 N. The far-end crosstalk is never less than 9 N.

Generally the effective capacity between any two side circuits does not differ from the minimum value by more than 2·5% and never differs from this minimum value by more than 4%. In order to be able satisfactorily to correct far-end crosstalk it is necessary that all the side circuits should have the same phase delay so that if an artificial coupling is introduced, perhaps in phase opposition to a natural coupling within the cable, the result will be independant of the location of the natural coupling within the cable and of the point along the cable at which the artificial couping lis introduced.

Within a factory length, the transmission time is not always the same for the different groups of conductors and small differences have been observed due to differing lengths of lay and differences in the positions of the groups in the cable cross-section (centre or layer). These small differences are directly proportional to frequency and length and can result in an appreciable difference on a repeater section of cable. By suitably " crossing " the different groups of conductors in a systematic manner at jointing points, the differences in transmission times are reduced to an acceptable amount.

Within repeater section all the circuits are made up of equal lengths of pairs of the various groups of conductors having differing velocities so that, taken over the complete repeater section all circuits have the same phase delay. The best method of " crossing " is to make an interchange between groups every kilometre, that is to say to have a cyclic transposition of all the groups of conductors in the cable. The " crossing " is thus made in accordance with a predetermined plan which does not depend on measurements on factory lengths after laying.

At other jointing points and also at the kilometre points, systematic " crosses " are made. Experience has shown that within a group, the far-end crosstalk coupling $t_{\text{I-II}}$ has a " symmetrical " component t_s and an " unsymmetrical " component t_a, so that:

$$t_{\text{I-II}} = t_s + t_a$$
$$\text{but } t_{\text{II-I}} = t_s - t_a,$$

t_s being reactive and t_a being non-reactive. It is not possible to compensate for the " unsymmetrical " component because if it is desired to improve $t_{\text{I-II}}$ from the value $t_s + t_a$ to the value t_s, it would result in worsening the value $t_{\text{II-I}}$ from $t_s - t_a$ to $t_s - 2\,t_a$. This effect is due to the groups of conductors being laid up in spiral form but it can be avoided by crossing the spiral, that is to say by crossing either pair I or pair II of the group or by interchanging the two pairs. The Dutch Administration uses this latter method at kilometer points in joints where there are no group " crosses ", that is to say where groups having the same number (and consequently the same length of lay) are connected together.

These crosses are made in accordance with a predetermined plan, no electrical measurements being necessary.

The joints having been made as described above the real and imaginary components of the artificial couplings to be inserted to compensate for the residual coupling within the cable can then be measured. Three joints, at quarter, half and three quarter points along the repeater section are left open and by making suitable crosses at these points, the most favourable values are selected: the crosses are made so as to give the lowest values for the real part of the couplings. Finally, the imaginary part of the couplings is balanced out by means of small capacitors. The measurements are made at a frequency of 200 kc/s; the values of the balancing capacitors are equally correct at other frequencies.

The measurements are made by means of a heterodyne detector, the cable being terminated by impedances as near as possible to the cable impedances in order to avoid measurement errors caused by reflections. All the " side " circuits are measured against all other " side " circuits, II being measured against I as well as I against II.

Because, with the method described above, the real part of the couplings are reduced by " balancing " the cable in accordance with the pre-determined plan, it is sufficient to use adjustable capacitors to balance out the residual far-end crosstalk; these should be adjustable with an accuracy of 1 μμ F and should have a maximum value of at least 30 μμ F. It is not necessary for these capacitors to be of the differential type; when two simple capacitors may be connected between a " side " circuit and any other side circuit, only one of these capacitors need be inserted according to whether the sign is pósitive or negative. For a cable with N pairs the number of capacitors needed is thus N (N — 1). All the capacitors are mounted on a frame in such a way that when the cable is connected to the frame all the side circuits are connected to all other side circuits by capacitors.

It is recommended that the capacitors be connected so that the total number of capacitors between a particular side circuit and all the other side circuits should be divided equally between the *a* and *b* wires of this side circuit.

The Dutch Administration recommends the placing of the crosstalk balancing francs at the end of the cable and in the repeater station. In order to reduce the effects of any disturbing field it is recommended that the frame be connected to the " send " end of the cable.

ANNEX 7

METHOD USED BY THE FRENCH TELEPHONE ADMINISTRATION FOR BALANCING REPEATER SECTIONS OF CABLES CONTAINING UNLOADED SYMMETRICAL PAIRS DESIGNED TO BE USED FOR 60-CHANNEL CARRIER SYSTEMS

General

In order to avoid having to solve the difficult problem of near-end crosstalk between different directions of transmission, symmetrical pairs designed to transmit 60 carrier telephone channels are included in two different cables: one of the cables is used for transmission in one direction and the other for transmission in the opposite direction.

Manufacture and allocation of factory lengths

Symmetrical pairs to be used for 60-channel transmission are made up as starquads. The insulation and lays are chosen so as to ensure that the propagation characteristics are very nearly the same for all pairs.

The cables generally have 7 or 12 starquads and may be made in lengths of either 460 metres or 230 metres.

These cable lengths are laid so as to form sections of 1 830 metres corresponding to loading coil sections of audio cables which, generally, are laid at the same time as the carrier cables.

This method of construction facilitates testing of the cables (resistance, resistance unbalance, dielectric strength, insulation, gas pressure).

Within these sections and especially within the two end sections connected to the repeater stations, the factory lengths are selected so as to avoid variations of impedance (measured at 120 kc/s) between one length and the next. Furthermore for these two end sections lengths having good near-end crosstalk are selected.

Jointing of factory lengths

The lengths are jointed together to form balancing sections which generally consist of 8 lengths of 230 metres. All the couplings, within and between quads, are measured at 240 kc/s (both real and imaginary components). These measurements are made either by means of an admittance unbalance bridge or of a crosstalk meter giving the real and imaginary components of the crosstalk voltage. The lengths are then jointed so that the residual far-end crosstalk values are reduced. If necessary a check is made to verify that the inverse couplings do not differ too much from the direct couplings.

Near the repeater stations, regard is also paid to near-end, within-quad crosstalk (measured at several frequencies between 120 and 240 kc/s). Impedance regularity also is checked if necessary.

Jointing of balancing sections

The balancing sections are then jointed together in twos and then in fours etc., using the same measuring and jointing technique.

The joint at the centre of the repeater section is made having regard to all couplings between quads and all combinations, direct and inverse, are measured at several frequencies between 160 and 240 kc/s.

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ANNEX 8

METHODS USED IN MEXICO BY THE SOCIEDAD TELEFONOS DE MEXICO FOR BALANCING UNLOADED SYMMETRICAL-PAIR CABLES DESIGNED TO BE USED FOR CARRIER SYSTEMS

New symmetrical-pair cables providing 12 or 24 carrier telephone channels

In the factory the characteristic impedance of each pair of a factory length is measured at 60 kc/s by means of an instrument according to Figure 1.

As both ends of the factory length are available on the drum the method gives a quick and easy way of finding the characteristic impedance. The different cable drums are then distributed along the route according to Figure 2 which shows an actual example.

Two factory lengths are spliced together in such a way that the higher impedance values of one side are counteracted by corresponding lower values on the other side. These values are obtained by means of a special " Admittance Deviation Measuring Set " which is shown in Figures 3 and 4.

At the same time unbalances to earth are measured with an instrument according to Figure 5.

The double lengths are spliced arbitrarily according to a predetermined schedule in order to avoid any kind of regularity.

Note. — See also an article published in *Ericson Review* Nos 1 and 2, 1945 entitled " Deloading a cable with a view to using it for multi-channel carrier telephony " by S. Janson and R. Stålemark.

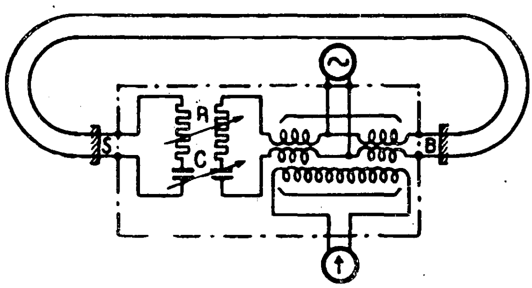


FIGURE 1. — *Impedance measuring set*

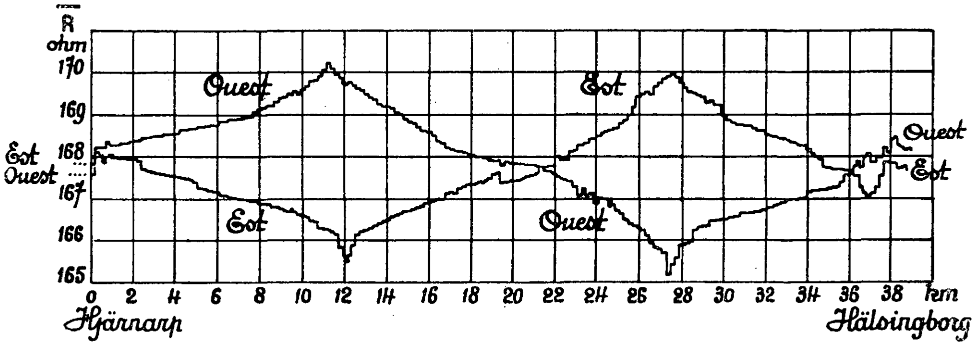


FIGURE 2. — *Distribution of factory lengths*

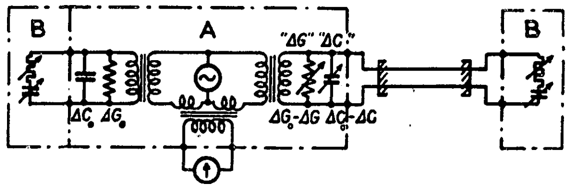


FIGURE 3. — *Admittance deviation measuring set*

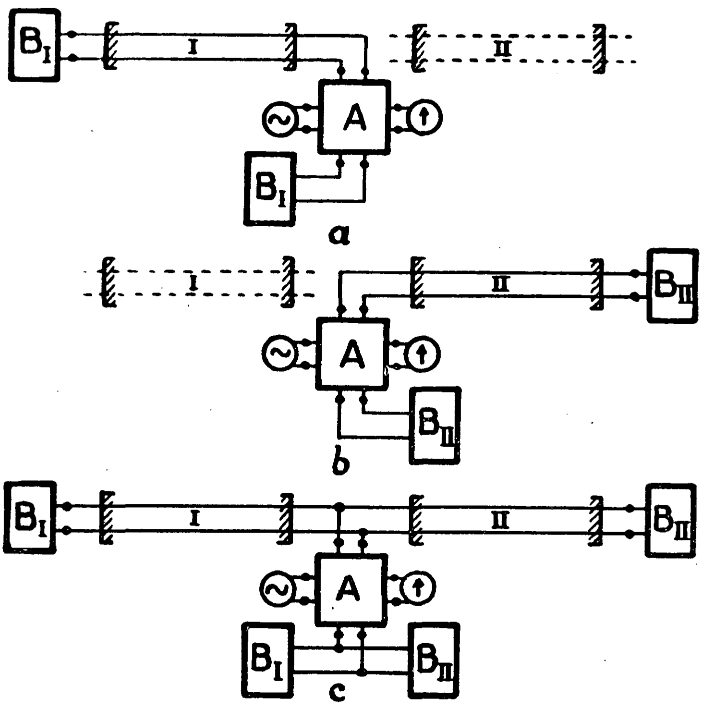


FIGURE 4. — *Admittance deviation measuring set*

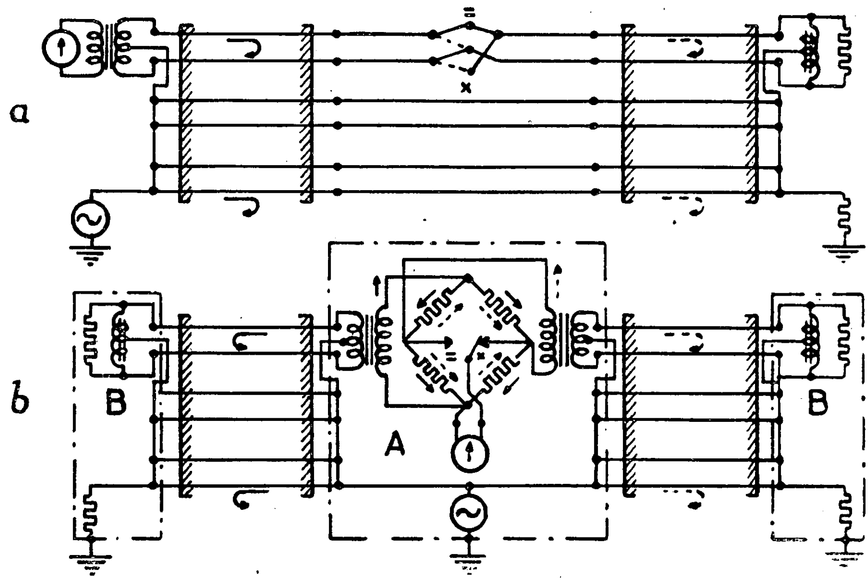


FIGURE 5. — *Unbalance measuring set*

ANNEX 9

SPECIFICATION FOR FAR-END CROSSTALK BALANCING NETWORKS USED BY THE BRITISH TELEPHONE ADMINISTRATION

1. *Scope.* — This specification details the electrical and mechanical requirements of a cable terminating bay incorporating distant-end crosstalk balancing networks, for a pair of 24-circuit type carrier cables. The requirements for the provision of the associated phantom circuit transformers and wiring are also included.

2. *Mechanical Features.* — The framework shall be drilled and tapped so that a voltage regulator or fuse panel may be mounted on either vertical.

3. *Balancing Network Cabinet.* — A cabinet designed to accommodate the balancing networks required for one 24-pair cable shall be provided. The cabinet shall contain a framework (nest) designed to accommodate 276 networks of the type detailed in paragraph 5 of this specification, and the framework shall have adequate rigidity and inter-network screening. The cabinet shall be designed to to exclude dust, but it is not necessary that it shall be airtight. Covers are to be provided at the back and front, such covers being designed to lift off.

4. *Balancing Network Framework.* — At both the front and back of the bay the strips connection associated with the cross connecting wires shall be marked in

such a manner that the nest associated with any combination of pairs may readily be identified. Bare cross-connecting wires shall terminate on tags at the sides, top and bottom of the network " nest ", the wires being of 20 guage (approximately 0·9 mm) tinned copper. They shall be arranged in horizontal and vertical formation, and form a tee to the main transmission path.

5. *Balancing Networks.* — Networks shall be provided for 276 combinations of pairs, the network mounting being installed in the " nests " provided within the cabinet. Each network shall be in accordance with Figure 2, and the wiring of the components shall be in accordance with Figure 3.

The network mounting shall be constructed of a material having high electrical resistivity, and it shall have space and terminals on each side for the following components:—

- — one condenser CD No. 1 or one condenser CD No. 2 to specification;
- — one fixed condenser of approved type (see later);
- — Two chemical type resistors of approved type (see later) the resistors being connected in parallel.

The fixed condenser shall be mounted with a longer side vertical, and in a plane at right angles to the centre partition. It shall be fixed by means of its connection to tags. When installed each network mounting shall be equipped with 2 condensers CD No. 1 or CD No. 2, but the number of fixed condensers and resistors provided will depend on the configuration of the network necessary to meet the crosstalk requirements.

The chemical type resistor shall be of approved type. Normally a resistor will not be required and the resistor terminals shall then be short-circuited by means of an uninsulated strap. When a resistor is found to be necessary and it is required to provide a value intermediate between standard values, two resistors may be joined in parallel. The resistor tags shall be such as to enable two resistors to be joined to each tag in addition to the wires from the terminals which are joined to the cross-connection wires.

All inter-connection of network components shall be carried out with stiff wire. All joints shall be soldered effectively.

The condensers CD No. 1 or CD No. 2 shall be mounted in such a way that the zero marks on both rotor and stator are visible when the mounting is in its " nest ". After adjustment, only one of the two condensers on a mounting shall have other than minimum capacity; an exception to this will occur when it is necessary to use fixed resistors; in this case both of the condensers will have other than minimum capacity. Resistors shall always be used in series with a condenser.

The Condensers CD No. 1 or CD No. 2 shall be so mounted that they cannot be subjected to mechanical stress which would cause strain to upset the normal mechanical relationship between rotor and stator.

With each bay there shall be provided a spanner or a set of tommy bars so designed that the Condensers CD No. 1 or CD No. 2 can be adjusted while in position in a " nest ". The design of the spanner shall be such that hand and earth capacities are not introduced to such an extent as to render adjustment difficult.

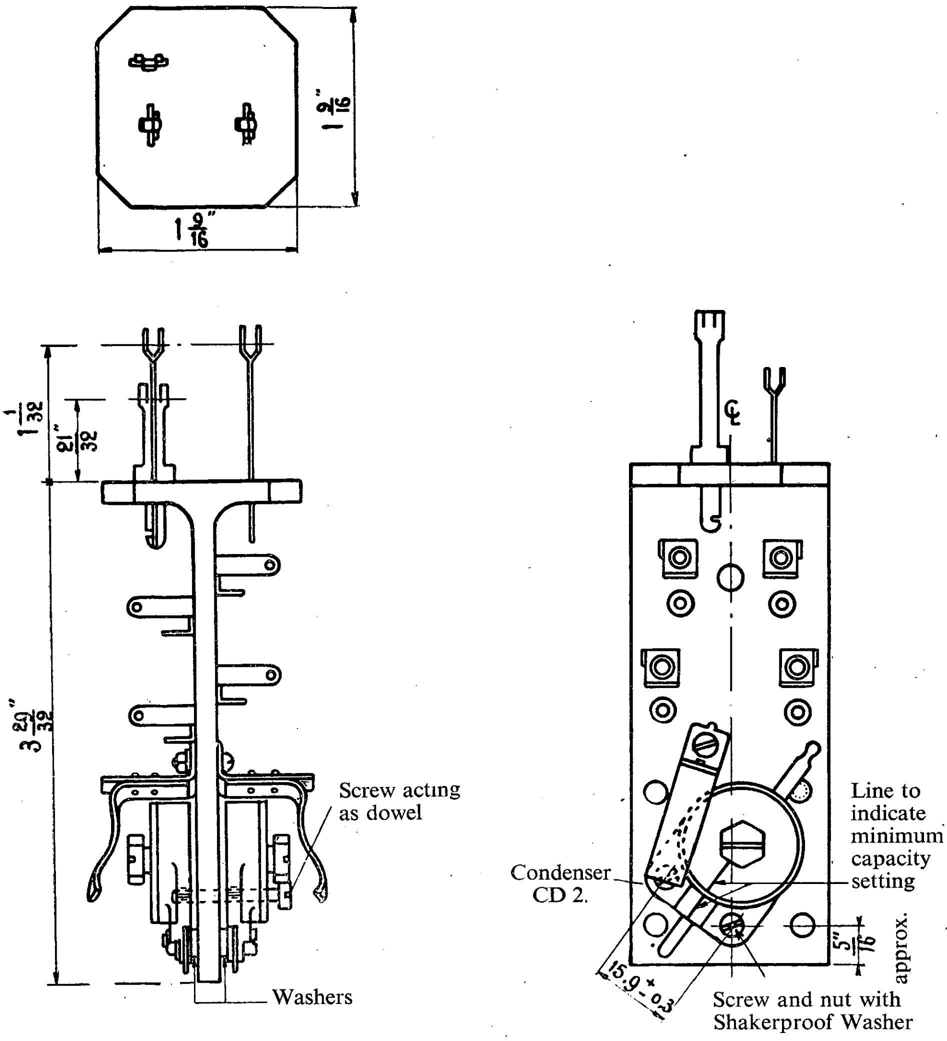


FIGURE 1. — *Mounting for condensers and resistors used on carrier-cable distant-end crosstalk balancing networks*

Note. — Dimensions of the ceramic condensers will be approximately as shown. The size of the fixing holes and distance between their centres will be **rigidly** adhered to.

The condensers CD No. 1 or CD No. 2 will be provided by the Department, but all other network components shall be provided by the Contractor.

Mounting shall be so inserted in the " nest " that the short terminal tags of adjacent networks are associated with A and B wires respectively (see Fig. 2).

6. *Test Tablets.* — Immediately above the top of the cabinet there shall be provided mounting details suitable for the accommodation of a high-insulation test lead terminal box.

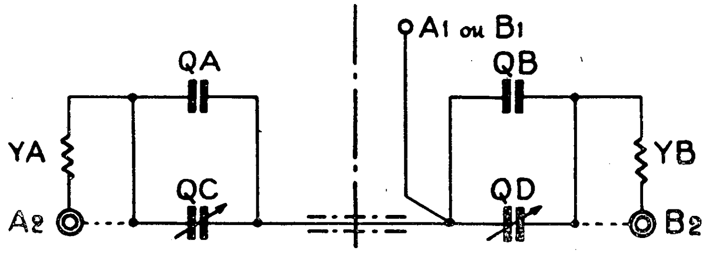


FIGURE 2. — *Schematic*

Distant-end crosstalk balancing networks
Connections of condensers and resistors on a mounting

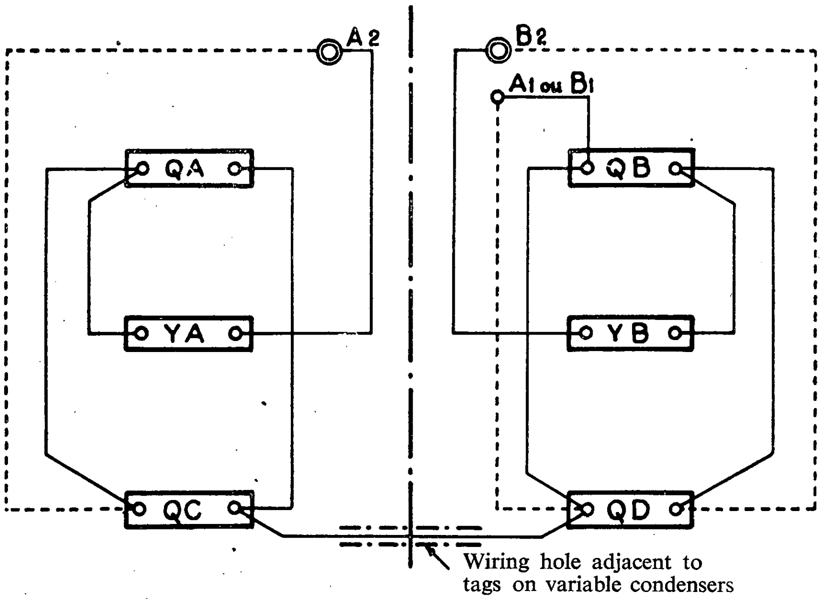


FIGURE 3. — *Mining*

○	Long terminal for connexion to cross-wiring
◎	Short terminal for connexion to cross-wiring
QA and QB	Condensers T.C.C. M Type
QC and QD	Condensers C.D. No. 2
YA and YB	Resistors NR chemical type
- - - - - - - -	Direct wiring normally used (resistors and condensers QA and QB not fitted)
————	Wiring to be used when resistors and condensers QA and QB fitted

Note. — The components on opposite sides of the broken centre line are on opposite sides of the mounting.

Three " Tablets Trunks, 24 Circuit ", shall be provided. The two tablets which are to be associated with the main cables shall be provided with 24 pair, 40 lb. (1.27 mm) P.C.Q.T. Carrier Type " Tails ", 5 feet in length, and the joints shall be made in specified positions.

An electrostatic screen shall be provided between the test tablet associated with the Transmit cable and the other test tablets. This screen shall be in effective electrical contact with the bay framework.

7. *Interpanel Wiring.* — Interpanel wiring shall be carried out with single pair screened cable of approved type. The layout of the forms shall be such that crosstalk is reduced to a minimum.

8. *Connections Strips.* — Connection strips shall be fitted. The connection strips associated with the Transmit and Receive cables shall be provided with removable electrostatic screens, and such screens shall, when in position, be in effective electrical contact with the bay framework.

9. *Phantom Equipment.* — Phantom equipment shall be provided.

10. *Bus Bars.* — Standard bus-bar assemblies shall be provided.

11. *Insulation Resistance.* — The insulation resistance measured at the office side of either cable terminating test tablet between any wire and the remainder earthed and after adjustment of the networks, shall not be less than 200 megohms. This test will include the cable on the distant repeater station (with the cable side of the distant cable termination only included) and the local bay equipment and the wiring to the tag blocks, with the phantom equipment disconnected.

ANNEX 10

SPECIFICATION FOR CROSSTALK BALANCING NETWORKS USED IN MEXICO BY THE SOCIEDAD TELEFONOS DE MEXICO

All pairs of the cable are connected to a frame, where every pair can be balanced against any other pair.

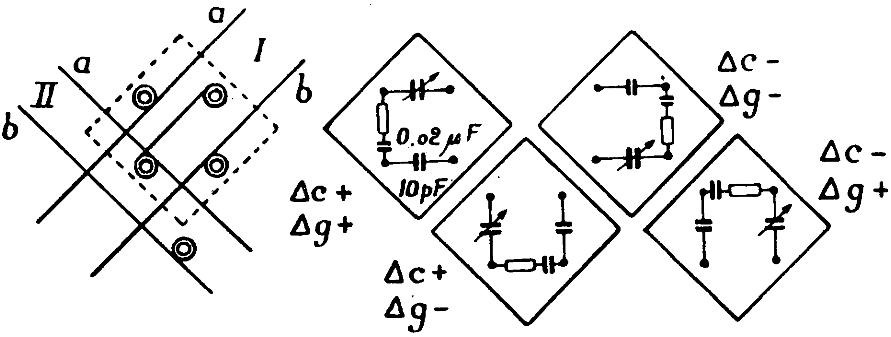
Figure 1 shows the arrangement of the balancing elements and their connections to a cross point between two pairs.

The balancing units consist of a small variable capacitance $\Delta C p$ F and a conductance Δg μ mho. With such a combination full compensation can theoretically be achieved only at one frequency, but a good compromise can usually be obtained giving a considerable improvement of the crosstalk attenuation over the total frequency range.

The instrument that is used to measure the values Δg and Δc is shown in Figure 2.

The complete set of instruments used in balancing is shown in Figure 3. It is of interest to mention that the oscillator 1 is of a special kind. The output is a continuous thermal noise with an even amplitude distribution over the frequency range of interest, for instance 12-60 kc/s. The detector 4 is of the square law type and consequently the values Δg and Δc giving a minimum of crosstalk are the ones that give the best RMS value for the whole frequency range. The method reduces the time necessary to find the best combination of Δ *g* and Δ *c* to only a fraction of the time used with previous methods. A slight improvement of the result has also been observed.

Figure 4 shows the crosstalk measuring instrument used.



FIGURES 1. — *Connection of balancing units to two pairs of wires*

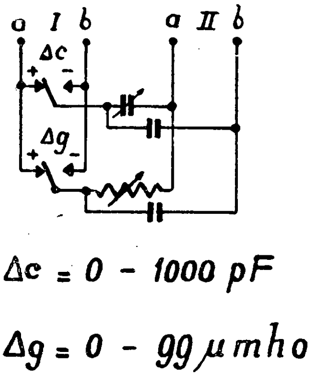


FIGURE 2. — *Apparatus for measuring the capacity unbalances Δ c and the conductance unbalances Δ g*

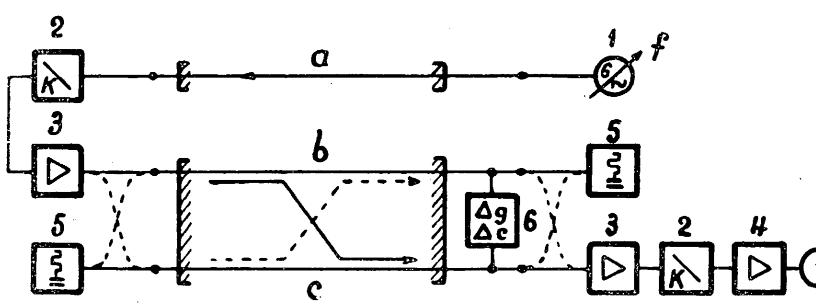


FIGURE 3. — *Arrangement of the instruments used to compensate far-end crosstalk on a repeater section*

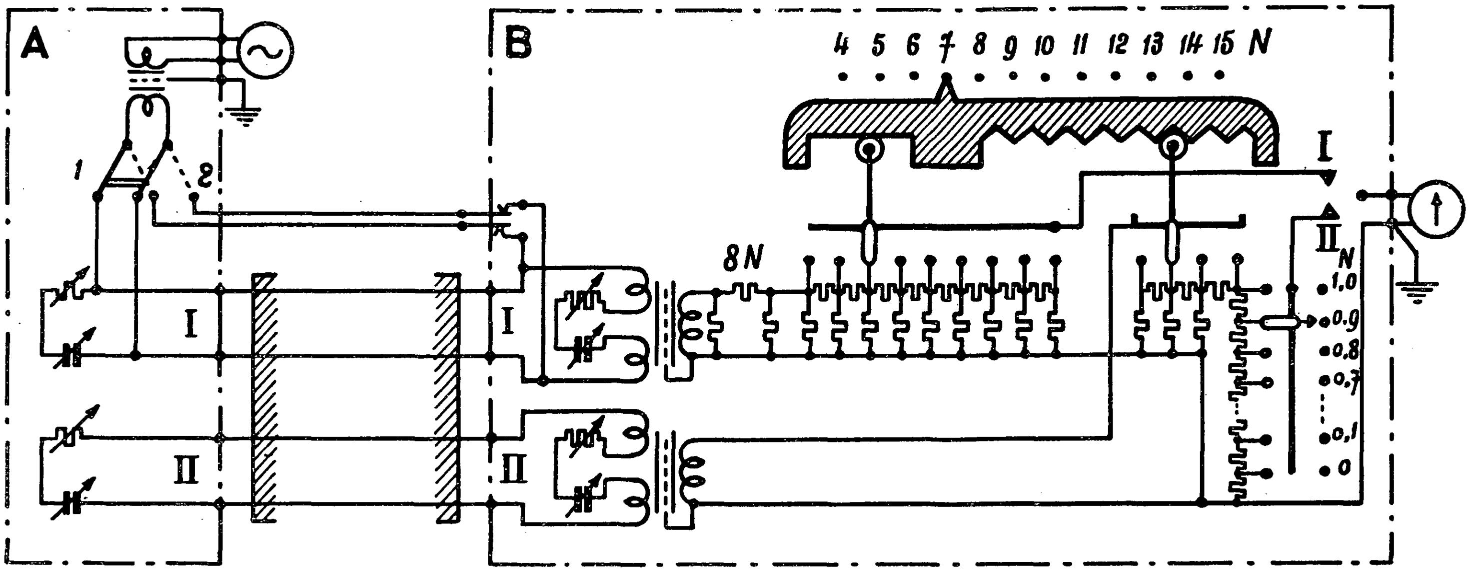


FIGURE 4. — *Crosstalk measuring set used in Mexico by the Empresa de Teléfonos Ericsson*

ANNEX 11

METHOD OF SYNCHRONISING FREQUENCIES USED BY THE BELL SYSTEM IN THE UNITED STATES ON L1 AND L3 CARRIER SYSTEMS

All pilot, channel, group and supergroup frequencies used in the L1 carrier system are multiples of 4 kc/s and are all produced by " harmonic generators " under control of a 4 kc/s frequency generated by a " 4 kc/s frequency supply circuit ". This 4 kc/s frequency supply circuit is a 128 kc/s crystal oscillator with five stages of 2 to 1 frequency reduction, and with a 64 kc/s tap taken off for synchronizing purposes. One of the 4 kc/s frequency supply sources in a system is designated the " master supply ", located at the " master office ". The frequency of any other supply circuit in the system is kept synchronized with the master supply by adjustment of a capacitor in the 128 kc/s feed-back circuit. This capacitor is driven by a synchronous motor under control of the difference between the 64 kc/s synchronizing frequency of the master and the 64 kc/s frequency of the other supply circuit.

1. If the other supply is at the same office as the " master supply " the two 64 kc/s synchronizing frequencies are fed directly into a " frequency comparison circuit " in which the frequency difference controls the motor for adjusting the capacitor.

2. If the other supply is at some other office, the 64 kc/s line frequency coming from the direction of the " master office ", is picked off the line by means of a high impedance bridge and pick-off filter, amplified and then fed into the comparison circuit along with the 64 kc/s synchronizing frequency from the local 4 kc/s frequency supply circuit.

The synchronizing arrangement for the L3 system has not been worked out in detail, but it is expected that it will be basically the same as for L1 except that the frequency used for synchronizing will be 308 kc/s instead of 64 kc/s. Since 308 kc/s does not appear in the frequency supply circuit, it will be taken from a " 308 kc/s pilot generator " and amplified for application to the comparison circuit. The 308 kc/s reference frequency applied to the comparison circuit is derived from the master supply in the manner described above at the master office. At any other office, it is picked off the line and amplified as in the L1 system.

All of this apparatus is an integral part of the system design. With the synchronizing arrangement here summarized the difference in frequency between any two terminals is kept within about one part in ten million. The individual supply circuits are inherently stable to about ± 2 parts in a million. If the control frequency is interrupted at any point, the next succeeding frequency supply takes control of the remainder of the system, maintaining its last adjusted frequency within the limits of accuracy of its own oscillator. Normally, the master supply is synchronized with the Bell System Primary Standard of Frequency, which is manually corrected as required to maintain an absolute accuracy of one part in ten million.

ANNEX 12

METHOD USED IN FRANCE FOR CHECKING MASTER OSCILLATORS OF A COAXIAL AND SYMMETRICAL PAIR CABLE NETWORK USED FOR CARRIER SYSTEMS

The checking of the " master oscillators " of a network of coaxial and symmetrical pair carrier systems is gradually nearing the following arrangement.

All the master oscillators are manually checked for frequencies (around once per month) and any necessary adjustment made.

For this a master oscillator situated in a station at the far end of a line regulating section is nominated as a sub-standard oscillator in each " partial region ". This oscillator is compared to the national standard in the following manner. Two signals of frequency respectively 620 and 2 620 c/s are sent simultaneously on any telephone circuit between the station in which is situated the national standard and the station where it is desired to adjust the sub-standard oscillator. At the sending station an auxiliary oscillator supplies the frequency of 620 c/s and, by mixing with a signal of 2 000 c/s derived from the national standard, the frequency 2 620 c/s. It is thus the difference between the two frequencies transmitted to line which forms the reference frequency. The values of the frequencies transmitted to line are selected so that harmonics and intermodulation products do not cause interference at the receiving end.

On receipt of the two signals they are, after filtering, applied to a modulator which gives out 2 kc/s, the difference between the two received frequencies, which is not affected by any frequency change in the circuit over one or more carrier systems.

The 2 kc/s signal is then used, after the required multiplication, for the adjustment by comparison with the frequency of the sub-standard of the station in question.

The line regulating pilot or pilots originating from this oscillator are distributed over the line regulating sections terminating in this station; one or the other of the pilots enables the manual adjustment of all the master oscillators which are situated in the stations of these sections.

Experience shows that it is easy to obtain by this adjustment an error relative to the difference between the regulated oscillator and the comparison pilot of less than 10^{-5}.

From the oscillators so regulated regulating pilots are generated which in their turn serve as standards for other oscillators.

It is foreseen in France to limit to 5 the number of regenerations which will guarantee an adjustment error less than 5×10^{-8} for the last oscillator adjusted. This limit of the number of regenerations may be obtained in all cases by retransmitting on certain line regulating sections the line regulating pilot or pilots to another section after having stabilised their amplitude.

Note. — The method which has been described above for the calibration of sub-standard oscillators may be applied in a similar manner each time it is desired to transmit a frequency standard to some points if at least one telephone circuit is available.

ANNEX 13

SYNCHRONISATION OF CARRIER FREQUENCIES IN THE CARRIER CABLE NETWORK IN THE UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND

There are in the United Kingdom telephone administration several different types of carrier systems and the method of ensuring that the frequency difference between a tone at the input to the system and the corresponding received tone lies within agreed limits varies with the system considered. In this annex, however, only two systems are outlined. The first is the chief one in operation today and applies to the bulk of the carrier network, and the second is the preferred system which is being applied to new installations.

In the first system the carrier frequencies at one terminal of the carrier network are derived from a 4 kc/s oscillator of fairly high stability which is controlled from a 60 kc/s incoming pilot tone. Where the frequency difference between the locally generated 4 kc/s signal and a 4 kc/s signal derived from the 60 kc/s pilot is δ c/s, two signals of frequency 15 $\times$ δ and with a 90° phase angle between them are applied to a motor controlling the 4 kc/s local oscillator. This difference tone of 15 $\times$ δ energises the motor and by rotation of a variable capacitor the oscillator frequency is adjusted in such a sense that the frequency error is reduced. Due to mechanical inertia in the motor system there can be for short periods a frequency error of perhaps $\pm$ 2 parts in 10^{-5}. When the motor has brought the local oscillator frequency to within a few parts in 10^{-6} of the pilot frequency the oscillator locks to the incoming tone due to the direct injection of this tone into the oscillator, and the frequency error should then not exceed a few parts in 10^{-7}. There is a frequency deviation alarm panel which raises an alarm when the difference in frequency between the local and incoming signals exceeds about $\pm$ 2 parts in 10^{-5}. No device for the accurate comparison of frequency is however built into the equipment.

Considering the carrier network as a whole, at the present time certain carrier terminal oscillators are controlled from a 60 kc/s tone generated by an oscillator which is itself controlled. However the majority of the oscillators are controlled from a 60 kc/s standard tone, and in a short time all oscillators will be controlled from the standard in this way.

In the second system which will be applied to most new installations each terminal will derive the carrier frequencies from a 124 kc/s master oscillator which will be maintained to an accuracy of $\pm$ 2.5 parts in 10^{-7}. There will be two or three such master oscillators in each terminal station, depending upon the size of the station and there will be a periodic routine check on the frequency difference between the individual oscillators and the standard tone. The check is made either with a cathode ray tube or a meter indicating the phase difference between the frequencies.

The standard 60 kc/s tone which will be used for controlling the motor-control oscillators and checking the crystal oscillators of the carrier network, will normally be derived from a 124 kc/s master oscillator. Frequency will be maintained to an accuracy of $\pm$ 5 parts in 10^{-8} and the checking will be done against the British Post Office standard frequency source at the research laboratories, Dollis Hill, London. The final national reference of frequency is controlled by the National Physical Laboratories, Teddington, Middlesex, England.

ANNEX 14

MAIN CHARACTERISTICS OF STATIONS EMITTING STANDARD FREQUENCIES AND TIME SIGNALS

(Information supplied by the C.C.I.R., brought up-to-date in August 1954 by Mr. Decaux, Chairman of Study Group VII of the C.C.I.R.)

Stations		Hawai	Johannesburg [5]	Rugby	Tokyo	Torino	Uccle [22]	Washington
Call signs		WWVH	ZUO	MSF	JJY	IBF	—	WWV
Service		Experimental	Experimental	Experimental	Experimental	Experimental	Experimental	Experimental
Power of carrier (kW)		2 [1] *)	0.1	0.5	1	0.3	0.02	10 [1]
Type of aerial		Vertical dipole	Inverted L	Vertical dipole	Vertical dipole	Horizontal Dipole [18]		Vertical dipole
Number of simultaneous transmissions		3	1	3	1	1	1	6
Number of carrier frequencies used		3	1	3	3	1	1	5
Transmissions	Days per week	7	7	7	7-2 [12]	1 [19]	7	7
	Hours per day	22	24 [6]	24 [9]	24	6 [20]	22	24
Standard frequencies emitted	Carriers (Mc/s)	5; 10; 15	5	2.5; 5; 10 [10]	2.5 [13]; 5 [14] 10 [15] [16]	5	2.5	all
	Modulation (c/s)	1 [2]; 440; 600	1 [7]	1 [2]; 1 000	1 [17]; 1 000	1 [2]; 440; 1 000	none	1 [2]; 440; 600
Duration of the audio modulation (min.)		4 in 5 [3]	—	5 in 15	9 in 20	5 in 10 [21]	—	4 in 5 [3]
Accuracy of frequency (10^{-8})		± 2	± 2 [8]	± 2	± 2	± 2	± 1	± 2
Max. monthly drift of oscillator (10^{-8})		+ 2	+ 4	+ 0.5	+ 1	+ 4	—	+ 1
Max. steps of frequency adjustment		1	2	2	2	2	—	1
Duration of time signals (min.)		continuous	continuous	5 in 15	continuous	5 in 10	none	continuous
Accuracy of time intervals		$\pm 2 \times 10^{-8}$ ± 1 µs	$\pm 2 \times 10^{-8}$ ± 10 µs	$\pm 2 \times 10^{-8}$ ± 1 µs	$\pm 2 \times 10^{-8}$ ± 1 µs	$\pm 2 \times 10^{-8}$ ± 1 µs	—	$\pm 2 \times 10^{-8}$ ± 1 µs
Method of adjusting time signals		by frequency [4]	by frequency [4]	in steps of 50 ms [2]	adjusted on the basis of average time signals	by frequency [4]	—	by frequency [4]

* See notes on following page.

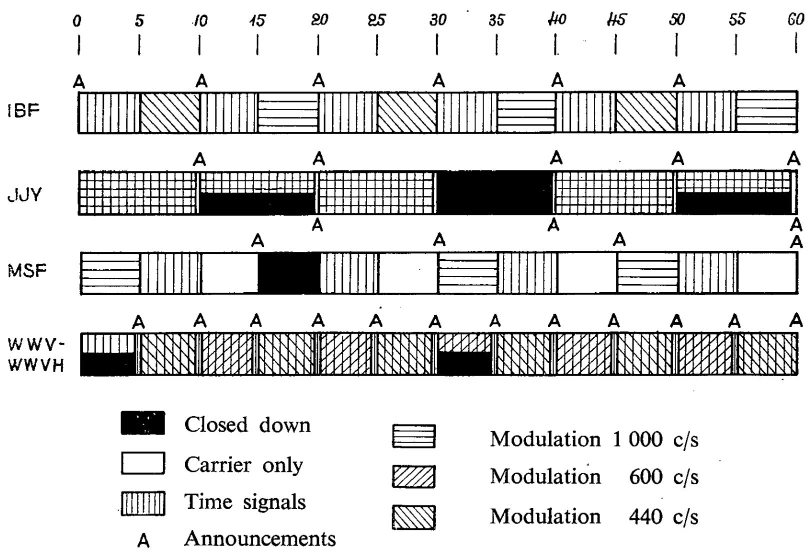
1) Maximum values: reduced power is used on certain frequencies and on certain days.
2) Pulses of 5 cycles of 1 000 c/s modulation.
3) 440 and 600 c/s alternately.
4) No phase adjustment on the time signals themselves.
5) Transmission controlled by the Observatory of the Union of South Africa.
6) Interruptions for short periods.
7) Pulses of 100 cycles of 1 000 c/s modulation.
8) With respect to WWV.
9) Transmission interrupted at 15 and 20 minutes past each hour.
10) Transmissions are also made on 60 kc/s.
11) On the 1st of the month if necessary.
12) See " Carriers ".
13) From 7 to 23 hours U.T.
14) Monday.
15) Wednesday.
16) Transmissions are also made on 4 and 8 Mc/s.
17) Transmission interrupted for 20 ms.
18) Direction of maximum radiation NW-SE.
19) Tuesday.
20) From 8 to 11 h. and from 13 to 16 h. U.T.
21) 440 and 1 000 c/s alternately.
22) Transmission controlled by the Royal Belgian Observatory.

Brought up to date in August 1954 *.

Nnote:

A more up-to-date table appears on pages 13-15 of C.C.I.R. Document 107 E (Study Group VII, Warsaw 1956).

Comparison of time tables of transmissions of standard frequencies and time signals



ANNEX 15

FREQUENCY STANDARD USED BY THE ITALIAN TELEPHONE ADMINISTRATION

For the routine checking of master oscillators for carrier systems, the Italian telephone Administration will use its frequency standard at Rome (*Istituo Superiore delle Poste e delle Telecomunicazioni*) which has the following characteristics:

accuracy: $\pm 2 \times 10^{-8}$

maximum monthly drift: $\pm 3 \times 10^{-8}$.

ANNEX 16

MULTI-PURPOSE PILOTS USED IN THE UNITED STATES OF AMERICA BY THE AMERICAN TELEPHONE AND TELEGRAPH COMPANY

There are obvious advantages in locating pilot frequencies either below the transmitted frequency band or in the space between two adjacent supergroups. In the L1 type coaxial cable system at present used in the United States of America by the Bell System, four line pilots are transmitted, 64, 556, 2 064 and 3 096 kc/s. These are used as follows:

— the 2 064 kc/s pilot controls the regulators in every second auxiliary repeater stations and also in all the main repeater stations;

— the 64, 556, and 3 096 kc/s pilots control supplementary regulation and equalization at main repeater stations;

— with the switching system used at present, the 64 and 556 kc/s pilots also control devices by means of which a " reserve " line section, with its equipment, and having a length of 50 to 100 miles (1 mile = 1 609 metres), is automatically subsituted for a faulty working section;

— at each terminal station, the master oscillator which generates the carrier and pilot frequencies is synchronized by means of the 64 kc/s line pilot.

Except in so far as additional pilots are needed because of the larger frequency band transmitted, the L3 type coaxial cable system makes use of the pilots generally in the same way as in the L1 system described above. Articles published in *Bell System Technical Journal*, July 1953, give further details of the L3 system.

ANNEX 17

MULTI-PURPOSE PILOTS USED BY THE FRENCH TELEPHONE ADMINISTRATION

The French Telephone Administration at present use the two pilots 308 and 4 092 kc/s for multiple functions.

The pilot of 308 kc/s serves as:

— the lower line regulating pilot,

— the pilot for periodic frequency checking,

— the supervisory pilot for the line amplifiers and to provide an alarm on a disconnection.

The pilot of 4 092 kc/s serves as:

— the higher line regulating pilot,

— the pilot for periodic frequency checking together with the pilot of 308 kc/s.

ANNEX 18

MULTI-PURPOSE PILOTS USED BY THE BRITISH TELEPHONE ADMINISTRATION

The United Kingdom Telephone Administration has a number of types of multichannel carrier systems in service. The pilot frequencies used are detailed in the following paragraphs. When discussing level control, distinction is made between " regulation " which implies that the change made in gain is a function of frequency and fully corrects for a change which is a function of frequency (e.g. change of cable attenuation with cable temperature), and " automatic gain control " which implies that a change is made in gain which is independent of frequency.

1. Multi-channel carrier telephony systems on symmetrical pair cables

A pilot of 60 kc/s at a level of — 5 db relative to 1 mW at a point of zero relative level is used for synchronisation of master oscillators or frequency comparison. At present this pilot is transmitted on selected cable pairs only, but in the near future will be stabilized in level at the origin of a regulated line section and transmitted on all pairs for the purpose of manual regulation of level dependent upon the measurement of the pilot level at intermediate repeater stations.

2. Multi-channel carrier telephony and television transmission systems on coaxial pair cables

The pilots used on the types of systems used in the United Kingdom are given below. In all cases the level of the pilots is continuously monitored at the receive terminal stations of a regulated line section by means of recording decibelmeters.

2.1. 10-SUPERGROUP TELEPHONY LINKS

2.1.1. *System A*

(a) 300 kc/s at a level of + 16 db relative to 1 mW at a point of zero relative level, is used for:

1. Synchronisation or frequency comparison. For this purpose it is converted to 60 kc/s at the receive line terminal.

2. Maintaining the overall gain of the line section constant by means of an automatic gain control unit at the receive terminal.

3. Visual indication of the overall gain at 300 kc/s of the line section.

4. Automatic changeover to a reserve line amplifier.

5. Indication of a fault on the wideband line.

(b) 2 852 kc/s at + 16 db relative to 1 mW at a point of zero relative level and used for visual indication of the overall gain at 2 852 kc/s of the line section.

2.1.2. *System B*

(a) 60 kc/s pilot at a level of — 10 db relative to 1 mW at a point of zero relative level is used for:

1. Synchronisation or frequency comparison.

2. Automatic regulation of the line in main repeater stations *.

3. Indication of a fault on the wideband line by an alarm given at main repeater stations. *

(b) 2 604 kc/s at — 10 relative to 1 mW at a point of zero relative level and used for:

1. Automatic Regulation of the line at all line amplifiers.

2. Indication of a fault on the wideband line by an alarm given by all repeater stations. This indication is limited to the information that can be obtained by the comparison at each station of the level of the pilots in the two directions of transmission.

2.2. 16-SUPERGROUP TELEPHONY AND TELEVISION LINKS

2.2.1. *System C*

(a) 308 kc/s at a level of 1 mW at a point of zero relative level, is used for:

1. Synchronisation or frequency comparison. For this purpose it is converted to 60 kc/s at the receive line terminal.

2. Maintaining the overall gain of the line section constant by means of an automatic gain control unit.

3. Visual indication of the overall gain at 308 kc/s of the line section.

4. Automatic changeover to a reserve line repeater.

5. Indication of a fault in the wideband line.

(b) 4 340 kc/s at a level of 1 mW at a point of zero relative level and used for visual indication of the overall gain at 4 340 kc/s of the line section.

2.2.2. *System D*

(a) 308 kc/s at a level of — 10 db relative to 1 mW at a point of zero relative level is used for:

1. Synchronisation or frequency comparison. For this purpose it is converted to 60 kc/s at the receive line terminal.

2. Visual indication of the overall gain at 308 kc/s of the line section.

(b) 4 092 kc/s at a level of — 10 db relative to 1 mW at a point of zero relative level is used for:

1. Automatic regulation of the line at all line amplifiers to correct for changes in the cable attenuation due to change of cable temperature.

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*) On system B, a main repeater station is a station where additional regulation is applied to the high frequency line; it is normally a " power feeding station " as defined by the C.C.I.F.

2. Indication of a fault on the wideband line by an alarm given by all repeaters.

(c) 2 792 kc/s at a level of — 10 db relative to 1 mW at a point of zero relative level, is used on regulated line sections exceeding about 100 miles (about 160 km), to apply automatic regulation at main repeater stations * to correct for changes due to variations in the ambient temperature of repeater stations.

2.2.3. Future coaxial line equipments transmitting the frequency range 60 kc/s to approximately 4 Mc/s will use similar pilots to those of System D, but the upper pilot may be 4 340 kc/s. It is also possible that the 308 kc/s pilot may be changed to 60 kc/s for special applications.

2.3. Additional pilots

In addition to the pilot frequencies described above, other pilot frequencies standardised by the C.C.I.F are used when required for the measurement of line regulated sections, and measurement of groups and supergroups.

2.4. Suppression of pilots

The pilot frequencies of all 16 supergroup telephony and television systems are suppressed at the extremities of line regulated sections. On 10 supergroup systems the upper pilot is suppressed at the extremity of a line regulated section when two or more sections are connected together to form a line link. The suppression of the 300 kc/s pilot however presents considerable difficulty and this problem is still being studied.

ANNEX 19

STEPS BEING TAKEN OR PLANNED TO BE TAKEN IN DIFFERENT COUNTRIES TO IMPROVE TRANSMISSION ON OLD TYPE TRUNK/TOLL CIRCUITS

1. General

The increasing use of an enlarged frequency band (from 300 to 3 400 c/s) on all types of lines used for the international service concerns not only the international

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*) On system D, a main repeater station is a station where provision is made for:

a) residual equalization of the line,

b) extraction and/or injection of supergroups at line frequency.

Main stations are normally " power feeding stations " as defined by the C.C.I.F.

circuits but also the national trank/toll circuits and equipments, local networks, and subscriber's installations.

As regards new installations this implies avoidance of livies and equipments which unduly restrict the frequency band within the limits 300 to 3 400 c/s.

As regards existing plant, it is possible either to make modifications which will enlarge the frequency band effectively transmitted or to use it for groups of circuits unlikely to be used for international calls, that is to say to be used for short distance terminal traffic.

NEW INSTALLATIONS

(a) *Long distance network.* — Many future long distance circuits will be carrier on unloaded symmetrical pairs in multi-pair cables and on coaxial pairs. The use of a 4 kc/s spacing between carrier frequencies enables the band 300 to 3 400 c/s to be obtained, and this spacing should be used for all circuits which may form part of an international connection.

In cases where for economic or other reasons there are advantages in installing audio circuits, the loading should be so chosen that the cut-off frequency is at least 4 kc/s and the repeaters and other equipment should allow of equalization of the frequency band 300-3 400 c/s wherever possible.

(b) *Local network.* — Where intermediate loaded lines are used and these may form part of an international connection, a cut-off frequency of about 4 kc/s should be used and the general use of such a cut-off frequency may be desirable to give a degree of flexibility in the use of lines.

EXISTING LINES AND INSTALLATIONS

The choice between modification of existing installations and restricting their use should be based on examination of several factors such as, for example the difficulty and cost of making the modification, the need for additional facilities for long distance calls and the rate of increase of short distance terminal traffic.

The following are examples of methods which might be used to modify existing lines and installations:

(a) *Two-wire circuits with extra light loading.* — The repeaters can be modified (for example by fitting new filters) so as to permit the transmission of as wide a band of frequencies, up to 3 400 c/s, as possible having regard to the singing points of the cable circuits. Where necessary these circuits should be used only for shorter distances, new systems being installed for longer distance circuits.

(b) *Four-wire circuits with extra light loading.* — The frequency band can be extended to 3 400 kc/s by changing the filters in the terminations, by replacing the terminations, or by changing the repeaters, because singing points do not in this case impose a limitation.

(c) *Circuits with medium heavy loading.* — The loading of these circuits can be altered to give a higher cut-off frequency if the need for circuits for terminal traffic is not sufficient to absorb the circuits of this type within a reasonable time and if new plant is provided for longer distance traffic.

If the loading coil spacing cannot be halved, the change in inductance of the loading coils will result in an increase in attenuation and additional repeaters will be needed.

2. Procedure planned by the Swiss Telephone Administration

To increase generally the frequency band effectively transmitted between two subscribers, the Swiss Telephone Administration, at the end of 1946, made the following arrangements:

(a) H 177/63 loading used for multiple twin trunk/toll cables and H 177 for rural twin or star quad cables used up till now will be retained on old cables. It is however envisaged that in future the loading will be changed so that short distance circuits will transmit the enlarged frequency band of 300 to 3 400 c/s. For new installations, H 88.5/31.5 loading will be used for multiple twin trunk/toll cables, H 88.5 or H 88.5/36 for rural twin cables and H 88.5/B 72 for rural star quad cables.

Also in new trunk/toll and rural cables a some of the pairs will be arranged to be suitable for carrier telephony.

The characteristics of the new cables will be as follows:

Multiple twin trunk/toll cables

Loading		Spacing 1 830 m, loading 88·5-31·5 mH			
Diameter of conductors in mm		0·9	1·0	1·4	1·5
Capacitance in μF per km	side circuit	0·035	0·035	0·038	0·038
	phantom circuit	0·055	0·055	0·060	0·060
Cut-off frequency in c/s in ohms	side circuit	4 200	4 200	4 030	4 030
	phantom circuit	5 540	5 540	5 330	5 330
Characteristic impedance	side circuit	1 210	1 210	1 160	1 160
	phantom circuit	545	545	550	550
Attenuation at 800 c/s in mN/km	side circuit	25·5	21·0	12·0	10·5
	phantom circuit	26·5	22·0	12·5	11·0

Trunk/toll and rural star quad cables

Loading		Spacing: 1 830 m Loading: 88·5/36 mH		Spacing: 1 830/915 m Loading: 88·5/42 mH	
Diameter of conductors in mm		1·0	1·2	1·0	1·2
Capacity in μF per km	side circuit	0·035	0·035	0·035	0·035
	phantom circuit	0·091	0·091	0·091	0·091
Cut-off frequency in c/s	side circuit	4 200	4 200	4 200	4 200
	phantom circuit	4 100	4 100	4 100	4 100
Characteristic impedance in ohms at 800 c/s	side circuit	1 210	1 210	1 210	1 210
	phantom circuit	445	445	960	960
Attenuation at 800 c/s in mN/km	side circuit	19·0	14·0	19·5	14·5
	phantom circuit	25·0	18·0	13·0	9·5

(b) Outside the network of two-wire circuits, there are, on the main arteries of the trunk/toll network, large groups of carrier circuits. These are on new 24 symmetrical pair unloaded cables, on deloaded pairs in audio cables, or on coaxial cables. The symmetrical;qair unloaded cables are used for 24, 36 or 48 carrier telephone channels on each pair, while the deloaded audio pairs are used only for, at the most, 24 carrier telephone channels; the coaxial pairs can be used for a maximum of 960 carrier telephone channels on each pair. The bulk of the long-distance traffic is carried on these carrier circuits.

In order to increase the number of rural circuits without laying new cables the introduction of a new carrier system is being considered; this system which will be economic for short distances will provide 5 carrier circuits using a single pair of wires for the two directions of transmission. The spacing between carriers is 6 kc/s and each channel will transmit the band from 300 to 3 400 c/s.

(c) When the above arrangements are completed, and with the introduction of an improved subscriber's set, it will be possible for the new telephone network to transmit effectively a frequency band of 300 to 3 400 c/s.

3. Procedure planned by the French Telephone Administration

(a) *Two-wire circuits*

For economic reasons the French Telephone Administration makes best use of heavily loaded circuits (177/63 and 177/107) by reserving them mainly for very short direct traffic routes. The loading of these circuits will not be changed.

As regards existing lighter loaded circuits (88/36), the French Telephone Administration proposes to use them up to 3 200 c/s. The rule allowing their use up to 0.7 of the cut-off frequency can in practice, be stretched for short circuits and especially on modern cables with a very smooth impedance/frequency characteristic.

The French Telephone Administration proposes to use for H 88 loaded side circuits, a factor of 0.8 of the cut-off frequency, as well as on the better of the heavy loaded circuits.

The upper frequency transmitted by the most common types of circuit will thus be:

H 177/63	side	2 300 c/s
	phantom	3 000 c/s
H 88/36	side	3 200 c/s
	phantom	3 400 c/s

The French Telephone Administration now has a new design of repeater which will allow the frequency bands proposed for these circuits to be achieved.

Under these conditions and for new cables, the French Telephone Administration envisages the standardisation for two-wire circuits of the following loading:

88 mH at 1 830 metres on side circuits
(capacitance 38.5×10^{-9} Farads per kilometre)

36 mH 1 830 metres on phantom circuits
(capacitance 62.5×10^{-9} Farads per kilometre)

(b) *Four-wire circuits*

Circuits with heavy loading H 177/63. — These circuits will be kept out of the general telephone network and will be used for direct traffic on shorter routes.

Circuits with lighter loading H 44/18. — These circuits will in future be equipped progressively to provide transmission up to a frequency greater than 3 400 c/s.

1 + 1 carrier circuits H 22/9. — The French Telephone Administration does not at present envisage changing the frequency band transmitted by these circuits (2 600 kc/s) because of the enormous cost of modifying the loading and the transmission equipment.

Plans for the French network. — In principle new cables will provide only coaxial and 12 channel carrier circuits which will transmit effectively the frequency band 300 to 3 400 c/s.

In all the circumstances it seems that apart from new cables and existing H 44/18 circuits which can be improved at reasonable cost, each Administration, within the framework of the possibilities, should be free to make the best use of its existing circuits.

Nevertheless, the French Telephone Administration wishes to see circuits with the enlarged band of 300 to 3 400 c/s used wherever possible in the international network.

4. Practice followed by the British Telephone Administration

Most of the trunk/toll circuits in Great Britain and Northern Ireland are set up on modern carrier systems on symmetrical pairs or on coaxial pairs. The audio cables loaded with 88 mH coils spaced at 2 000 yds (1 828.8 m) generally are used only to extend the circuits a short distance from main repeater stations.

Consequently in most cases the frequency band effectively transmitted by the circuits conforms to the C.C.I.F. recommendations for modern circuits.

5. Procedure used by the Administration of the Federal German Republic

To enlarge the frequency band transmitted to 300 to 3 400 c/s, the Posts and Telecommunications Administration of the Federal German Republic has standardised for new cables a loading coil inductance of 80 mH for side circuits and 40 mH for phantoms with a loading coil spacing of 1.7 km. The electrical characteristics of the various types of conductors are given in tables 1 and 2.

TABLE 1

Telephone circuits in Multiple Twin Cables						
Diameter of conductors in mm	1·4		1·2		0·9	
	Circuit		Circuit		Circuit	
	side	phantom	side	phantom	side	phantom
Capacitance in μF per km	0·036	0·058	0·035	0·056	0·034	0·054
Cut-off frequency in kc/s $f_0 = \frac{1}{\pi \sqrt{L_0 C_0}}$	4·53	5·05	4·60	5·14	4·67	5·23
Maximum frequency transmitted f_m in kc/s	3·4		3·4		3·4	
$\eta_m = \frac{f_m}{f_0}$	0·45	0·67	0·74	0·66	0·73	0·65
Characteristic impedance in ohms $Z_0 = \sqrt{\frac{L_0}{C_0}}$	1 152	642	1 168	654	1 185	666
Attenuation at 0·8 kc/s in nepers/km	1·0117	0·0105	0·0150	0·0134	0·0244	0·0217

TABLE 2

Telephone circuits in Star Quad Cables			
Diameter of conductors in mm	1·4	1·2	0·9
	Side circuit	Side circuit	Side circuit
Capacitance in μF per km	0·036	0·035	0·034
Cut-off frequency in kc/s $f_0 = \frac{1}{\pi \sqrt{L_0 C_0}}$	4·53	4·60	4·67
Maximum frequency transmitted f_m in kc/s	3·4	3·4	3·4
$\eta_m = \frac{f_m}{f_0}$	0·75	0·74	0·73
Characteristic impedance ohms $Z_0 = \sqrt{\frac{L_0}{C_0}}$	1 152	1 168	1 185
Attenuation at 0·8 kc/s in nepers/km	0·0108	0·0140	0·0234

On existing cables with the old type loading of 140 mH on side circuits and 56 mH on phantoms, and with a spacing of 1.7 km, the cut-off frequences can be increased to a value $f_0 \times \sqrt{2}$, by connecting, at each loading point, two 140/56 mH loading units in parallel, this giving a loading of 70/28 mH. This has already been done and results in the values given in table 3.

TABLE 3

Diameter of conductors in mm	1·4		1·2		0·9	
	Circuit		Circuit		Circuit	
	side	phantom	side	phantom	side	phantom
Capacitance in μF per km	0·036	0·058	0·035	0·056	0·034	0·054
Cut-off frequency f_0 in kc/s	4·85	6·05	4·90	6·15	5·00	6·35
Maximum frequency transmitted f_m in kc/s	3·4		3·4		3·4	
$\eta_m = \frac{f_m}{f_0}$	0·70	0·56	0·69	0·55	0·68	0·54
Characteristic impedance Z_0 in ohms	1 070	530	1 085	540	1 100	550
Attenuation at 0·8 kc/s in nepers/km	0·011	0·011	0·015	0·015	0·025	0·025

ANNEX 20

DIELECTRIC STRENGTH TESTS

For tests of dielectric strength on factory lengths of cable, some Administrations and Private Operating Companies prefer to use, instead of the period of application of two seconds given in Specification A 1, a period of two minutes. The International Telephone Committee has no objection to this.

This annex deals with the relation between dielectric strength tests made with direct current and those made with alternating current.

1. *General.* — If it is desired to have a general rule allowing the replacement of direct current tests by alternating current tests for dielectric strength of a type of cable or of any apparatus whatsoever, and no matter what method of construction, and dielectric are used, it can be stated that the facts and the results of practical experience so far published indicate that the constants to be used in the formula relating to such a change have yet to be determined. On the other hand, it is present practice to use an empirical value for the ratio of the direct current test voltage to the alternating current test voltage, this ratio being peculiar to each particular type of cable and for each particular piece of apparatus (for example a capacitor). Nevertheless, this common practice should be considered as strictly conventional and having no relation to basic theory.

2. *Impregnated paper.* — Most of the work on this section of the theory of dielectrics (ratio of the alternating current test voltage to the equivalent direct current test voltage) has been done on impregnated paper dielectrics in cables and, in particular, in power cables. The most important article on this subject is, without doubt, the Japanese article— reference [3] in the Bibliography.

From the articles it is possible to deduce that:

(a) The ratio of the direct current voltage to the equivalent alternating current voltage for dielectric strength tests on impregnated paper depends on the moisture content of the papers: increased moisture reduces the ratio of the direct current test voltage to the alternating current test voltage;

(b) the duration of application of the voltage during the dielectric strength test is very important when fixing the ratio of the equivalent direct and alternating current test voltages. When there is a slow breakdown the behaviour is quite different and there is no apparent relation. In this connection it is pointed out that most of the dielectric strength tests with direct current last less than 30 minutes; usual durations are 15 minutes, 5 minutes and 1 minute;

(c) the thickness of the insulation seems to have an important effect on the ratio of the equivalent direct and alternating current test voltages. The ratio of the direct current voltage to the alternating current voltage tends to increase with the thickness of the dielectric because the value of the alternating current voltage per unit of thickness decreases while the value of the direct current voltage remains more or less constant.

(d) the ratio of the equivalent direct and alternating current test voltages depends on temperature: it decreases as temperature increases.

As has been mentioned above, these remarks apply only to impregnated papers, for which, in routine tests, the ratio of the direct to the equivalent alternating current test voltage is ordinarily assumed to be of the order of 1.5 to 2.0.

3. *Gaseous dielectrics.* — At the other end of the range of dielectrics, discharge in air may be considered (see Bibliography, references [6] onwards). The breakdown voltage between two polished spheres should be the same for direct current and alternating current (maximum voltage). This condition however does not apply to tests generally. At the other extreme there is the combination of a point and a plane surface for which there are two district cases. If the point is negative and the plane positive the direct current voltage at which discharge starts seems to be about double the value obtained when the point is positive and the plane negative. The peak value of the alternating current voltage at which discharge starts seems to be equal to the value of the direct current voltage in the latter case. If a dielectric consisting mainly of air is considered, generally there will be no factor allowing the direct calculation of the ratio of the direct current test voltage to the equivalent alternating current test voltage; also, for mechanical reasons, there will generally be solid substances in the electric field which will give rise to distortion and make the calculation more complicated.

4. *Other dielectrics.* — Combinations of paper and a gas are often used as an insulating medium, for example in telephone cables, but there is not sufficient published data to enable empirical formulae to be recommended. This is probably because of important differences in construction so that complex combinations of gas and solids have to be dealt with.

Similarly, there is very little information available on the subject of solid dielectrics such as mica, glass, bakelite, polystyrene etc.

With apparatus using such dielectrics, in practice, discharge in air over the surface of the insulating material is often the limiting factor and, as this is similar to the point and plane, this introduces some complexity.

5. *Empirical formulae.* — For paper insulated capacitors and paper insulated power cables, the following empirical formula has been used: direct current voltage $= 1.5 \times$ effective value of the alternating current test voltage. This formula is, for example, quoted in British Standard Specifications Nos. 7 and 480 dealing with power cables. But in these specifications the formula only applies to cables after laying. The test is made with direct current after laying because, on long cables, the charging current can become very great and it would be almost impossible to have a power transformer with sufficient power handling capacity for a high voltage alternating current dielectric strength test. Nevertheless it is generally agreed that logically the ratio of 1.5 should be interpreted as follows: the maximum

alternating current test voltage that may be applied safely is known and if the direct current voltage is 1.5 times as great there is no danger of breakdown if the cable is satisfactory. It is not claimed that the direct current voltage giving rise to breakdown is 1.5 times the effective value of the alternating current voltage giving rise to breakdown. However, this direct current test has some merit, because it sometimes shows up a fault in the installation under test, e.g. a faulty joint or ingress of moisture. Also it shows up the fault without dissipating much power, and without damage to adjacent cables.

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ANNEX 21

NOTE BY THE FRENCH ADMINISTRATION ON THE DEFINITION OF THE CUT-OFF FREQUENCY OF A LOADED CABLE

General method for calculating " attenuation/frequency" and " impedance/frequency " characteristics of a loaded cable

The following general method may be used. If the loading coil is represented by a homogeneous line with distributed inductance and capacitance and Z_0 and $2\ \theta_0$ represent the characteristic impedance and the transfer constant of the coil,

Z the characteristic impedance of the cable and
θ the propagation constant of a half loading section, the diagram of figure 1 is obtained.

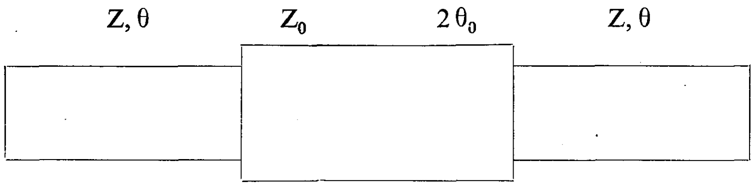

FIGURE 1

The matrix of the resultant quadripole is:

$$M = \begin{Vmatrix} A & B \\ C & D \end{Vmatrix} = \begin{Vmatrix} \text{ch}\,\theta & Z\,\text{sh}\,\theta \\ \dfrac{\text{sh}\,\theta}{Z} & \text{ch}\,\theta \end{Vmatrix} \begin{Vmatrix} \text{ch}\,2\theta_0 & Z_0\,\text{sh}\,2\theta_0 \\ \dfrac{\text{sh}\,2\theta_0}{Z} & \text{ch}\,2\theta_0 \end{Vmatrix} \begin{Vmatrix} \text{ch}\,\theta & Z\,\text{sh}\,\theta \\ \dfrac{\text{sh}\,\theta}{Z} & \text{ch}\,\theta \end{Vmatrix}$$

The propagation constant Γ and the characteristic impedance Z of the loaded cable is given by the formulae:

$$\text{ch}\,\Gamma = A = \text{ch}\,2\theta \cdot \text{ch}\,2\theta_0 + \left(\frac{Z}{Z_0} + \frac{Z_0}{Z}\right) \frac{\text{sh}\,2\theta \cdot \text{sh}\,2\theta_0}{2}$$

$$Z = \sqrt{\frac{B}{C}} = Z \sqrt{\frac{\text{sh}\,2\theta \cdot \text{ch}\,2\theta_0 + \text{sh}\,\theta_0 \left[\dfrac{Z}{Z_0}\,\text{sh}^2\,\theta + \dfrac{Z_0}{Z}\,\text{ch}^2\,\theta\right]}{\text{sh}\,2\theta \cdot \text{ch}\,2\theta_0 + \text{sh}\,\theta_0 \left[\dfrac{Z_0}{Z}\,\text{sh}^2\,\theta + \dfrac{Z}{Z_0}\,\text{ch}^2\,\theta\right]}}$$

Definition of the cut-off frequency of a loaded cable

The following notes relate to the defining of the cut-off frequency of a loaded cable:

1. The introduction of elements with only small losses generally only modifies slightly the essential characteristics of a filter. The effect of the losses, for example, is to smooth the abrupt transition from the pass band to the stop band, but the notion of cut-off frequency may nevertheless be retained.

2. The effect of propagation, on the other hand, may be very important and in certain cases can change completely the characterists of a transmission system. For example, a length of cable which at very low frequencies behaves as a capacitor, can, at certain frequencies appear as an inductor.

This leads one to define the cut-off frequency of a filter, or more generally of a quadripole with losses as that of an ideal quadripole having the same reactive elements but no losses, account being taken if need be of propagation phenomena.

On this basis, the cut-off frequency of a loaded cable may be calculated with a fair degree of accuracy using a formula similar to the classical formula and which the French Administration proposes to use when there is need for a formula more accurate than the classical one:

$$\Omega_0^2 = \frac{4}{s \cdot \overline{C} \cdot \overline{L_0}}$$

where Ω_0 = cut-off frequency (in radians per second),
s = loading coil spacing in km,

and in which:

$$\overline{C} = C + \frac{C_o}{3s}$$

$$\overline{L_o} = Ls + \frac{Ls}{3}$$

with: C = capacitance per km of the unloaded cable
C_0 = capacitance of the loading coil
L_0 = inductance of the loading coil
L = inductance per km of the unloaded cable

ANNEX 22

STUDY OF TELEGRAPH DISTORTION ARISING FROM PHASE DISTORTION OF THE VOICE FREQUENCY TELEGRAPH CIRCUIT

(Note by the French Telephone Administration)

This study relates to single current, amplitude modulated V. F. telegraphy, which is the most commonly used system at the present time. The conclusions apply equally to double current telegraphy.

It is limited to:

1. showing that phase distortion of a given type results in telegraph distortion of particular types of telegraph signals;

2. calculation of distortion under these conditions.

The object of the study is to fix a limit for the phase distortion of circuits. Unfavourable conditions for the production of telegraph distortion by a given phase distortion have therefore been chosen.

Special conditions

The variation of transmission time is assumed to be an even function of the ratio of the frequency ω to the frequency Ω of the carrier.*

* This variation of transmission time corresponds to a " phase/frequency " characteristic *b* (ω) having a point of inflection at a frequency equal to the carrier frequency.

The transmission time being θ_0 at the carrier frequency $\frac{\Omega}{2\pi}$, it is:

$$\theta_0 \pm k\omega \qquad (1)$$

for the angular frequency $\Omega \pm \omega$ radians, k being a constant.

There are:

first, telegraph signals 1/1, that is to say signals alternately + 1 and — 1, of frequency

$$f_0 = \frac{\omega_0}{2\pi} = \frac{1}{2\tau} \quad (\tau \text{ being the duration of an element});$$

and second, telegraph signals 2/2, that is to say signals of half frequency.

The first type of signals can be represented by the function:

$$S_1 = \frac{h}{\pi} \sum_0^\infty \frac{1}{2n+1} \sin (2n+1)\, \omega_0 t$$

The second by:

$$S_2 = \frac{h}{\pi} \sum_0^\infty \frac{1}{2n+1} \sin (2n+1) \frac{\omega_0}{2} t$$

The corresponding harmonics with single current are:

$$SH_1 = \sin \Omega t \left[\frac{1}{2} + \frac{2}{\pi} \sum_0^\infty \frac{1}{2n+1} \sin (2n+1)\, \omega_0 t\right]$$

$$= \frac{1}{2} \sin \Omega t + \frac{1}{\pi} \sum_0^\infty \frac{1}{2n+1}\, 2 \sin \Omega t \sin (2n+1)\, \omega_0 t$$

$$= \frac{1}{2} \sin \Omega t + \frac{1}{\pi} \sum_0^\infty \frac{1}{2n+1} \cos \left[\Omega - (2n+1)\, \omega_0\right] t$$

$$- \frac{1}{\pi} \sum_0^\infty \frac{1}{2n+1} \cos \left[\Omega + (2n+1)\, \omega_0\right] t$$

$$SH_2 = \frac{1}{2} \sin \Omega t + \frac{1}{\pi} \sum_0^\infty \frac{1}{2n+1} \cos \left[\Omega - (2n+1) \frac{\omega_0}{2}\right] t$$

$$- \frac{1}{\pi} \sum_0^\infty \frac{1}{2n+1} \cos \left[\Omega + (2n+1) \frac{\omega_0}{2}\right] t$$

Filtering

The signals are assumed to be filtered by a perfect filter with sharp cut-off, without phase distortion, centered on the carrier frequency and with cut-off frequencies

$$\frac{\Omega - \omega_e}{2\pi} \text{ and } \frac{\Omega + \omega_e}{2\pi}$$

such that

$$\omega_o < \omega_e < \frac{3\ \omega_o}{2}$$

Under these conditions the filter eliminates all components of the signal of the form

$$\cos\left[\Omega \pm (2n+1)\ \omega_o\right] t \text{ et } \cos\left[\Omega \pm (2n+1)\ \frac{\omega_o}{2}\right] t$$

for which $n > O$.

The signals after passing through the filter become:

$$SH'_1 = \frac{1}{2} \sin \Omega t + \frac{1}{\pi} \cos (\Omega - \omega_o)\ t - \frac{1}{\pi} \cos (\Omega + \omega_o)\ t$$

$$= \frac{1}{2} \sin \Omega t + \frac{2}{\pi} \sin \Omega t \sin \omega_o\ t \qquad (2)$$

$$SH'_2 = \frac{1}{2} \sin \Omega t + \frac{2}{\pi} \sin \Omega t \sin \frac{\omega_o}{2}\ t \qquad (3)$$

$$= \frac{1}{2} \sin \Omega t + \frac{1}{\pi} \cos (\Omega - \frac{\omega_o}{2})\ t - \frac{1}{\pi} \cos (\Omega + \frac{\omega_o}{2})\ t$$

No account has been taken of the fixed delay in the filter as this only shifts the time origin.

Effect of phase distortion on the signals

Going back to the expression (1) for the transmission time, with the signal SH, expressed as in (2), the phase distortion results in the following delays:

$$\theta_o \text{ for the } \Omega \text{ term}$$

$$\theta_o + k\,\omega_o \text{ for the } \Omega \pm \omega_o \text{ terms}$$

These signals become:

$$SH''_1 = \frac{1}{2} \sin \Omega\ (t - \theta_o)$$

$$+ \frac{1}{\pi} \cos (\Omega - \omega_o)\ (t - \theta_o - k\omega_o)$$

$$- \frac{1}{\pi} \cos (\Omega + \omega_o)\ (t - \theta_o - k\omega_o) \quad \text{ou}$$

$$SH''_1 = \frac{1}{2} \sin \Omega\ (t - \theta_o) + \frac{2}{\pi} \sin \Omega\ (t - \theta_o - k\omega_o) \sin \omega_o\ (t - \theta_o - k\omega_o) \qquad (4)$$

The characteristic instants of the signals occur when

$$\sin \omega_o (t - \theta_o - k \omega_o) \text{ vanishes.}$$

They are then delayed by $\theta_o + k \omega_o$.

Similarly the 2/2 type signals are delayed only by:

$$\theta_o + \frac{k \omega_o}{2}$$

There is thus for the two types of signals a difference in delay of: $\frac{k \omega_o}{2}$

which corresponds to a telegraph distortion: $\delta = \frac{k \omega_o}{2\tau}$

Primary and secondary telegraph distortion

The above study shows that the displacement of the characteristic instants of signals is the same as the variation in delay so long as the telegraphic frequency remains greater than $\frac{\omega_e}{3}$, $\frac{\omega_e}{\pi}$ being the pass band of the filter

If ω_e is taken to equal ω_o, the frequency of the signals may vary from $\frac{\omega_o}{3 \times 2\pi}$ to $\frac{\omega_o}{2\pi}$ without passing outside the band of frequencies corresponding to $\Omega \pm 3\omega$.

Between the signals of frequency $\frac{\omega_o}{2\pi}$ and those of $\frac{\omega_o}{3 \times 2\pi}$ the displacement of the characteristic instants, equal to the variation in delay, will be: $\frac{2k \omega_o}{3}$ and the corresponding distortion to: $\frac{2k \omega_o}{3\tau}$ with τ (unit time) $= \frac{\pi}{\omega}$

This is the maximum primary distortion produced by the phase distortion.

Equation (4) shows that the part of the complex signal due to the modulation has undergone a time displacement. This displacement does not affect the characteristic instants because the variation of the carrier amplitude around $\frac{1}{2} \sin \Omega (t - \theta_o)$ is proportional to $\sin \omega_o (t - \theta_o - k \omega)$. But this displacement can give rise to a change in the magnitude of the variation of amplitude around $\frac{1}{2} \sin \Omega (t - \theta_o)$ a consequently a material change in the amplitude of the detected signals around their mean value. If the receiving relay were " ideal ", this would not be important but, in practice, it results in a variation of the relay " operate " time and in additional distortion.

If the secondary distortion is evaluated at 50% of the primary distortion, the total distortion becomes

$$\delta = \frac{k \omega_o}{\tau}$$

and of the rate of variation of transmission time is expressed in terms of frequency,

$$\delta = \frac{k' f_o}{\tau}.$$

Numerical example

$k' = 20\ \mu$ sec./cycle $\qquad f_o = 25$ c/s

$\tau = 20$ milliseconds $\qquad$ then $\delta = 2{\cdot}5\%$.

ANNEX 23

NOTE BY THE FRENCH TELEPHONE ADMINISTRATION ON THE USE OF V.U. METERS FOR THE CONTROL OF PROGRAMME TRANSMISSIONS

The French Telephone Administration, together with *Radiodiffusion Française*, considers the most satisfactory characteristic to measure at the sending end of a programme circuit, is the " volume ". This opinion is based on the following considerations:

The continuous control of the modulation is, for the broadcasting apparatus, essential for ensuring the technical quality of the programme. This problem is far from being simple and the solution adopted must permit at the same time, accuracy and ease of control.

In so far as the technical quality of the modulation is concerned, the various parameters to be controlled are the following:

— control of the peak level, which must not exceed a certain value, in order to avoid overloading (and consequent distortion) of the system, in particular the radio transmitters;

— control of the " troughs " (or, more exactly, the lowest levels), in order to keep a reasonable dynamic range having regard to the particular listening conditions;

— control of the mean level which, on the one hand must be as high as possible in order to utilise to the best advantage the high frequency power (hence the efficiency) of the transmitters, and on the other hand must be as constant as possible, to avoid too great variations in the mean sound volume at the receiver, which would cause the listener to have to continually readjust the volume control;

— further, so that control is easy, there should be only one control device, whose readings should be easily and correctly understood.

Unfortunately, the ideal device with facilities for controlling the three levels and complying with the fourth condition, does not exist. The oscillograph for example, gives readings which are too rapid to be usable. The peak volt meters, as their name indicates, only permit of the control of the peak level, and their use in practice leads to undermodulation of the transmitters. Modulation meters * do not provide for the control of the mean level (which is a very important characteristic), and are also costly and not very stable.

Radiodiffusion Française has for some time used experimentally, the American " v.u. meter " (that is to say with an integration time to about 2 dB of about 165 ms, and a time to reach 99% of the final reading of 300 ms with a zero scale reading corresponding to a level of 4 dB with respect to the " American Reference Volume " which is equal to a power of 1 mW into 600 ohms). If this device does not comply strictly to any of the four conditions given above, it can be said that in fact it does not sacrifice any particular one, above all if its scale on the low level end is extended somewhat. This is particularly important as it very soon became clear that the only control, although accurate, of the peak levels, was clearly insufficient.

The volumeters are also often considered to have the disadvantage that they do not indicate very short high level peaks which would overload the various components of the transmission link and above all the radio transmitter. In practice, this disadvantage is of very little importance, because the very short peaks do not exist at the output from a studio. The sound which builds up rapidly does not die away as quickly, no source of sound gives sounds with an impulsive form, in addition the studio reverberation always extends short sounds. In these conditions the volumeter gives useful readings, and the minor peaks, which could however escape control, have such small energy that the resulting distortion would not be detectable to a listener.

Even though the current experiments are not yet completed, the results obtained tend to prove that the volumeter is, amongst existing control devices, the only one which enables a satisfactory level of modulation to be maintained. *Radiodiffusion Française* is therefore, going to equip with volumeters its various installations, studios, programme distribution centres and transmitters.

The problem of the long-distance lines is different; they have above all, to ensure the stability of the transmission level, to verify that the peak levels do not exceed the values permissible for their equipment and that the general quality of the circuit is good as regards unwanted noise and distortion.

As regards control of levels, it would be very desirable that the same devices should be used in the studios and on the lines: this is desirable in order that the control officers (either of the lines or of the studios) should speak the same language, so that localisation of a fault can be made more easy and this advantage would seem to be very important.

It is obvious there is no problem for steady state tests as the measuring devices then give strictly comparable readings. A more difficult case is when the circuit is in use and is carrying a programme continuously. If a variation of level is noticed, the cause must be found quickly, and in order to do this, it is necessary that the various control devices should give comparable readings under conditions of a

* That is to say voltmeters with damping.

varying level of signal. In these circumstances it is desirable that the organisation responsible for the maintenance of the circuits should control the levels with volumemeters which are the same as those used by the broadcasting authority.

Various other advantages of volumemeters should be noted. For short peaks, peak voltmeters in particular can, under certain conditions, give readings which are not comparable throughout the transmission link, because the maximum value of a peak can be changed appreciably after passing over a long line, on account of the different transmission times of the various signal components. The volumemeter which is less sensitive to phase differences, does not appear to have this disadvantage and gives comparable readings at all points on the transmission link.

For this reason the French Telephone Administration proposes to equip its new programme transmission installations with volume measuring devices which were used for earlier installations.

ANNEX 24

NOTE BY THE TELEPHONE ADMINISTRATION OF THE FEDERAL GERMAN REPUBLIC ON THE USE OF PEAK PROGRAMME METERS FOR THE CONTROL OF PROGRAMME TRANSMISSIONS

The outcome of research described in a report published by the Federal German Republic Telephone Administration is that, during a programme transmission, the peak value is a more certain measure of the maximum amplitude permissible on programme circuits than the volume determined from the indication of a v.u.meter. For programme transmission systems in which less severe conditions on the accuracy of control of the maximum amplitude, are imposed, and as a result on the quality of the breadcast transmission, or in which there is a relatively large reserve of power, the v.u.meter is suitable however, also for controlling peaks if input sensitivity is sufficient and if the coefficient of harmonic distortion resulting from its use can be accepted.*

---

* The input sensitivity of the v.u. meter, in the position of greatest sensitivity (+ 4 v.u.) is only just sufficient to show the " maximum useful effective voltage " of 3.1 volts, at present used in Germany on programme circuits (corresponding to + 1.4 nepers or + 12 decibels with respect to 1 mW into 600 ohms). The maximum useful effective voltage, sent from studios in Germany is at present 1.55 volts. It is therefore lower by 6 decibels than the maximum useful effective voltage on programme circuits. The v.u. meter is therefore not sufficiently sensitive and should be preceded by an amplifier; by doing this to some extent it loses its cost advantage over maximum amplitude measuring devices and also its independence from variations of supply voltages.

In the position of greatest sensitivity (+ 4 v.u.) the coefficient of harmonic distortion produced by the connection of the v.u. meter in a circuit of 600 ohms is about 0.3% [5] a value which is of the same order as the non-linear distortion of programme repeaters.

If a greater precision of control of the maximum amplitude is required, in particular if it is desired to avoid overloading the broadcasting transmitters, and if the quality of the transmission is not to be reduced by overloading the transmission system, it is necessary to use a maximum amplitude indicator, having an integration time of not more than 10 ms. The technical commission of E.B.U. also came to this conclusion at the IVth Meeting, which took place on the 25th to 27th September 1952 in Lugano.*

The E.B.U. states that a maximum amplitude indicator of the same type as that used in the studio, is necessary at least at the sending end of a programme circuit. They add that this is not a reason for not also using v.u.meters along a programme circuit, once a connection is set up. This point of view is not true in all cases, as the indication of the v.u.meter depends too much on the type of programme and its " control ". It is necessary to adjust the input sensitivity (or measuring intervals) in each case, according to the type of programme, after a subjective judgment (based on statistical data). There will naturally be errors in assessing the maximum amplitude on the programme transmission system under consideration.

The reading of the v.u.meter is not in direct relation to the magnitude of the characteristics measured, such as current, voltage or power. For this reason a new unit has been introduced, which is the " unit of volume (v.u.) ". Nevertheless this new unit (v.u.) does not have the most important quality which a unit should have, which is its independence of the measuring device. It is thought that this is a fundamental defect in the v.u.meter. Nowadays the tendency is, on the contrary to replace subjective methods of measurement by objective methods of measurement.

When fixing the electrical and dynamic characteristics of a standardised v.u.meter, it must not be overlooked that the apparatus must be capable of being used also for the adjustment of the relative levels on very long programme circuits *during* a transmission. This is necessary when a line network cannot be made available for a measurement with a sinusoidal voltage. In European countries the relative levels of programme circuits can always be adjusted with a sinusoidal test voltage. This is necessary because otherwise it would not be possible to maintain the narrow limits of level of $\pm$ 0.1 nepers or $\pm$ 0.2 nepers (0.9 or 1.7 decibels) fixed by the C.C.I.F. It is nevertheless usual in Germany to compare the reading of the maximum amplitude indicators at different repeater points on the longer programme circuits *during* a programme transmission, and to make certain corrections if necessary. Using the indicator in this manner as a maximum amplitude indicator has not been troublesome up to the present; the phase distortions of the programme circuits have not introduced a significant error [3.5].

The non-linear distortions of the programme circuits rarely exceed 1% in the limits in which one can, according to the characteristics of the repeaters, handle

* See Appendix IV of the verbatim report of the meeting (some Notes on Broadcast Programme Level Indicators).

the greatest amplitudes. The readings of the maximum amplitude indicator are therefore not incorrect, as had often been feared [3].

For the maximum amplitude indicator it is necessary to have valves and thus a greater cost. Nevertheless, it does result in the possibility of arranging the apparatus so that its input sensitivity enables it to be used also the measure extraneous voltages which arise on programme circuits. These devices can be equipped with a logarithmic scale *and* can therefore have a greater range than the v.u.meter, so so that they can be used for controlling maximum amplitude in the studio. It is therefore possible to use the same type of apparatus throughout the transmission path (microphone — programme circuit — radio transmitter). This method is obviously very profitable and practicable. Further, if peak indicators are used, it is possible to have a relatively small margin of power handling capacity in the repeaters and thus to reduce their cost.

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ANNEX 25

NOTE BY THE BRITISH TELEPHONE ADMINISTRATION ON PEAK PROGRAMME METERS USED IN AGREEMENT WITH THE BRITISH BROADCASTING CORPORATION FOR MONITORING PROGRAMME TRANSMISSIONS

The United Kingdom Telephone Administration together with the British Broadcasting Corporation (B.B.C.) consider that the most satisfactory characteristic to measure during a broadcast programme transmission is the peak voltage.

While the v.u.meter is undoubtedly the simplest volume meter, the more impulsive the sound the greater will be the peak value relative to the meter reading compared with their relative values on steady tone. When lining up the system account has to be taken of this; a factor (usually about 10 db) is assumed to ensure that the transmitter is not overmodulated. This factor, usually about 10 db, is however quite arbitrary and varies from one organisation to another. The v.u.meter is also more difficult and tiring to read, particularly over long periods.

Appreciating that it is desirable that both the telephone Administration and the Broadcasting Authority of a country should use the same instruments, the United Kingdom Telephone Administration uses the Peak programme Meter standardized by the B.B.C.

Description of Peak Programme Meter

Initially a circuit was developed which was capable of fully registering peaks lasting only 10 microseconds but this speed of response was found quite unnecessary. Extended tests were carried out with a unit in which 80% of the full peak value of a square wave was registered in 0.5 milliseconds, from which the interesting fact emerged that if the duration of a peak is very short the ear does not have time to detect distortion produced in the transmission system by over-modulation. Therefore in general the shorter the peak the greater the percentage of over-modulation that can be tolerated; further tests showed that a circuit registering 80% of the peak value of a square wave in 4 milliseconds provided the best compromise. Such a meter will not record fully peaks of shorter duration and will therefore cause the operator to control his programme in such a way that momentary overloads will take place; but the resulting distortion will, by and large, pass unnoticed by the ear and the average modulation depth will be correspondingly raised.

The peak programme meter used has a buffer amplifier to give the required sensitivity and to isolate the variations of the impedance of the rectifier measuring stage from the feeding circuit. The measuring circuit consists of a full wave rectifier (because the positive and negative peaks on some sounds, particularly speech, may differ by as much as 8 db), followed by a resistance-capacitance network and a valve stage with a meter in the anode circuit. This valve circuit is so designed that the change of anode current is approximately a logarithmic function of the variation in potential between grid and earth. The resistance-capacitance network has a charging time-constant of 2.5 milliseconds and a discharge time constant of 1 second.

As the decay time-constant is only 1 second, corresponding to 8.7 db per second, a special quick-acting meter is required to permit registration of peaks of short duration signals to within 1 db. The specification for the meter includes tests of " undershoot " and " overshoot " under specified test conditions.

As one of the advantages of the peak programme meter is that for prolonged observation the relatively show movement reduces eye-strain, considerable thought has been given to the meter scale to reduce this strain as much as possible. The principal features are:

(*a*) A black scale with white pointer and lettering;

(*b*) A minimum number of marks on the scale, arbitrary figures 1 to 7 indicating 4 db intercepts. Present practice is for " 4 " to correspond to 40% modulation and " 6 " therefore represents 100% modulation.

Checking of meters at two separate points on a sound broadcast network

In practice, it was found difficult for two operators to compare the fluctuating readings of their instruments. This difficulty is overcome by slugging the meter by means of a switch which introduces a series resistance and a capacitance shunting the meter and series resistance. This arrangement is found to give a satisfactory indication of the average programme volume which enables meters along a sound broadcast chain to be compared with accuracy.

ANNEX 26

NOTE BY THE TELEPHONE ADMINISTRATIONS OF FRANCE AND GREAT BRITAIN ON METHODS OF CALCULATING TRANSIENT RESPONSE

The following brief notes on the methods employed for dealing with the general problem of the transient response of a chain of quadripoles and the particular problem of the correction of the waveform of transmitted signals by means of waveform-correctors (" time-equalizers "). It serves as an introduction to the bibliography given at the end.

More precisely, considering a system of transfer function $Y(2\pi jf)$, f being the frequency, the first question is that of characterizing the distortion of the system traversed by a signal in such a manner that it can be corrected.

If we take two transmission system connected in tandem, the overall transfer function is the product YZ of the individual transfer functions. The equalization problem is then very simply expressed algebraically by the equation

$$YZ = 1 \qquad (1)$$

The function Y may be calculated or not, but it exists; it is of the form

$$Y(2\pi jf) = \int B(t) \exp(-2\pi jft)\, dt \qquad (2)$$

Under conditions often met in practice, the function Y may be written

$$Y(2\pi jf) = \sum_{k} A_k \exp(-2\pi jf\tau_k) \tag{3}$$

that is to say, the integral (2) may be replaced by the series (3).

If the τ_k are all integral multiples of τ, the function (3) of f is periodic, of period $\frac{1}{\tau}$.

The frequency $\frac{1}{2\tau}$ must thus in general be greater than the band of frequencies utilized.

French method. — A raised-cosine pulse is applied to the system Y and the response is observed. The following propositions are involved:

1. Let $I(t)$ be the pulse used for the test of the system and let $\Phi(f)$ be its spectrum limited to the range $-f_0$ to $+f_0$. Let $\varphi(f)$ be the spectrum of the response $s(t)$, equally limited. Evidently

$$Y(2\pi jf) = \frac{\varphi(f)}{\Phi(f)}. \tag{4}$$

It is necessary to distinguish, from the frequency f_0, the maximum useful frequency transmitted; let this be $f_u \leqslant f_0$. f_u is the limit of the spectrum $\varphi(f)$.

The signal $s(t)$ may then be put into the form

$$s(t) = \sum_{k} A_k \, I(t - t_k). \tag{5}$$

the t_k s being in arithmetic progression with common difference $\frac{1}{2f_0}$. The A_k s are the same coefficients as those which appeared in formula (3) and we have

$$\frac{1}{2f_0} \leqslant \frac{1}{2f_u}.$$

In effect, a condition is placed upon $\Phi(f)$ that it shall not have a null point within the range $-f_u$ to $+f_u$.

2. The elementary signal chosen is a raised-cosine pulse. Let T be the half-amplitude width of this signal. Its spectrum is substantially limited to the first null point at $f_0 = \frac{1}{T}$, so that this signal offers the advantage of being limited in time and, in practice, limited in frequency (see figs 1 and 2).

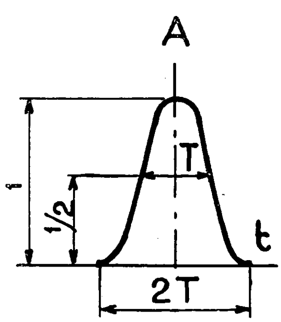

FIGURE 1
t = time
A = amplitude

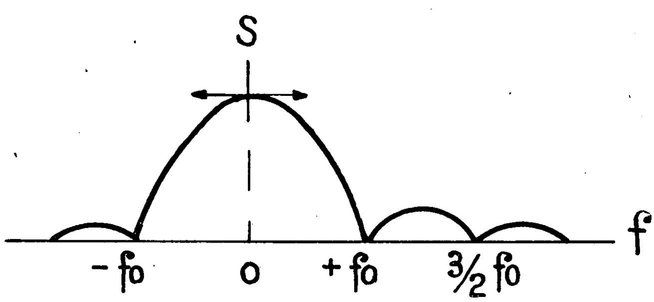

FIGURE 2
f = frequency
S = spectrum amplitude

It is not the same in the case of the signal $\frac{\sin 2\pi f_0 t}{2 f_0 t}$ of which the spectrum is limited to the band $-f_0 + f_0$ but of which the duration is unlimited.

3. If the elementary signal is repeated at the frequency f_0, this frequency does not appear in the signal thus created because it is absent from the original signal (a continuous component is obtained). It follows that f_u must be less than f_0 because Y $(2\pi jf)$ cannot be reconstituted with the amplitudes A_k repeated at the frequency f_0. It is necessary that f_u should be sufficiently small compared with f_0 for frequencies close to f_0 in Y $(2\pi jf)$ to be able to be reconstituted with given precision. Without the choice being absolute, $f_0 = 2 f_u$ has been chosen for the French method.

The interval of the time-series τ_k is thus equal to $\frac{1}{4f_u}$ or $\frac{1}{2f_0}$, f_u being the highest frequency utilized, and f_0 the limiting frequency of the elementary signal.

Summarizing, given a transmission system Y for which it is desired to put Y into the form (3), a raised-cosine pulse is applied to the system and the response is observed. If f_u is the band utilized, the chosen signal has a half-amplitude width of $T = \frac{1}{f_0}$; the observed response is of the form $\sum_k A_k \, . \, I\,(t - t_k)$, the t_k s being in arithmetic progression with common difference $\frac{1}{2f_0} = \frac{1}{4f_u}$. The A_k s are determined with sufficient approximation, from ordinates of the response curve taken at intervals of $\frac{1}{4f_u}$, by means of a simple calculation (see J. Ville— *Décomposition d'un signal en composantes en cosinusoïde surélevée*, reference [27] in the bibliography below)

Method of the British Administration. — A signal of which the spectrum is limited to the range $-f_u$ to $+f_u$ is completely defined by a series of equidistant ordinates at intervals of $\frac{1}{2f_u}$. This fact has been made well known by the work of Shannon ([18], [21]). This signal $s\,(t)$ may thus be put into the form

$$s\,(t) = \sum_{k=-\alpha}^{k=+\alpha} s\,(t_k) \frac{\sin 2\pi f_u (t - t_k)}{2\pi f_u (t - t_k)}, \tag{6}$$

$$t_k = t_0 + \frac{k}{2f_u};$$

Here, f_u is both the limiting frequency of the signal and that of the band utilized. This analysis makes direct use of the amplitudes of the response curve, and these amplitudes are half as numerous as in the French method. However, it is impossible to produce a pulse of the form $\frac{\sin 2\pi f_u t}{2\pi f_u t}$ which, is, theoretically, the response to a Dirac function of an ideal low-pass filter of cut-off frequency f_u. This is the major difficulty.

This difficulty is overcome in the following way.

To the system Y is applied a raised-cosine pulse, producing a response $s\,(t)$. Imagine now a system such that the application of I (t) to it results in a pulse of the form $\sigma(t) = \frac{\sin 2\pi f_u t}{2\pi f_u t}$. Let $E(p) = E(2\kappa jf)$ be the transfer function of this system.

Let $\Phi(p)$ and $\Sigma(p)$ be the Laplace transforms of the functions $I(t)$ and $\sigma(t)$. Then

$$\Sigma(p) = E(p) \cdot \Phi(p) \tag{7}$$

Also

$$\varphi(p) = Y(p) \cdot \Phi(p) \tag{8}$$

[$\Phi(p)$ being the transform of $I(t)$]

Now applying $s(t)$ to the hypothetical system, the response will be $s_1(t)$ such that: [$\varphi_1(p)$ being the transform of $s_1(t)$]

$$\varphi_1(p) = E(p)\,\varphi(p) = \frac{\Sigma(p)}{\Phi(p)}\,Y(p)\,\Phi(p) = \Sigma(p)\,Y(p) \tag{9}$$

In other words, $s_1(t)$ is the response of the system under test to a pulse $\sigma(t)$, and $s_1(t)$ is obtained from $s(t)$ by passing $s(t)$ through a hypothetical system defined by the transfer function

$$E(p) = \frac{\Sigma(p)}{\Phi(p)} \tag{10}$$

Hence the method: a raised-cosine signal is applied to the system under test, which is characterized by the transfer function $Y(p)$, and the response $s(t)$ is observed, the ordinates of $s(t)$ at intervals of $\frac{1}{2f_u}$ then being corrected by means of the factor (10).

It is by making this correction that it is possible to halve the number of ordinates.

Conclusion. — The two methods use the same principle, that of applying a raised-cosine pulse to the system and analysing the response curve into equidistant ordinates. The final result is the transfer function in the form of a series given by the formula (3). The t_k s are in arithmetic progression, with a common difference of $\frac{1}{4f_u}$ in the French method, $\frac{1}{2f_u}$ in the British method.

The determination of the value $\frac{1}{4f_u}$ of the difference τ, in the French method, is not final and this question of the optimum value of τ remains for study. The methods used by each Administration for the determination of equalizing networks should remain independent. However, it is essential to agree on the manner of defining $Y(2\pi jf)$ and the corresponding distortion. It is in effect necessary that the same values of t_k shall be used in their calculations.

Take, for example, the specification of equalizing networks. It is required to determine the coefficients B_k sich that:

$$\Sigma A_k \exp(-j\omega\tau_k) \cdot \Sigma B_k \exp(-j\omega\theta_k) = 1 \tag{11}$$

The θ_k do not need to be equal to the τ_k, but the formula (11) in spite of its appearance, is not symmetrical from the technical point of view between the τ_k and the θ_k. In effect, the calculation of the inverse of $\Sigma A_k \cdot e(-j\omega\tau_k)$ could be made if the θ_k were further apart than the τ_k, but not if they were closer together. It is thus necessary to take the τ_k s as close together as possible without excessively complicating the calculations. Such is the present state of this question.

As the design of waveform-correctors (" time-equalizers ") is closely connected with the present subject, references to these devices have been included in the following bibliography although arrangements intended primarily for cancelling individual echoes have been excluded. The first disclosure of an invention meriting the title of " time-equalizer " is believed to be that of Blumlein, Kallman and Percival (2).

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ANNEX 27

DESCRIPTION OF A VOLUME REGULATOR USED ON RADIO-TELEPHONY CIRCUITS BY THE BRITISH ADMINISTRATION

The British Administration is making tests with an automatic volume regulator satisfying the following conditions:

(1) the output level remains constant to about ± 1.5 db (or ± 0.17 N) while the input level varies over a range of 36 db.

(2) control is effected within a maximum operating time of 50 milliseconds.

(3) After the initial control has been established, its value is maintained unaltered, unless the input level undergoes a change which persists for about 1 second.

(4) When speech ceases, the automatic volume regulator is blocked at the control value during the previous period of 10 seconds, and this condition persists while the speech currents transverse the return channel.

(5) It is possible to control the speech volume of the local operators, either when an operator uses the circuit as an order wire or when an operator speaks in parallel with a subscriber.

ANNEX 28

METHODS USED IN SWITZERLAND FOR AVOIDING INCORRECT OPERATION OF SINGING SUPPRESSORS

The means used in Switzerland for preventing a singing suppressor from operating under the influence of circuit or apparatus noise, or of telegraph interference, are as follows:

In the Type C2 Terminal, an automatic volume regulator is used, incorporating a singing suppressor for the two directions of transmission which, once put into operation, requires little manual adjustment under normal propagation conditions.

This equipment is described in the *Bell System Technical Journal*, October 1940, p. 611 under the title " Radio-link Extensions to the Telephone System ".

At the receiving end, a " noise reducer " is inserted, which is described in the *Bell System Technical Journal* of October, 1937, p. 475 under the title " Radio Telephone Noise Reduction by Voice Control at the Receiver ". This equipment reduces noise caused by radio static or by the received signal strength being too low, without reducing the speech level.

If the interfering signals increase to a point where they are 10 decibels below the wanted signals, the radiotelephone link will become unusable. Such values have been experienced in practice and are valid whether the suppressor is connected at the receiving or transmitting end.

To avoid incorrect operation of a singing suppressor, the received signal may be attenuated; the sensitivity being controlled by means of a potentiometer.

If radiotelephony interference is experienced efficient adjustment of the suppressor is impossible and it must be made inoperative.

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PART TWO

LINE MEASUREMENT TECHNIQUE

SECTION 1

STEADY-STATE A.C. MEASUREMENTS

1.1. Measurement of effective insertion loss and of insertion loss; tests of line transformers.

1.1.1. Measurement of effective insertion loss or effective insertion gain of a quadripole

Given a quadripole Q placed between a generator, of E.M.F.E. and of impedance Z_E, and a receiver, of impedance Z_R (see fig. 1), if U_2 represents the voltage

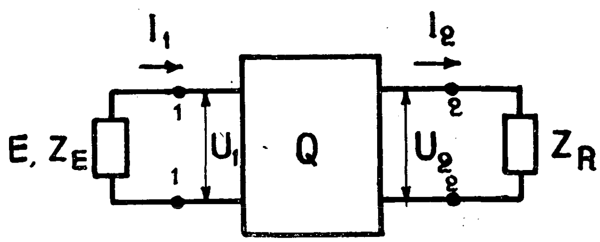


FIGURE 1. — *Definitions of Insertion Loss or Gain*

accross the terminals of the receiver and I_2 represents the current which it produces then it follows from the definition * of " effective insertion loss " (or gain). As that:

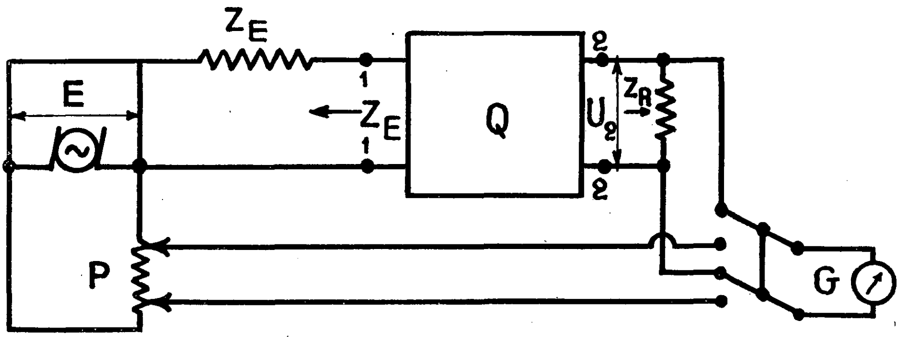
$$\begin{cases} e^{A_S} = \left| \dfrac{E}{2\,U_2} \sqrt{\dfrac{Z_R}{Z_E}} \right| \\ e^{A_S} = \left| \dfrac{E}{2\,I_2} \dfrac{1}{\sqrt{Z_E\,Z_R}} \right| \end{cases}$$

* *Draft vocabulary of definitions of terms used in telephony*, term C 21.

Translation note: The literal translation " composite attenuation " given in C 21, is quite meaningless in English. The quantity defined above is sometimes given the name of " effective insertion loss " and this expression has been used throughout the present document.

(a) *First method of measurement*

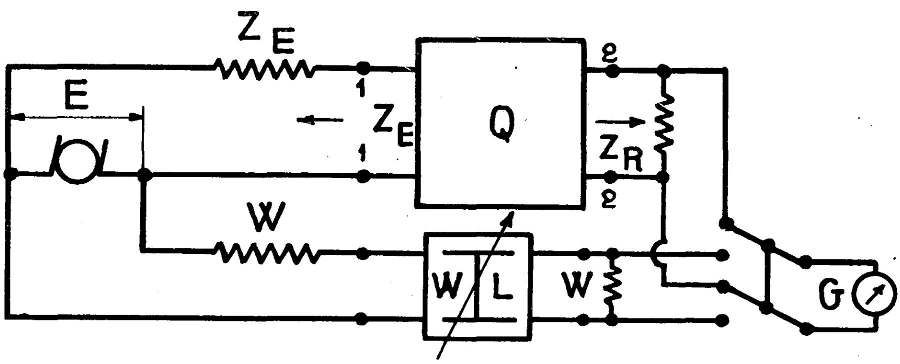
The first method of measurement of effective insertion loss follows directly from the formulae and consists in measuring the voltages E and U_2. To do this, the generator applies a voltage E to the quadripole and to a potentiometer P (or alternatively to an attenuator inserted between two resistors each equal to the characteristic impedance of the attenuator so that its effective insertion loss and the image-attenuation are identical). A measuring-instrument, G, such as a valve-voltmeter of impedance very high by comparison



Q = quadripole P = potentiometer

FIGURE 2 a. — *Measurement of loss: use of a potentiometer*

with the impedance *Zx* and *Zx* is used and the ratio $\left|\frac{U_2}{E}\right|$ is read on the potentiometer. The schematics shown in figures 2 a or 2 b are obtained.



Q = quadripole L = attenuator

FIGURE 2 b. — *Measurement of loss: use of an attenuator*

When the arrangement shown in figure 2 b is used, the attenuator setting giving equal voltages across the terminations Z_R and W gives the value of $\ln \left|\frac{E}{2\,U_2}\right|$ when the terminating impedance Z_E and Z_R differ, the term $\ln \sqrt{\left|\frac{Z_R}{Z_E}\right|}$ in the above formula for A_S must be calculated.

For measuring effective insertion gain, the same method may be used, but the comparison between E and U_2 is made, for example by taking a known fraction of U_2 from the terminating impedance Z_R. A simple arrangement is to use this impedance as a comparison protentiometer.

(b) *Second method of measurement: Z-R method*

Another method of measuring effective insertion loss (known as " the Z-R method ") uses the arrangement shown in figure.

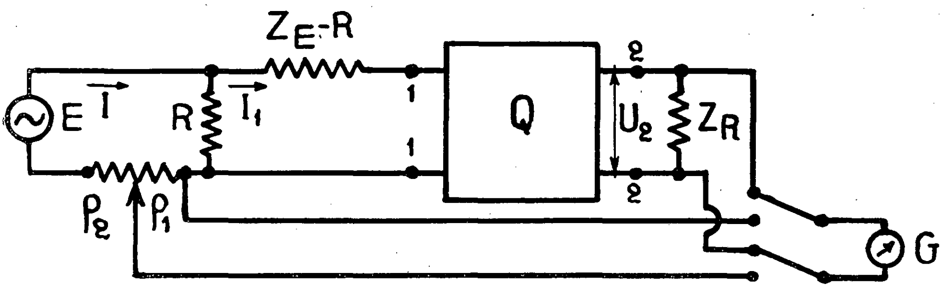


FIGURE 3. — *Measurement of loss by the* Z — R *method*

A portion, R, of the terminating impedance Z_E is connected across the circuit before the quadripole. By definition, either the rotation of figure 3, the effective insertion loss A*s* of the quadripole, expressed in nepers, is

$$e^{As} = \left| \frac{IR}{2\,U_2}\sqrt{\frac{Z_R}{Z_E}} \right|$$

In the section carrying the current I (before the parallel R), a potentiometer $\rho_1\ \rho_2$ is inserted and adjusted so that the voltage ρ_1 I is equal to U_2 in magnitude.
Then

$$e^{As} = \left| \frac{IR}{2\rho_1 I}\sqrt{\frac{Z_R}{Z_E}} \right| = \frac{R}{2\rho_1}\sqrt{\left|\frac{Z_R}{Z_E}\right|}$$

from which the effective insertion loss may be found.

(c) *Variation of the first method: use of the automatic level recorder*

An automatic recorder may be used to measure effective insertion loss or gain by means of the first method described above.

The apparatus, shown principle schematically in figure 4 following comprises:

(i) a sending unit consisting of a beat-frequency oscillator where frequency may be varied uniformly and whose output may be connected to the terminals of the quadripole under test;

(ii) A receiving unit connected to the output terminals of the quadripole and consisting of a level-measuring set (see later text concerning measurement on telephone circuits) associated with a recording instrument.

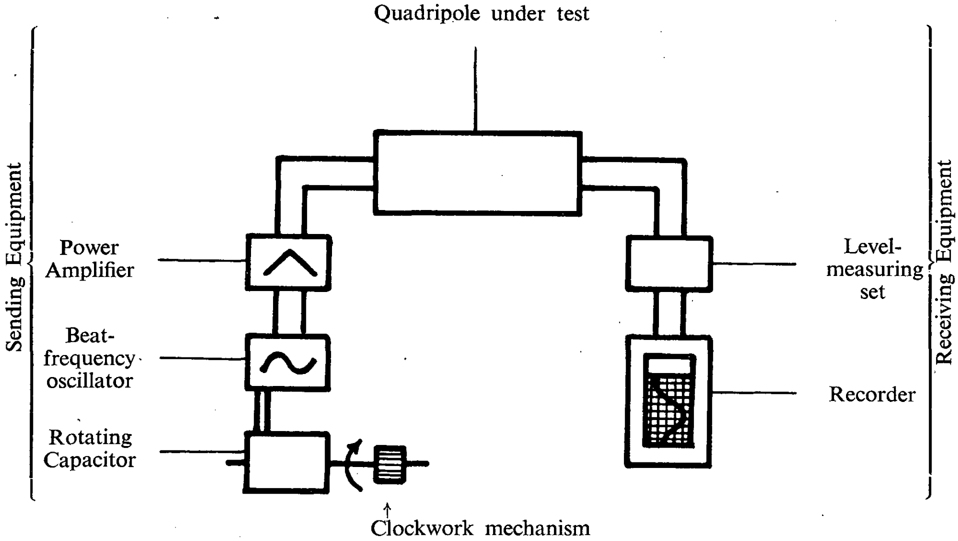


FIGURE 4. — *Schematic of the automatic level recorder*

In one form of automatic level recorder a starting signal is given by the sending unit shortly before the series of test frequencies is transmitted, this signal sets in action the receiving unit so that the recording scale correspond in time with the series of test frequencies; a frequency scale is printed in advance on the recording paper and a trace of the curve showing the variation of magnitude with frequency is obtained. (The essential characteristics of this apparatus, particularly as regards the start signal and the variation with time of the series of test frequencies are given in section 1.2.3 following.)

In an alternative form of automatic level recorder, a start signal is not used and the frequency scale is not printed in advance on the recording paper. A tuned circuit in the receiving unit operates an electro-magnet which marks on the recording paper the precise instant at which the particular frequency, to which it is tuned, is transmitted. Knowing the variation with time of the series of test frequencies, the recording paper may be marked with a rubber stamp after cutting.

The automatic level recorder described above may, for measurement of effective insertion loss or gain, give directly the ratio $\left|\frac{E}{2\,U_2}\right|$. Alternatively, the logarithms of the impedances Zx and Zx may be measured directly as indicated later and the effective insertion loss or gain calculated from the formula

$$A_S = \ln\left|\frac{E}{2\,U_2}\right| + \frac{1}{2}\ln\left|Z_R\right| - \frac{1}{2}\ln\left|Z_E\right|$$

To measure an impedance Z with the aid of the automatic level recorder, that impedance may be connected to the generator in series with a high resistance R so that the current is practically independent of the value of the impedance under test (fig. 5 a). Then the p. d. across the impedance Z under test is proportional to the modulus of that impedance and may be recorded directly by the automatic level recorder.

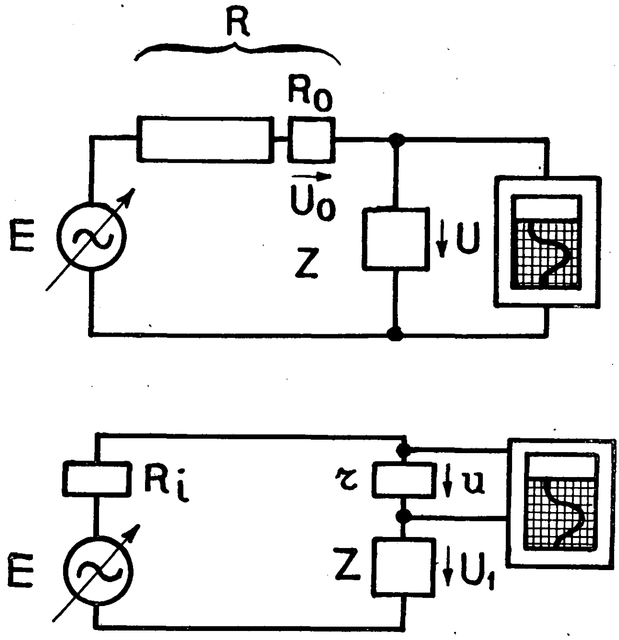


FIGURE 5 b

Measurement of Impedance with the Automatic Level Recorder.

An alternative procedure is to connect the impedance Z under test to a generator of low internal impedance and to deduce its value from that of the current which is proportional to the p. d. across the low resistance *r* of constant value connected in series with the impedance Z under test (fig. 5 b). However, since the automatic level recorder is essentially a current—and not a voltage-measuring device, the former method is preferred. It is not, however, essential for the series resistance R (fig. 5 a) to be very large because the measured value can readily be corrected. It is sufficient for the purpose to measure the p. d. U_o in a part R_o of the resistance R. Then, in figure 5 a,

$$U = E \frac{Z}{|R + Z|} \; ; \; U_o = E \frac{R_o}{|R + Z|}$$

whence

$$Z = R_o \frac{U}{U_o}$$

As the voltage U_o is practically constant, the impedance Z under test is effectively proportional to U.

To make impedance measurements as accurately as possible and without correction, a generator giving a high output, and a highly sensitive receiver should be used.

When measuring effective insertion loss or gain, natural logarithms of the moduli of impedances Z_E and Z_R are needed, however these values may be read directly from the neper scale of the automatic level recorder.

Measurement of effective insertion loss or gain may be further simplified for quadripoles for which the determinant is equal to unity. This is the case for all passive quadripoles (symmetrical or asymetrical) and all active quadripoles which have the same transfer co-efficient for the two directions of transmission.

To determine the effective insertion loss or gain in such cases, two measurements are made, with the automatic level recorder as in the preceding examples, of the logarithmic voltage ratio $2 \,.\, \ln \left| \frac{E}{2\, U_2} \right|$, first as shown in figure 6 and secondly in the other direction of transmission, the e.m.f. which acted in the direction Z_E to Z_R being removed and an e.m.f. of the same value applied in the direction Z_R to Z_E.

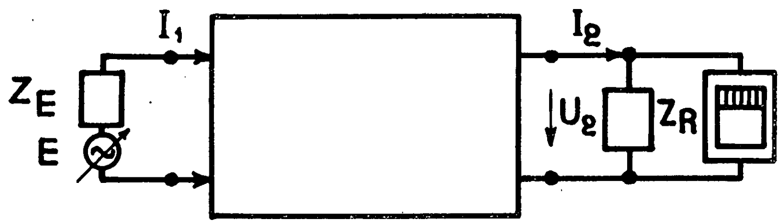


FIGURE 6. — *Measurement of Effective Insertion Loss or Gain with the Automatic Level Recorder*

The effective insertion loss or gain is the arithmetic mean of the two logarithmic voltage ratios (as an be shown by applying the reciprocity theorem).

1.1.2. Measurement of insertion loss or gain of any quadripole

To measure the insertion loss or gain of a quadripole between a sending system Z_E and a receiving system Z_R, an amplifier-detector is connected across the receiving termination Z_R and used to measure the p. d. across the termination before and after the insertion of the quadripole under test. The desired value of insertion loss or gain in nepers or decibels may be deduced from the ratio of these two voltages.

Alternatively insertion loss may be measured by comparison between the quadripole under test and a variable attenuator calibrated in nepers or decibels; insertion gain may similarly be determined from a comparison between, first, direct connexion of the sending and receiving systems and secondly, their connexion via a variable attenuator and the amplifier whose gain is to be determined.

1.1.3. Tests of line Transformers

(a) *Measurement of Effective Insertion Loss at Voice Frequency.* — If Z_1 and Z_2 are the nominal impedances of the primary and secondary circuits of the transformer (see fig. 7) the effective insertion loss, in nepers is equal to:

$$\ln \frac{V_1}{2\,V_2} - \frac{1}{2} \ln \frac{Z_1}{Z_2} \,.$$

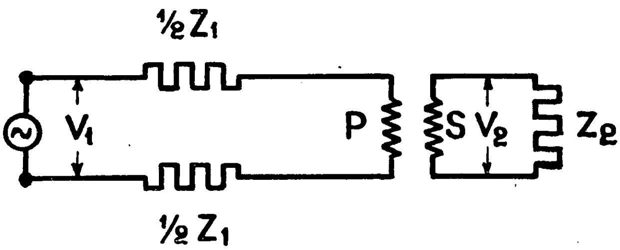


FIGURE 7

V_1 is the p.d. measured at the terminals of the generator; V_2 is the p.d. measured across the secondary winding when it is closed with the impedance Z_2; the impedance Z_1 is adjusted to the standard value for international circuits; the impedance Z_1 is equal to $Z_2\,u^2$, u being the turns ratio of the primary and secondary windings.

(b) *Measurement of power efficiency to low-frequency signalling currents (16 to 25 c/s)—First method.* — Method based on the use of a wattmeter (fig. 8 or fig. 9).

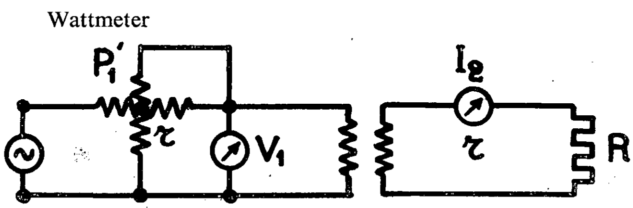


FIGURE 8

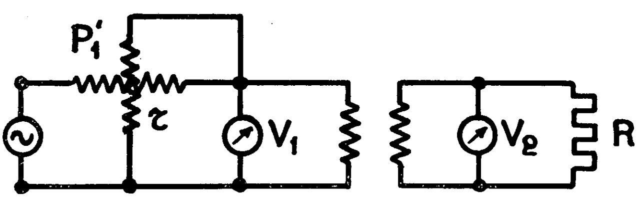


FIGURE 9

The power efficiency is equal to the ratio $\frac{P_2}{P_1}$, P_1 being the real power measured at the input to the transformer; P_2 the P_1 real power measured at the output of the transformer.

$$P_1 = P'_1 \text{ (power supplied) } - \frac{V_1{}^2}{r} \text{ (power absorbed by the wattmeter)}$$

$$P_2 = I_2{}^2\,(R + r) \text{ or } \frac{V_2{}^2}{R} \,.$$

In the diagrams, V_1 and V_2 are electrostatic voltmeters. In the formulae, V_1, V_2 and I_2 represent r.m.s. values and R represents the effective resistance.

Second method. — Method based on the use of a variable attenuator (fig. 10).

The power efficiency of a line transformer is defined by the ratio between the real power obtained at the output and the real power applied at the input to the line transformer.

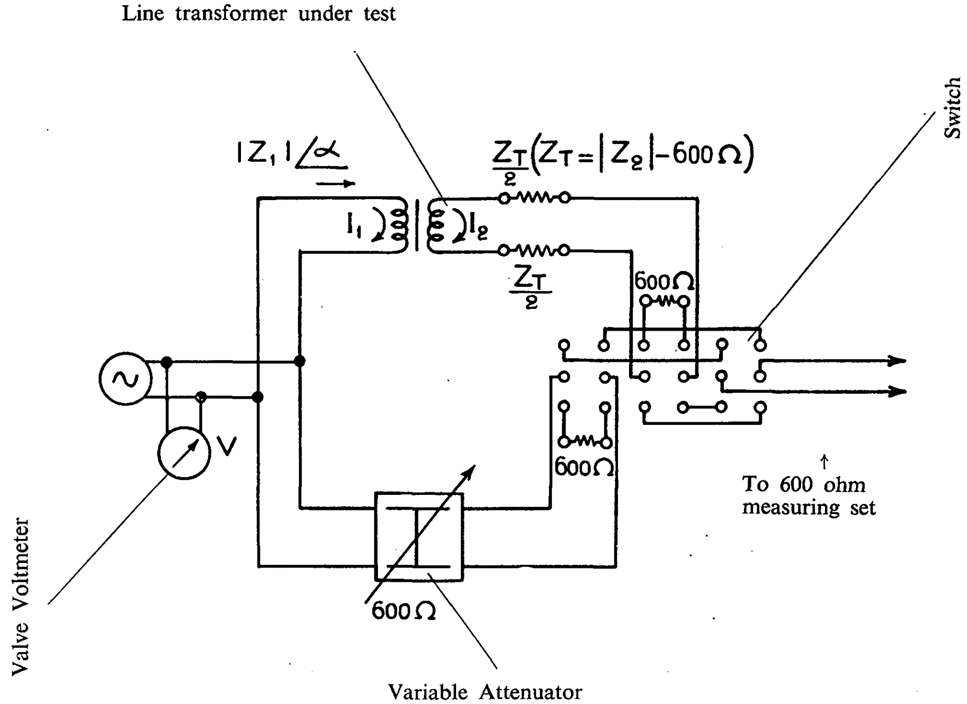


FIGURE 10

If $| Z_1 |$ is the modulus and α is the argument of the input impedance Z_1 of the transformer corresponding to an output impedance of Z_2 having modulus $| Z_2 |$ and argument β, the power efficiency, defined as above, is

$$\eta = \frac{I_2^2 \, | Z_2 | \cos \beta}{I_1^2 \, | Z_1 | \cos \alpha},$$

where I_1 and I_2 are, respectively the r.m.s. values of the input and output currents, (see fig. 10).

The modulus (Z_1) and argument may easily be measured at low frequencies by means of a Maxwell Bridge, the detector being a vibration galvanometer. The galvanometer should be tuned to the measuring frequency. Harmonics in the current source will enlarge the galvanometer spot on the screen, but sufficient accuracy may be obtained by adjusting for minimum size of the spot.

Similarly the modulus $|Z_2|$ and argument β of the impedance connected at the output of the transformer may be measured, the voltage at the transformer terminals having a value corresponding to those met with in practice.

The factor $\frac{\cos \beta}{\cos \alpha}$ may be calculated.

The factor $\frac{I_2^{\,2} \, |Z_2|}{I_1^{\,2} \, |Z_1|}$ may be obtained from measurements made with the arrangement shown in figure 10.

The output current from the variable attenuator may be adjusted until it is equal to the output current from the line transformer. The voltage at the input terminals of the attenuator is then equal to the voltage at the input terminals of the transformer, this voltage being the same as the voltage at the transformer terminals during the impedance measurements.

If A is the attenuation setting for equality, then:

$$A = 10 \log_{10} \frac{(I_1 \times |Z_1|)^2}{(I_2 \times 600)^2} = 10 \log_{10} \frac{I_1^{\,2} \, |Z_1|}{I_2^{\,2} \, |Z_2|} \cdot \frac{|Z_1| . |Z_2|}{(600)^2}$$

Z_1 and Z_2 being known, $\frac{I_1^2 |Z_1|}{I_2^2 |Z_2|}$ may be calculated and hence the power efficiency obtained.

1.2. Measurement of transmision equivalent and of level over a frequency band

1.2.1. Measurement of transmission equivalent of telephone circuits*

For measuring the transmission equivalent, the two following methods are recommended:

Method 1 (attenuator comparison) (fig. 11)

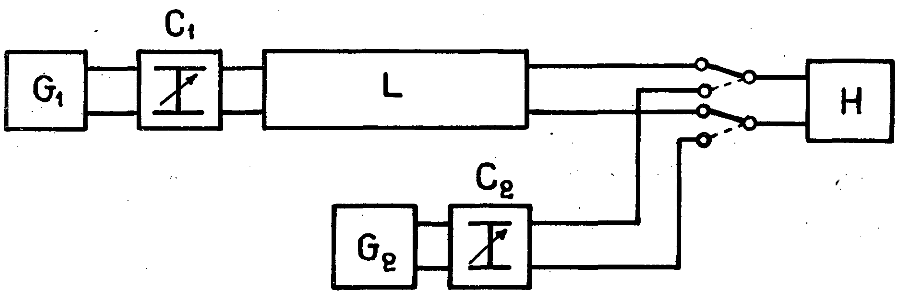


FIGURE 11

G_1, G_2 = standard generators L = line under test

C_1, C_2 = attenuators (600 ohms)

H = level measuring set, input impedance 600 ohms resistive (for specifications of measuring apparatus, see section 1.2.3 later).

* Measurement of transmission equivalent of programme circuits is not mentioned here as the recommendations relating to programme circuits are being modified in Vol. III of the *Green Book* such that voltage levels, absolute or relative, and not transmission equivalents are to be measured.

The standard generator G_2 and the attenuator C_2 are in the sending station; the generator G_1, the attenuator C_1 and the level-measuring set are in the receiving station. The attenuator C_1 is adjusted to an attenuation A_1 so that the telephone circuit is not overloaded (when the relative level at the input to the circuit under test is below zero). The attenuator C_2 is then adjusted to a value A_1 until the reading of the level-measuring set is unaltered by throwing the switch.

The difference of the attenuations A_1 and A_2 is then equal to the transmission equivalent of the telephone circuit.

Note. — This method permits the use of an uncalibrated indicator (having an input impedance of 600 ohms) instead of a level-measuring set.

Method 2 (direct reading) (fig. 12)

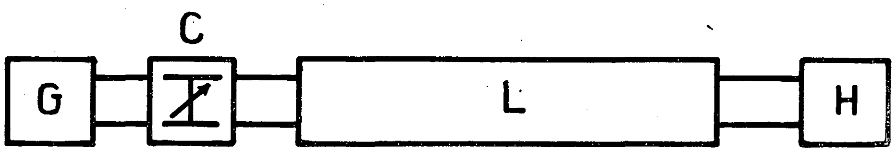


FIGURE 12

G = standard generator
C = attenuator (600 ohms)
H = level-measuring set, input impedance = 600 ohms resistive, calibrated in absolute level (for specifications of measuring apparatus, see section 1.2.3 later).

The attenuator is adjusted to an appropriate attenuation A such that the telephone circuit is not overloaded (when the relative level at the input of the circuit under test is below zero). The level measuring-set indicates the level n_R at the output of the circuit, the transmission equivalent q of the line is:

$$q = -n_R - A$$

$$\begin{aligned} \text{Par exemple: } A &= 0{\cdot}4\ \text{N} \\ n_R &= -1{\cdot}2\ \text{N} \\ q &= 0{\cdot}8\ \text{N} \end{aligned}$$

Note. — If the transmission equivalent is to be measured as an function of frequency, the fixed-frequency generator may be replaced by a generator whose frequency varies automatically and the level-measuring set may be replaced by a hypsograph or by a hypsoscope (specification, see section 1.2.3 later).

1.2.2. **Measurement of absolute or relative levels and of difference in level**

(a) *Measurement of absolute level*

For measurement of absolute voltage level * a level-measuring set such as described in section 1.2.3 may be used.

It is assumed that the line is terminated at the measuring point in conformity with its normal conditions. The level-measuring set, having a high impedance is connected across the measuring point. If the modulus Z of the line impedance at the measuring point is equal to 600 ohms, the absolute voltage level is equal to the

* *Draft vocabulary of definitions of essential terms used in telephony*, Term B 7.

$$\frac{1}{2} \ln \frac{Z}{600\ \Omega} \text{ nepers}$$

$$\text{ou } 10 \log_{10} \frac{Z}{600\ \Omega} \text{ decibels}$$

absolute power level. If not, it is necessary to subtract from the readings of the level-measuring set to obtain the absolute power level.

(b) *Measurement of relative levels*

The absolute voltage level at the point considered on the line is measured in accordance with paragraph *(a)* and from it is subtracted the value of absolute voltage level measured at the origin of the line.

(c) *Measurement of difference of level*

If the sending system at the origin of the line is a standard generator *, the absolute voltage level at an intermediate point on the line (for example, at an amplifier output) or at the end of the line represents the " difference of level at that point. In a similar way, the absolute power level at a particular point is equal to the "difference of power level" at that point**. When voltage levels are being measured on 2-wire circuits the direction of transmission not being measured should be made inoperative.

1.2.3. **Apparatus for measurement of transmission equivalent and of level**

A. Generator for measurements on telephone circuits

(a) *Frequency range and accuracy of frequency*

The generator should be adjustable to any frequency within the range 300 to 3 400 c/s, any chosen frequency being accurate to ± 2% without a frequency meter being required.

It will usually be sufficient if the generator can give a certain number of discrete frequencies; in certain cases the frequency of 800 c/s alone will suffice.

(b) *Internal resistance*

In the frequency range 300-3 400 c/s, the generator should have a pure resistance of 600 ohms ± 2%. This resistance should be balanced about earth. The accuracy of balance should be at least 52 db (6 N).

(c) *E.M.F.*

It should be possible to adjust the generator to give an e.m.f. of at least 2 × 0.775 volts = 1.55 volts (absolute voltage level of + 0.69 nepers (+ 6.0 decibels). Adjusted to this value, the generator is a "standard generator". It will then deliver a.p.d. of 0.775 volts and a power of 1 milliwatt to a pure resistance of 600 ohms (absolute level zero).

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* *Ibid.*, term B 12.

** In the case of telephone circuits, it is generally the " difference of power level " which is shown; in the case of programme circuits, it is the " difference of voltage level ".

The adjustment of the e.m.f. (or the p.d. across a resistance of 600 ohms) may be determined by means of a level-measuring set.

The variation of the e.m.f. with frequency, relative to the value measured at 800 c/s, should not exceed ± 2% (0.02 N or 0.2 db).

The harmonic distortion should be below 2%.

B. Generators for measurements on circuits for programme transmission

(a) *Frequency band and accuracy of frequency*

The generator should be adjustable to any frequency within the band of 50 to 10 000 c/s at least.* It should be possible to adjust the chosen frequency to within about ± 2% without the aid of a frequency meter. (Sometimes the single frequency 800 c/s will suffice.)

(b) *Internal Impedance*

Within the frequency band of 50 to 10 000 c/s, the generator should have as low an internal impedance as possible. The modulus of this impedance should not exceed 30 ohms. The impedance should be balanced about earth.

(c) *E.M.F.*

It should be possible to adjust the e.m.f. of the generator at least to the values 2.2 and 4.4 volts (absolute voltage level of 1.04 and 1.73 nepers = 9 and 15 decibels).** When the generator would deliver 8 milliwatts and 32 milliwatts respectively to a resistance of 600 ohms.

Adjustment of the e.m.f. can be made with the aid of a level-measuring set for programme circuits.

The variation of the e.m.f. as a function of frequency, relative to the value measured at 800 c/s, should not exceed ± 2% (0.02 N or 0.2 db).

The harmonic distortion should not exceed 2%.

Note. — A generator having an internal impedance equal to a pure resistance of 600 ohms is suitable not only for measurement of level but also (with adequate additional apparatus) for measurement of impedance, return-loss, gain and crosstalk.

C. Level-measuring sets for telephone and for programme circuits

(a) *Frequency band*

The level-measuring set for telephone circuits should be suitable for measurements made in the frequency range 300 to 3 400 c/s least; the level-measuring set for programme circuits should be suitable for measurements made in the frequency range 50 to 10 000 c/s at least.***

---

* For very exact measurements, it is desirable to have generators with a wider frequency range.

** At the present time, generators giving different values of voltage are used.

*** For very exact measurements, it is desirable to have level-measuring sets of greater bandwith.

(b) *Input impedance*

The modulus of the input impedance should be high relative to 600 ohms; for example, greater than 20 000 ohms. It is sometimes desirable to alter, by means of a switch, the input impedance to a value of 600 ohms ± 2%.

In the both cases, the input impedance should be balanced about earth. The degree of balance should be at least 6 N (52 db).

(c) *Scale markings*

The level-measuring set should be graduated in values of absolute voltage level (in nepers or in decibels) by steps of not more than 0.05 N or 0.5 db. Calibration should be made with reference to the r.m.s. value of a simusoidal voltage.

(d) *Range and accuracy of measurement*

At a frequency of 800 c/s the accuracy of measurement of levels between + 2 and — 2 N (+ 20 and — 20 db) at least, should be ± 0.02 N (± 0.2 db).

Over the whole frequency band, the accuracy of measurement of levels between + 2 and — 2 N (+ 20 and — 20 db) should be ± 0.04 N (± 0.2 db).

Note. — For very precise measurements, it is desirable to use generators covering a wider frequency range.

D. AUTOMATIC LEVEL RECORDERS (APPARATUS FOR THE AUTOMATIC RECORDING OF THE ABSOLUTE VOLTAGE LEVELS AT DIFFERENT FREQUENCIES)

Automatic level recorders used on European international circuits (commercial telephone circuits and normal programme circuits) should satisfy the following conditions:

(a) *Frequency band*

30-10 000 c/s at least.

(b) *Law of succession of frequencies with time* (see fig. 13)

from 0 to 100 c/s, linear scale,
from 100 to 10 000 c/s, logarithmic scale,

in a continuous manner from low to high frequencies.

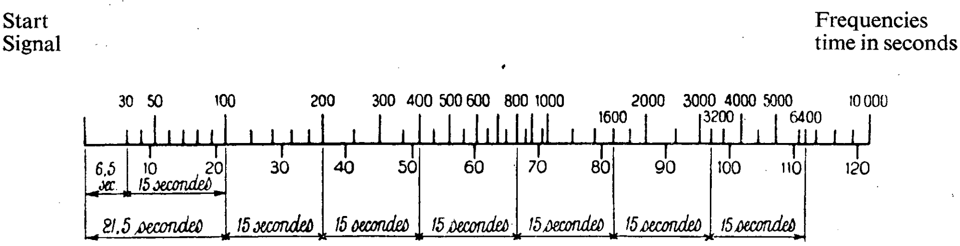


FIGURE 13
Law of succession of frequencies recommended for the automatic level recorder

* For very precise measurements, it is desirable to have automatic level recorders with a wider frequency range.

(c) *Duration of transmission and recording speed*

Duration of transmission of the band from 30 to 100 c/s, 15 seconds;

Duration of transmission of an octave in the band from 100 to 10 000 c/s, — 15 seconds;

Speed of recording paper, 2 mm/sec (7 200 mm/hr) for example, with a tolerance of ± 2%.

Note. — In certain cases it may be convenient to reduce or increase the duration of transmission of an octave or the speed of the recording paper. The following supplementary values are typical:

time of transmission, 7.5 secs/octave and 60 secs/octave
speed of paper, 0.5 mm/sec and 4 mm/sec, in extreme cases 30 mm/hour.

It is convenient to arrange at the sending station for momentary suppressions of the sending voltage during the frequency sweep so as to facilitate identification of the frequencies at the receiving station.

(d) *Start signal*

A signal is sent from the transmitting station 6.5 seconds before the frequency 30 c/s is sent on the line. The characteristics of this signal are:

Frequency 1 300 c/s ± 2%;
Duration between 1 and 2.5 seconds.

The output voltage of this signal should be the same as the output voltage used for the measurements.

When the sensitivity of the receiver is adjusted in such a way that the highest level which may be encountered produces a full-scale deflection on the measuring instrument, the receiver so adjusted should operate immediately under the action of the start signal sent over a line having an attenuation of 2 N.

(e) *Sending circuit*

For measurements on commercial telephone circuits:

the sending circuit should have an impedance with a modulus of 600 ohms and zero argument and an e.m.f. of 1.55 volt.

For measurements on programme circuits:

the sending circuit should have a low internal impedance (modulus less than 30 ohms) and an e.m.f. between 2.2 and 4.4 volts * (1.04 and 1.73 N = 9 and 15 db).

(f) *Range and accuracy of measurement*

The accuracy of measurements made with the automatic level recorder should be at least ± 0.05 N (± 0.5 db) when the recording range for which the apparatus gives the greatest accuracy. In order to achieve this precision it is possible to

* At the present time, sending circuits giving different voltages are used.

provide facilities permitting readings being made, within the measuring range where the accuracy is greatest, of levels between + 2 and — 2 N (+ 20 and — 20 db). Values of levels lying between — 2 and — 3.5 N (— 20 and — 30 db) should be considered as indications only.

The recording range of the receiving apparatus should extend over at least 3 N or 25 db without its being necessary to operate a key.

E. Level-measuring display sets (apparatus for immediate observation of the absolute voltage level at various frequencies)

Level-measuring display sets operate on the same principle as automatic level recorders (see page 101) but are distinguished by the higher speed of transmission of the band of frequencies and of recording. A cathode-ray tube is used for recording. The measured values appear on the screen as a luminous trace.

(a) *Frequency range*

for telephone circuits, 300 to 3 400 c/s at least;
for programme circuits, 50 to 10 000 c/s at least.

(b) *Law of succession of frequencies with time*

Periodic transmission of a continuous succession of frequencies from low to high frequency with a logarithmic time scale, and, if appropriate, to return at the same speed to the low frequencies.

Duration of transmission of the total band of frequencies:

for telephone circuits, about 0.5 seconds;
for programme circuits, about 3 seconds.

(c) *Sending circuit*

For measurements on commercial telephones circuits:

the sending circuit should have an impedance with modulus of 600 ohms and zero argument and an e.m.f. of 1.55 volt.

For measurements on programme circuits:

the sending circuit should have a low internal impedance (modulus less than 30 ohms) and an e.m.f. of 2.2 and 4.4 volts (1.04 and 1.73 N = 9 and 15 db).

(d) *Synchronization of sending and receiving equipments*

The receiving equipment has a frequency discriminator which gives a voltage approximately proportional to the logarithm of the frequency. This voltage with sufficient amplification—is used for the horizontal deflexion of the cathode ray trace.

The luminous screen of the oscilloscope has a transparent graticule with a horizontal frequency scale and a vertical neper or decibel scale.

(e) *Range and accuracy of measurement*

The accuracy of measurements made with the level-measuring display set should be at least ± 0.05 N (or ± 0.5 db), within the range for which the apparatus has greatest accuracy. To achieve this degree of precision, it is possible to provide facilities permitting readings being made, within the range over which the accuracy is greatest, of levels between + 2 and — 2 N (+ 20 and — 20 db) levels between — 2 and — 3.5 N (— 20 and — 30 db) should be regarded as indications only.

The recording range of the receiving equipment should extend over at least 2.3 N or 20 db without its being necessary to operate a key.

1.3. **Measurement of repeater gain**

General

The object of this test is to check the operation of the repeater when the gain adjustment is set to its normal service value. In the case of amplifiers having a high degree of negative feedback, measurement of gain is of interest only to verify that the gain/frequency characteristics have the prescribed form.

The measuring circuit in the equipment is balanced about earth and should permit a result being obtained within about 0.05 N or 0.5 db.

The measuring level is chosen so that, on the one hand the amplifier will be overloaded and on the other hand basic noise will not affect the measured results.

In the case of measurements made on amplifiers in which the gain rises greatly with frequency, it is desirable that the generators used should have harmonic distortion less than 1% so that the generator harmonic shall not affect the measured values.

When two-wire repeaters are being measured, the direction of transmission which is not being tested should be made inoperative. Generally, it is the effective insertion gain (" gain composite ") of the amplifier, between impedance equal to its nominal input and output impedance in service conditions, which should be measured. It is often sufficient to terminate the two sides of the amplifier by pure resistances of values corresponding to the mean nominal impedances.

There are many methods known for the measurement of the gain of repeaters. Two methods only, applicable in all practical cases, will be mentioned below, one method of comparison with an attenuator and one method of direct measurement of input and output levels.

The attenuation of the attenuator C is adjusted to the value A, such that the level-measuring set indication is unaltered when the switch is operated. The effective insertion gain of the amplifier, from the definition (see above page 89), is then equal to

$$\ln \frac{R_1 + R_2}{R_2} - A - \frac{1}{2} \ln \left| \frac{Z_S}{Z_E} \right| \text{ nepers}$$

$$\text{or} \quad 20 \log_{10} \frac{R_1 + R_2}{R_2} - A - 10 \log_{10} \left| \frac{Z_S}{Z_E} \right| \text{ decibels.}$$

The attenuation A of the attenuator can assume positive values only, and resistances R_1 and R_2 must be chosen such that the value

$$\ln \frac{R_1 + R_2}{R_2} - \frac{1}{2} \ln \left| \frac{Z_S}{Z_E} \right|$$

is greater than that of the gain to be measured.

Method 1 (comparison with an attenuator) (fig. 14)

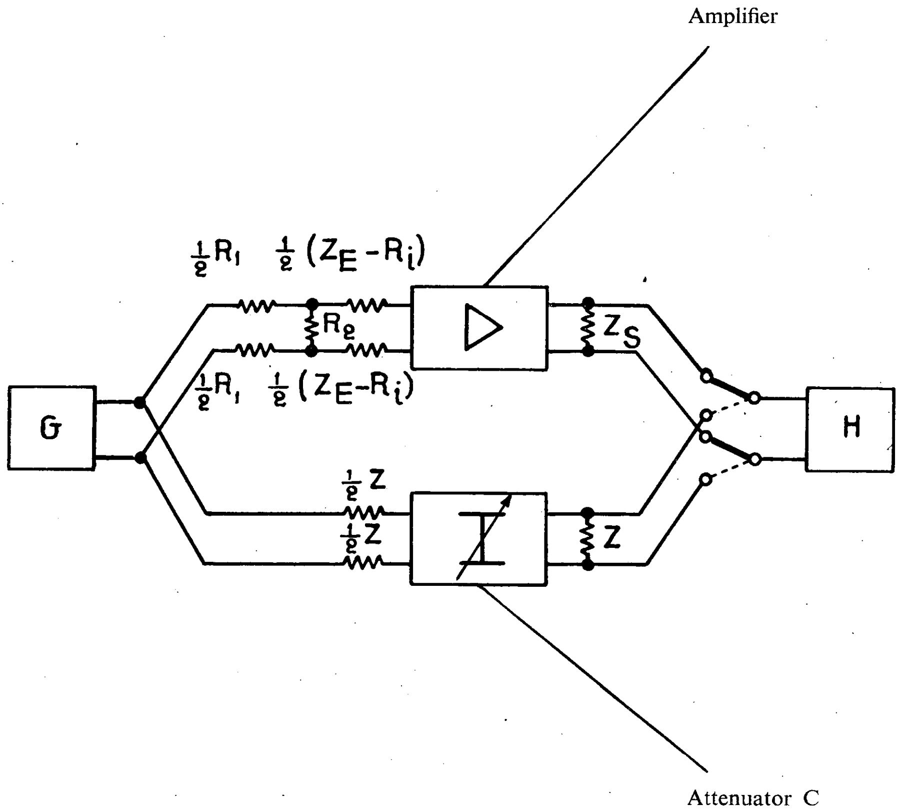


FIGURE 14

G = generator (e.g. standard generator)
H = high-impedance level-measuring set
Z = characteristic impedance of attenuator C
Z_E = terminating impedance at the input under operating conditions
I_S = terminating impedance at the output under operating conditions
R_1, R_2 = special attenuator, the resistance $R_1 = \frac{R_1 \cdot R_2}{R_1 + R_2}$ being fixed at a value sufficiently low with reference to the termination Z_E

Method 2 (direct measurement) (fig. 15)

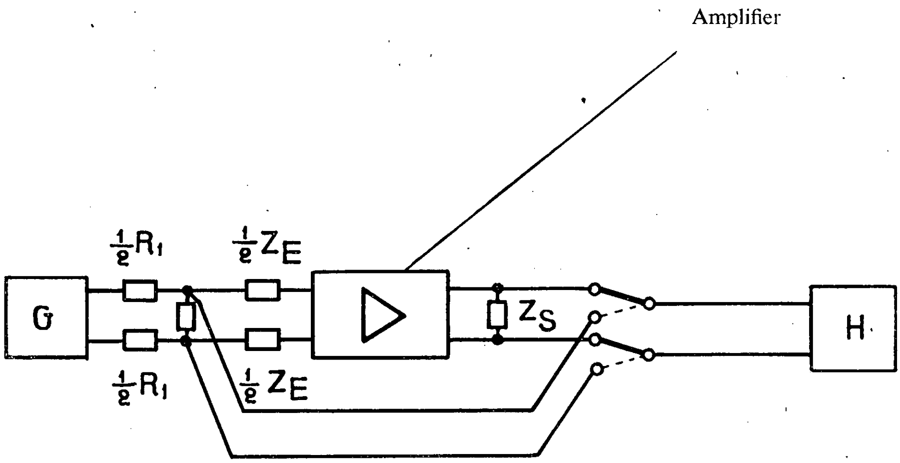


FIGURE 15
(same notation as for fig. 14)

The absolute voltage level n_1 is measured across the resistance R_2 and the absolute voltage level n_2 is measured across the impedance Z_2. The effective insertion gain of the amplifier, is, by definition (see page 89 above) is then equal to:

$$n_2 - n_1 + 0{,}69 - \frac{1}{2} \ln \left| \frac{Z_S}{Z_E} \right| \text{ nepers}$$

$$\text{or } n_2 - n_1 + 6 - 10 \log_{10} \left| \frac{Z_S}{Z_E} \right| \text{ decibels.}$$

1.4. Measurement of impedance and of capacitance or inductance unbalance.

1.4.1. Steady-state impedance measurements

Such measurements are usually made for the purpose of ensuring that the impedance of the various parts which make up a telephone circuit are within prescribed limits to ensure correct functioning of the circuit itself.

In a general way, the circuits used in telephony for measurement of impedance comprise on the one hand " null " networks (Wheatstone Bridge type) which give, after a null balance between two points on the network, the real and imaginary parts of the impedance or (less often) the modulus and argument of the impedance —and on the other hand of " direct-reading " circuits (bridge or ohmmeter types) which general give a reading of the modulus only of the impedance on a suitable apparatus, without the need of zero balancing.

In the choice of measuring apparatus, consideration should be given to various characteristics i.e. those of the generator, of the impedance-measuring device itself (bridge), and, further, for measurement of small values, to the characteristics of the amplifier used for measurement.

As regards the generator, it is necessary to fix the frequency range over which measurements are to be made, as well as the accuracy and stability of frequency, the harmonic content (which should be sufficiently low, particularly when selective measuring apparatus is not available). The maximum power output must also be fixed, the power must be in due proportion to the maximum power which may be applied to the apparatus under test. The generator should also have facilities —either as fixed switch positions or by continuous variation of tuning—to enable the desired frequencies to be obtained as well with as high a degree of precision as may be required for measurements. However, it should be possible to vary the power output of the generator so that the voltage applied to the apparatus under test may be compatible with its characteristics and with its eventual conditions of use. This latter condition is not, in general, satisfied by direct-reading measuring apparatus in which the voltage fed by the generator to the measuring apparatus must have a fixed value and it is not possible to adjust the voltage at the terminals of the equipment under test. In such apparatus, the generator is often incorporated in the measuring set itself.

In the choice of impedance-measuring apparatus (bridge) the frequency range should be decided (as in the case of the generator), the limiting values of impedance which are to be measured (these limits being expressed in real and imaginary parts, or in modulus and argument, or even in modulus alone in the case of direct-reading measuring apparatus), and the desired accuracy of measurement.

In the choice of the measuring amplifier, it is necessary to fix the frequency range (as in the case of the generator) as well as sufficient sensitivity to permit adequate output even with signals of a few microvolts (1 to 5 microvolts).

It is, further, necessary that such the gain of such amplifiers should be adjustable over a very wide range. For measurements at audio frequencies, the amplifier is generally not selective; for higher frequencies a heterodyne, selective, amplifier is generally used.

In direct-reading equipment, the measuring amplifier is not given special consideration because, as a general rule, it forms part, with the instrument on which the impedance modulus is read off, an integal part of the measuring instrument itself, and its characteristics are rigorously controlled by the characteristics of the complete apparatus. In most cases, in such apparatus the measuring circuits are not selective, even for frequencies above audio.

Direct-reading systems give a measuring accuracy much below that which can be obtained by null-balance systems (the error is in general of the order of 5 to 10%) and hence their use is limited to routine maintenance tests and fault location as well as measurements in which great rapidity is more desired than great accuracy.

In consideration of the different types of circuits for which impedances are to be measured, a general classification is given below of the principal characteristics required of apparatus needed in null methods of measurement, although particular tests for example, tests of capacitors, inductors, etc.) of characteristics which may be needed and may be different from those which are shown below; the latter are essentially related to measurements on lines and amplifiers.

A. Tests on audio-frequencies circuits

A — 1. *Generator*

(a) Frequency range: 20 to 20 000 c/s.

This frequency range assumes that measurements of programme circuits may be required.

If telephone circuits only are to be measured, the frequency range may be limited to a minimum of 200 to 4 000 c/s.

(b) Frequency accuracy: ± 2%.

(c) Output power, variable continuously or in sufficiently close steps up to a maximum value of at least 200 mW 600 ohms. Generators of current design for this frequency range have a maximum power appreciably above the power shown above, hence it will preferable to design for higher powers.

(d) Harmonic content: less than 2% for all frequencies above 50 c/s.

A — 2. *Measuring apparatus proper*

(a) Measuring range: the apparatus should enable measurements being made, over the whole frequency band quoted above, of impedances having a modulus between 1 and 10 000 ohms and an argument between — 90⁰ and + 90⁰.

Nevertheless, if a bridge is not intended for general use, the measuring range can be as limited as is expedient, particularly as regards the value of the argument.

(b) Accuracy of measuring apparatus: ± 1%.

(c) Output of apparatus as seen by test object: balanced.

B. Tests on symmetrical-pair carrier systems

B — 1. *Generator*

(a) Frequency range: 200 to 400 000 c/s.

This frequency range assumes a 60-circuit system.

In the case of a lesser number of circuits, the frequency range may conveniently limited.

(b) Accuracy of frequency: ± 2%.

(c) Output power: continuously variable, or by sufficiently small steps, up to a maximum value of at lest 100 mW, in 150 ohms. In this case also higher values of power are desirable.

(d) Harmonic content: less than 5%.

B — 2. *Measuring apparatus proper*

(a) Measuring range. The apparatus should permit measurement, over the above range of frequencies, of impedance having a modulus between 1 and 10 000 ohms and an argument between — 90⁰ and + 90⁰.

In this case also, the measuring range may with advantage be reduced when the apparatus is intended for a particular, well-defined use.

(*b*) Accuracy of the apparatus: ± 2%.

(*c*) Output of the apparatus as seen by the test object: balanced.

C. . . . . . .

C — 1. *Generator*

(*a*) Frequency range: 50 to 10 000 c/s.

This frequency range could conveniently be reduced or increased, depending on the actual needs of the system (telephony or television) used.

(*b*) Frequency accuracy: ± 2%.

(*c*) Output power: variable, continuously, or in sufficiently small steps, up to a maximum value of at least 50 mW in 75 ohms. In this case also, if possible, higher values of output power are desirable.

(*d*) Harmonic content: less than 5%.

C — 2. *Measuring apparatus proper*

(*a*) Measuring range: The apparatus should permit measurements being made, in the above frequency range, of impedances of modulus between 0.1 and 1 000 ohms and of argument between + 90° and — 90°. In this case also, the measuring range may conveniently be reduced, if it appears desirable, in apparatus designed for particular well-defined uses.

(*b*) Accuracy of the apparatus: ± 2%.

(*c*) Output of apparatus as seen by the test object: balanced.

D. Impedance measurements on un-repeatered lines

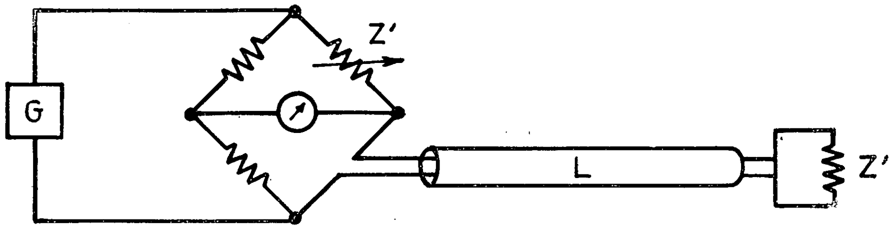
In the case of unrepeatered lines, for example, on factory lengths or on a repeater section of cable, it is normally desired to determine the characteristic impedance and its variation with frequency.

The best-known method is to measure the input impedances Z_1 and Z_2, the other end of the line being respectively open- and short-circuited. The characteristic impedance is given by $Z_C = Z_1 Z_2$. When the characteristic impedance of a coaxial pair is measured at high frequency, complicated work may be avoided by the choice of measuring frequencies which are multiples of quarter-wavelengths of the cable. In that case, Z_1 and Z_2 and Z_C are of practically realizable magnitudes.

This method of measurement has the disadvantage—particularly when short lengths of cable are to be measured—that very low and very high impedances have to be measured with a fair degree of accuracy. In the absence of specially suitable measuring apparatus, the following method may be used:

The characteristic impedance of the line (at a known frequency) is equal to the input impedance if the other end of the line is closed with the characteristic impedance in question.

This impedance being unknown, the far-end of the cable is closed with an impedance Z′ which is assumed to be the value of the characteristic impedance.



L — line under test

FIGURE 16

The variable arm of the bridge is made equal to the value Z′ (see fig. 16). Then the two impedances Z′ are varied—maintaining their equality—until the bridge is in balance (the adjustment may be made, for example, through a mechanical coupling if the cable is being measured on the drum). The characteristic impedance is then equal to the impedance Z′.

The attenuation of a long cable (for example, of a repeater section) may be sufficiently high for the closing impedance at the far-end of the cable to have no effect; it is then sufficient to terminate the cable with its nominal characteristic impedance.

Another method for measuring the impedance of a coaxial pair is indicated in Appendix 37 later. See also: " G. FUCHS, *nouvelle méthode de mesure des écarts d'impédance des paires concentriques, Revue Générale d'Electricité*, tome 55, March, 1956, pages 109 to 117 ".

1.4.2. **Impedance measurements in the time domain**

On coaxial-pair cables, impedance measures are generally made in the time domain by means of pulse-testers, the construction of which is appreciably more complicated than that of apparatus normally used for steady-state impedance measurements. The technique of pulse-testing has been developed with the aim of controlling the impedance regularity along a section, long or short, of coaxial pairs.

The tests are made by means of a series of pulses of convenient duration on the pair under test; each pulse is partially reflected by the various irregularities which it meets along the coaxial pair and it is possible displaying in a convenient way on an oscilloscope the trace of these reflexions to observe and locate early irregularity and to evaluate also the corresponding reflection coefficient.

This apparatus, furthermore, nearly always permits evaluation of the input impedance of the coaxial pair by means of a comparison method. The value of the impedance measured in this way may be considered to correspond to the impedance at a particular frequency fixed for each type of pulse-tester.

The accuracy of measurement which may be obtained by this method is generally very high (of the order of 1 %). However, it must be noted that this accuracy of measurement is with reference to the quadripole or cable used for comparison. Furthermore, apparatus of this type usually indicates only the modulus of the impedance with no indication of its argument.

The fundamental characteristics of pulse-echo testers are the duration, the pulse-repetition frequency, the shape and the peak value of the transmitted pulse. Generally, for pulse-echo testers of the above-mentioned type, the pulse-width is between 0.05 and 0.25 microseconds.

In addition to the above pulse-echo testers, which are principally designed for the control of impedance regularity of coaxial pairs, special pulse-echo testers are made for fault-location. These latter testers are not suitable for indicating small impedance irregularities but only major faults due to accidental causes after cables have been brought into use. However, they are suitable for examining very long cable sections as they use pulses, which are much longer than those described above. Pulse-echo testers which are used on symmetrical pairs and on open-wire lines and coaxial pairs do not, in general, provide for measurement of input impedance. By way of information, see also the following articles:

FUCHS, G.: Réflexions dues aux irrégularités d'impédance dans un câble coaxial, *Câbles et Transmission*, 1953, No. 2, pp. 122-141.

KRÜGEL, L.: Über eine Methode zur quantitativen Bestimmung von Inhomogenitäten in Breitbandkabeln mit Hilfe von Impulsen, *Fernmeldetechnische Zeitschrift*, January 1954, No. 1, pp. 3-9.

KADEN, H.: Über das Verhalten von Kabeln mit Wellenwiderstandsschwankungen bei Fernseh- und Messimpulsen, *Archiv für Elektrische Übertragung* (A.E.U.), Vol. 7, 1953, pp. 191-198.

Note. — For more details, see section 2 later, which is entirely devoted to measurements in the time domain, and the corresponding appendices.

1.4.3. **Measurement of capacitance unbalances**

For definitions of capacitance unbalance, see Vol. III of the *Green Book*, pages 129 to 132.

Capacitance unbalances are measured:

— in the factory for the production control of the factory lengths,

— during the installation and balancing of cables, on factory lengths or on balancing sections, in all cases on lengths which are short by comparison with the wavelength of the highest transmitted frequency.

The measuring apparatus is a bridge in which a differential capacitor calibrated in picofarads (pF) gives directly the value and the sign of the unbalance.

The apparatus should include necessary switches so that, the quad under test having been connected, it is possible to measure successively the six within-quad unbalances.

The centre-point of the ratio arms should be accessible on the panel of the apparatus so that it is possible, when measuring external unbalances, to place the other conductors of the cable at the same potential as the conductors under test.

This facility is obtained on older type apparatus in which the ratio arms are composed of resistors, connecting the cable conductors to the centre-point of the ratio arms by way of a variable resistor, suitably adjusted for each case.

In modern apparatus, the ratio arms are composed of a low-resistance coil with a centre-tap to which the cable conductors, being connected, are brought essentially to the same potential as the conductors under test.

It is recommended that the apparatus be provided with a variable differential conductance, for compensation of the unavoidable conductance unbalances and so make the measurement of capacitance unbalance more exact.

It is not generally necessary that this variable conductance should be calibrated, nevertheless this would be useful in some cases.

The differential capacitor should cover a range up to about + 200 pF. The scale should be large enough for graduations of 5 pF to be easily legible. It should be possible to extend the measuring range up to about ± 1 000 or 1 500 pF at least, by means of additional calibrated capacitors which may be brought into circuit by switches.

It is sometimes useful to measure with precision very small unbalances; it is recommended that this possibility be foreseen by reducing, with the aid of a switch, the maximum value of the capacitor to 1/5 or 1/10 of the value quoted above. Capacitance unbalances do not, in practice, vary with frequency hence they may be measured at audio frequency even for cables intended for use at carrier frequencies.

It is always convenient if the apparatus can also be used for measurements at frequencies above the cut-off frequencies of loaded circuits as it may sometimes be useful to control the capacitance unbalance in loading sections of cables already laid without its being necessary to cut the circuits at loading points.

With the exception of this particular case, an oscillator of about 1 000 c/s may be used as a generator, it is necessary that the oscillator should meet particular requirements for harmonic distortion.

1.4.4. **Measurement of inductance unbalances**

Inductance unbalances are ordinarily measured in the factory, so as to control the production of cable lengths, and, in particular, such tests are made on symmetrical pair cables which are to be used with carrier systems.

Such measurements are made also during cable installation; but, in general, in such cases it is recommended to measure and to balance the admittance unbalance resulting from the combined effects of inductance and capacitance unbalances.

For measurements of inductance unbalances, apparatus based on the following principles may be used.

A current is made to flow in the disturbing circuit, which has its far-end short-circuited, and induces an e.m.f. in the disturbing circuit which also has its far-end short-circuited. A fraction of this current, after having traversed circuits composed of calibrated variable elements produces another e.m.f. in the disturbed circuit.

The variable elements are adjusted to reduce to zero the net e.m.f. in the disturbed circuit; the real and imaginary components of the inductance unbalance may be deduced from the readings of the variable elements.

It is convenient if the maximum range of the measuring apparatus is of the order of 1 000 nanohenrys (nH); subdivided, for example, to ranges of 0 to 0, 0 to 10, 0 to 100 and 0 to 1 000 nH. In general, inductance unbalances vary with frequency in modulus and in phase, and particularly over the frequency band from zero to hundreds or thousands of cycles per second. It is therefore recommended that such measurements should be made at several frequencies within the frequency band to be transmitted or a least that the measurements should be made at a single frequency which is sufficiently high that it may be assumed that there will be no appreciable variations in the frequency band considered.

As the unbalances vary with frequency, it is recommended that the oscillator should have low harmonic distortion, nevertheless this characteristic is not essential if the receiver is selective.

1.5. Measurements of balance return loss, regularity return loss, return loss and active balance return loss.

1.5.1. Measurement of balance return loss

This measurement is made by means of a return-loss measuring set:

The return-loss measuring set, shown schematically in the figure, consists of a hybrid transformer T to which is connected a generator Z, the line Z whose balance return loss is to be determined, and the balance network W for the line.

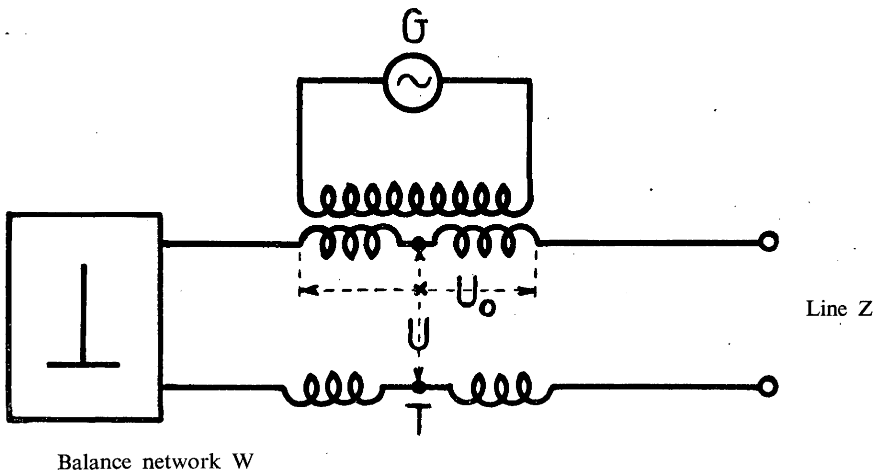


FIGURE 17. — *Return-Loss Measuring set*

By definition * if Z is the input impedance of the circuit at frequency *f* produced by the generator G and if W is the impedance of the balancing network at this frequency, then the balance return loss expressed in decibels is:

* *Draft list of definitions of essential terms used in telephony*, term C 31.

$$A = 20 \log_{10} \left| \frac{W + Z}{W - Z} \right|$$

that is to say twenty times the logarithm (to base 10) of the modulus of the ratio of the sum W + Z to the difference W — Z, or, expressed in nepers:

$$A = \ln \left| \frac{W + Z}{W - Z} \right|$$

If, on the other hand, U_o and U are the voltages measured at the terminals of the transformer T as shown in figure 17, then:

$$U = \frac{W}{W + Z} \times 2\, U_o - 2 \times \frac{U_o}{2}$$

whence:

$$\frac{W + Z}{W - Z} = \frac{U_o}{U}$$

and

$$A = \ln \left| \frac{W + Z}{W - Z} \right| = \ln \left| \frac{U_o}{U} \right| \text{ nepers}$$

or

$$A = 20 \log_{10} \left| \frac{W + Z}{W - Z} \right| = 20 \log_{10} \left| \frac{U_o}{U} \right| \text{ decibels}$$

First method

To measure the p.d. U an amplifier-detector is used, having an input impedance sufficiently high to avoid appreciable error due to its taking current. The indicating meter at the output of the amplifier-detector is graduated in decibels instead of in volts and gives the value of the signal at its input terminals relative to U_0. Instead of measuring the voltage U_0 the apparatus is calibrated by substituting for the line and its balance two resistors whose ratio corresponds to a calibration mark on the decibel scale of the meter and the apparatus is adjusted so that the needle is set to this mark. This done, the two resistors are replaced by the line and the balance and the balance return loss is then read directly in decibels from the control setting and the meter reading. If the " line " or " balance " terminals are open- or short-circuited, U should be equal to $2 \frac{U_o}{2}$ and the apparatus should indicate " zero decibels ".

Second method

To measure the voltages V_0 and U a level-measuring set calibrated in absolute voltages level and having a very high input impedance may be used. The balance return loss is given by the difference

$$A = n_o - n \quad ,$$

n_0 and n being the absolute voltage levels of the voltages U_0 and U.

If the voltage U_0 is equal to 0.775 volts the level-measuring set indicates directly the balance return loss.

$$A = -n \, .$$

Instead of the generator G and the level-measuring set, an automatic level recorder or a level-measuring display set may be used. The display set shows directly the effect of a variation of the value of the balance as a function of frequency. The automatic level recorder gives a documentary record of the curve of balance return loss. The hybrid transformer may be replaced by a pure resistance bridge (see fig. 18).

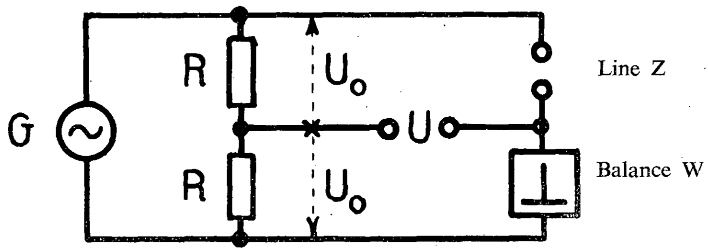


FIGURE 18

The formulas given above for balance return loss are applicable in this case also. The resistors R should be closely matched together and their value should not be too high (for example, R about equal to Z).

GENERAL NOTES

1. By the methods described above, the balance return loss of a circuit may be measured at a given frequency *f* with the aid of the return loss measuring set. Repeating this test for various frequencies within a given band will give the graph of the " balance return loss/frequency " characteristic of the telephone circuit considered.

2. When it is necessary merely to ensure that the balance return loss of a circuit remains above a certain lower limit over a given frequency range, the oscillator frequency may be rapidly varied over this band whilst maintaining the chosen voltage U_0 and verifying that the meter needle remains above the minimum required value.

RANGE AND MEASURING ACCURACY

The return loss measuring set and its accessories should permit the measurement of balance return loss of at least 4 N or 35 db. The accuracy of measurement should be at least

± 0·1 N or 1 db up to 2 N or 18 db
± 0·2 N or 2 db up to 4 N or 35 db.

The measuring accuracy may be determined by replacing the line and the balance by impedances of accurately known values. The return loss measuring set should, for example, indicate a balance return loss of 3 N between pure resistances of 600·0 and 663.2 ohms.

1.5.2. **Measurement of Regularity Return Loss**

The methods indicated above for measurement of balance return loss of a circuit may be applied to the measurement of the regularity of a circuit on condition:

(1) That the circuit is terminated in its nominal image-impedance calculated from the mean values of its primary coefficients (resistance, inductance, leakance and capacitance) and

(2) That the balance is replaced by an impedance equal to this nominal image impedance.

1.5.3. Measurement of return loss

The methods indicated above for measurement of balance return loss of a circuit may be applied to measurement of the return loss at the junction between two impedances Z and W provided that the line and the balance are replaced by the two impedances respectivement. However, in general, the two impedances Z and W are measured separately and calculation gives the reflection coefficient $\frac{Z - W}{Z + W}$ or the return loss of $\ln \left| \frac{Z + W}{Z - W} \right|$ nepers ou $20 \log_{10} \left| \frac{Z + W}{Z - W} \right|$ decibels.

1.5.4. Measurement of active balance return loss (echo attenuation)

The impedance at the origin of the circuit is measured:

(1) in the normal working condition (Z_1);

(2) when an endeavour has been made to suppress all echo paths by cutting out the gains in the return direction (Z_2). The active balance return loss (echo attenuation) is obtained from the expression.

$$\ln \left| \frac{Z_2 + Z_1}{Z_2 - Z_1} \right| \text{ nepers} \quad \text{ou} \quad 20 \log_{10} \left| \frac{Z_2 + Z_1}{Z_2 - Z_1} \right| \text{ decibels.}$$

Note. — The hybrid transformer used for these measurements should have a balance return loss greater than 6.5 N (56.5 db).

1.6. Measurement of transmission stability

1.6.1. Determination of singing point

This determination is made by means of one of the following methods:

(a) *Return loss measuring set.* — The return loss measuring set (fig. 19) is a termination (differential transformer) connected on side to the quadripole under test line and on the other side to an equivalent quadripole which is free from impedance irregularities (balance Z).

An amplifier giving an adjustable gain which is uniform over the frequency band over which the singing point is to be checked (300-3 400 c/s for example) is connected to the termination between terminals 1 and 2.

If the termination of figure 19 is well-balanced, the loss between the terminals 1 and 2 is, since the currents entering the line are separated from those leaving the line, in the form of reflected waves or echoes.

$$\ln \left| \frac{Z + W}{Z - W} \right| + \ln 2.$$

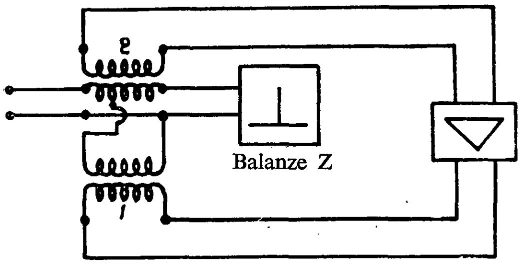


FIGURE 19. — *Return loss measuring set*

It follows that singing will not occur while the amplifier gain is adjusted to the above value, i.e., is equal to $K_0 + \ln 2$.

Measurement of singing point consists then in adjusting the gain of the amplifier up to the point when oscillations are maintained. If K is the gain in nepers of the amplifier when so adjusted, the singing point in nepers is:

$$K_c = K - \ln 2$$

To calibrate the amplifier (on the potentiometer of which the value of the singing point in nepers is usually read directly) the line and its balance network is replaced by two resistors whose difference corresponds to a well-known singing point (for example, 3 nepers or 26 decibels).

(*b*) Method using a two-wire repeater.

In order to measure the singing point on a two-wire circuit at a repeater station, it is possible to make use of the repeater itself by means of the following arrangement instead of using a return loss measuring set:

1. The line and the associated network to be tested are connected to the repeater normally used, whilst the other hybrid transformer has the line side short-circuited and the balance side open-circuited or vice-verse (fig. 20).

Under these conditions, if B is the effective insertion loss of the hybrid transformer on the left between the amplifier in the direction right-left and the amplifier in the direction left-right, then

$$A_1 = \ln \left| \frac{Z + W}{Z - W} \right| + \ln 2$$

Where Z is the line impedance and W is the impedance of the balance network.

The effective insertion loss A_2 of the hybrid transformer on the right between these two amplifiers has a value equal to zero.

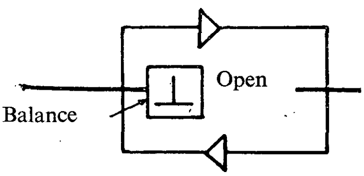


FIGURE 20

If K_{12} and K_{21} are the amplifier gains at the outset of singing, then

$$A_1 + A_2 = K_{12} + K_{21} .$$

If, on the other hand, k_{12} and k_{21} are the repeater gains, measured on an insertion gain set, between the " line " terminals of the hybrid transformer on the left and the " line " terminals of the hybrid transformer on the right, while the amplifiers are set to their gains K_{12} and K_{21} above; k_{12} and k_{21} are the " singing gains " of the two directions of transmission of the repeater and:

$$k_{12} = K_{12} - \ln 2$$

$$k_{21} = K_{21} - \ln 2 .$$

If the singing point is designated K_e (i.e., the balance return loss $\log_e \left| \frac{Z - W}{Z + W} \right|$ at the singing frequency) then:

$$K_e + \ln 2 = k_{12} + k_{21} + 2 \ln 2$$

whence

$$K_e = k_{12} + k_{21} + \ln 2$$

The singing point is then equal to the sum of the singing gains plus 0.7 N or 6 db.

2. The second hybrid transformer is connected on the line side to a pure resistance equal to the modulus of the characteristic impedance Z of the repeater, the " balance " side being closed with a resistance R variable from O to Z, or vice versa.

The gain is set to a pre-determined value. The resistance R is reduced (from the value Z) until singing begins and the value of the resistance R is then noted.

If k_{12} and k_{21} are the gains, measured with an insertion-gain measuring set, in the two directions of transmission (singing gains), then the singing point is given by the formula:

$$K_e = k_{12} + k_{21} - \ln \left| \frac{Z + R}{Z - R} \right| .$$

3. The second hybrid transformer is connected on the line side to a pure resistance equal to the modulus of the characteristic impedance Z of the repeater, the " balance " side being short-circuited, or vice versa.

The gain is increased until the repeater begins to sing and the gain of the two directions of transmission (singing gains k_{12} and k_{21}) measured with the aid of an insertion gain set.

The above formula (under 2) giving the singing point K_e then reduces to:

$$K_e = k_{12} + k_{21}$$

as the term $\ln \left| \frac{Z + R}{Z - R} \right|$ vanishes when $R = 0$.

Note 1. — When the reversal of the connexions mentioned above in 1, 2 or 3 gives a result differing by not more than 2 db (or 0.2 N) from that obtained before reversal, the lower of the two measured values is taken as the singing point; if the difference is above this limit, the presence of abnormal conditions is indicated.

Note 2. — When measurements of singing point are being made the two adjacent stations or exchanges should first be requested to close the line with a pure resistance approximately equal to the impedance of the circuit.

Note 3. — In the case of four-wire circuits forming part of a two-wire circuit, it is usually best to measure the singing point at the junction of the four-wire and two-wire circuits with a return-loss measuring set.

1.6.2. **Measurements of the stability of a Telephone Circuit**

This measurement is obtained from the definition of " Stability " of the circuit considered:

$$\sigma = q - \frac{q_1 + q_2}{2}$$

q being the mean of the nominal overall loss of the circuit in each of the two directions of transmission under normal working conditions and q_1 and q_2 being the singing points measured for the two directions of transmission respectively.

In order to measure these singing points in the case of a two-wire circuit, singing is started by increasing step by step and simultaneously for the two directions of transmission the gains of one or of several repeaters (preferably those in the middle of the circuits because they are usually in the most critical position from the point of view of singing). Having done this, without touching the adjustment which has been obtained, the transmission in the reverse direction is suppressed and the overall loss of the circuit at 800 c/s is measured for the forward direction of transmission; this is the singing point q_1 above. Next the transmission in the first direction is suppressed and the overall loss of the circuit at 800 c/s is measured for the reverse direction of transmission: this is the singing point q_2 above.

In the case of a four-wire circuit, any echo-suppressors there may be are first cut out, and the procedure for the case of a two-wire circuit followed; but in this case it is possible to choose any repeater at random for increasing the gain until singing begins. When the circuit is composed of two-wire and four-wire circuits, or carrier circuits, the method of measurement given for two-wire circuits is valid.

It is recommended that this stability should be determined with the ends of the circuit open-circuited; when these are high-impedance relays permanently connected across the line during a call, these relays may remain during stability tests. Singing may be observed on the line by monitoring on one of the repeaters in the circuit or at one of the carrier terminal stations.

1.6.3. Measurement of the Singing Margin (margin of stability) of a telephone circuit

The singing margin of a telephone circuit is measured by terminating the circuit in the most severe conditions (the ends open-or short circuited) and increasing the gain in the circuit up to the critical point where singing begins. The increase in gain thus obtained, expressed in transmission units (decibels or nepers), gives the required values of the " singing margin ".

1.7. Measurement of phase distortion

The significance of phase distortion is shown by the maximum value of the transient period, which is given by large difference in propagation time for different frequencies. Phase distortions present on a telephone line have, in general, little effect on timbre and intelligibility of transmitted sounds. To maintain conversational rhythm it is necessary merely to fit an upper limit to the mean propagation time. Conditions are different in television. In order that the image may be received correctly, it is necessary that the relation between amplitude and time (waveform) should be the same at the sending and receiving ends, i.e. the waveform of the signal should be transmitted unaltered.

A relation exists between the phase characteristic and the propagation time (group delay) of the generalized quadripole which is defined as follows:

$$\tau = \frac{d\alpha}{d\omega}$$

τ = propagation time (group delay)
α = phase as a function of angular frequency
ω = angular frequency.

This relation gives the possibility of expressing one of the two quantities in terms of the other.

1. A first method of measuring phase distortion consists in comparing the phase of a signal of frequency X at the input and at the output of a quadripole or a terminated line. To determine the phase-change, several methods are available.

(a) By comparison by Lissajous figures on the screen of a cathode-ray oscilloscope.

(b) By the Wattmeter method; the indicated value is proportional to cos $(\varphi_1 - \varphi_2)$.

(c) By a null method in which the phase and amplitude of one of the two signals are varied so that one signal is equal and opposite to the other.

(d) By a vector sum and difference method. Two circuits are supplied from a common source: the first contains an attenuator and the second comprises the circuit producing the phase distortion. The two amplitudes being made equal, the phase angle can easily be determined from the vector sum and difference of the voltage.

2. A second method of measurement of propagation time (group delay) is given by Nyquist. This method consists in amplitude-modulating a signal of

variable frequency *f*, by a constant frequency F and comparing the phases of the frequency F and the modulated envelope. The propagation time (group delay) of the modulated signal is given by the mean value of the wave-group (carrier and sidebands) which for the given envelope. The constant frequency F is made low enough for it to be small in relation to the phase/frequency relation of the circuit under test. The advantage of this method is that it is possible to determine the variation of propagation time (group delay) on a line which is not looped.

(See Appendix 40 following and the article by G. J. Hunt and L. G. Kemp entitled " Group-delay distortion-measuring equipment ". Proceedings of the Institution of Electrical Engineers, Paper No. 1250, p. 411.)

3. The third method of determining the attenuation and phase of a transmission circuit uses rectangular pulses. From the distortion of the pulses conclusions may be drawn regarding the different distortions. For example, in the case of television, the rise-time gives a measure of resolving power while under or over-shoots have an influence on the gradation of the image. On sending into the transmission system a periodic signal of known waveform and rich in harmonics, and recording the received waveform and submitting it to Fourier analysis, the phase delay for the system in question can be determined at the pulse frequency; this is only possible when the transmission system is not affected by other, non-linear, distortions. At the receiving end, a pulse-generator identical to that at the sending end and adjusted to the fundamental signal received on the line, produces locally the original signal. By means of phase-shifters and adjustable attenuators, the various harmonics on the two signals are equalized so permitting the relative loss and phase characteristics of the transmission system being determined. (See Appendix 39 following.)

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[15]

1.8. Measurement of non-linear distortion.

1.8.1. Measurement of harmonic distortion

The following apparatus is required:

(a) an oscillator (calibrated in respect of frequency) providing the fundamental frequency;

(b) a send unit which provides firstly an appropriate source impedance for the network under test (e.g. 600 ohms balanced to earth, 75 ohms unbalanced to earth) and secondly a means of measuring and adjusting the output power applied to the network under test;

(c) a selective measuring set with suitable input impedance(s)—many types will require to be preceded by a high-pass filter suppressing the fundamental frequency. The set comprises frequency selective input stages, followed by a frequency-changer and intermediate amplifier stages, detector and indicating meter.

The selective measuring set should have an absolute calibration, preferably with a substantially linear scale of decibel or nepers relative to 1 milliwatt, but may be calibrated as a millivoltmeter (e.g. several well known " Wave Analysers "). Alternatively, the measuring set may include a calibration circuit consisting of a local oscillator, h.f. meter and variable attenuator, as shown in figure 21. (This simplifies the design as the absolute gain need not then be constant with frequency.) These items of equipment are connected as shown in figure 21.

The fundamental frequency generated by the oscillator is applied to the network under test after being filtered of harmonics by the low-pass filter. As a guide to the discrimination necessary in this filter, considering sinusoidal signals of the same frequency (e.g. second harmonic produced in the network under test and second harmonic from the incompletely filtered oscillator output) which have a level difference of 40 db, the vector sum of the two will be within $\pm$ 0·1 db of the greater, depending upon the phase relationship. The error in measurement depends, of course, upon the addition law of the measuring instrument. The function of the filter preceding the measuring set is to suppress the fundamental frequency which, as it has a much greater magnitude than the generated harmonics, may overload the input (frequency-selective) stage of the measuring set.

Alternatively, the selective measuring set and preceding filter may be replaced by a band-pass filter passing the harmonic to be measured and a " flat " gain measuring set i.e. one having a constant gain over a wide frequency range. The sensitivity of this alternative arrangement is however, limited by the resistance noise corresponding to the bandwidth of the measuring set.

In both tests, it is important to pay careful attention to:

1. Circuit impedances.

2. Ensuring that the levels used do not overload any of the equipment.

3. Adequate screening including where practicable, the use of a truly coaxial construction.

4. Decoupling.

5. Earthing particularly at frequencies in the carrier range. Considerable errors can be obtained due to longitudinal voltages induced by differences of potential arising from the impedance of the earth connections. There is no golden rule for such problems—experience is essential— but techniques which assist when judiciously applied are:

(a) use of low impedance earth connections;

(b) returning all earth connections to a single point;

(c) use of longitudinal chokes. These are chokes wound with twisted wire for balanced circuits or coaxial type cable for unbalanced circuits which present a high impedance to " longitudinal " currents (flowing in the same sense in either or both conductors), but which do not affect transverse currents flowing in the normal " loop " circuit over the two conductors.

When making measurements in a repeater station and some of the equipment described above is not available, use can be made of spare translating equipment.

1. as a means of generating the required frequency taking advantage of the filters in the frequency translating (modulating) equipment to obtain the required frequency free of harmonics.

2. in certain cases as a means of selecting the frequency of interest and measuring it after frequency translation (demodulation) with a suitable level measuring set—not necessarily frequency selective.

1.8.2. Measurement of intermodulation products

Intermodulation products may be measured using similar apparatus, the only difference is that two or more oscillators are required in place of one. When combining these sources, care must be taken to preserve the correct impedance conditions; and this can most easily be achieved by the use of hybrid coils, resistance networks or, for example, when testing carrier systems, the use of spare frequency translating equipment. In the first method described above and shown in figure 21, the filter preceding the network under test must pass the disturbing frequencies but not their harmonics—in some cases this may be a high-pass filter with a suitable cut-off frequency; in other cases, a number of parallel band-pass filters are necessary. The filter at the output of the network must pass the required intermodulation products but not the disturbing frequencies. In some cases a high-pass filter is satisfactory—in other cases a band-pass filter is required. For some applications a variable band-pass is valuable; a typical circuit which has successfully been used in the carrier frequency range is a Parallel T network.*

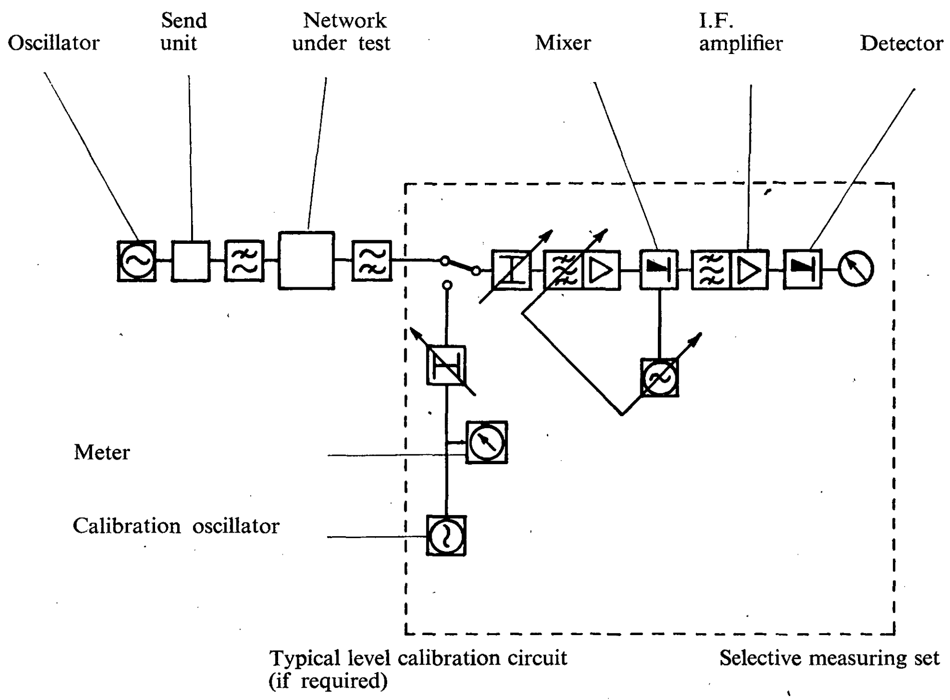

FIGURE 21. — *Typical assembly of test equipment for measurement of harmonic distortion*

1.9. **Measurement of crosstalk.**

General. — Crosstalk can be defined briefly as the sound heard in a receiver connected to one circuit due to currents in another circuit, but in practice the term is also used to include the power induced into the termination of one circuit through power being transmitted on another circuit at a frequency or frequencies above the audio range.

If, in figure 22:

(a) AC is the disturbing circuit with disturbing source G at A, and a termination Z_S at C equal to the characteristic impedance of the disturbing circuit, and

(b) BD is the disturbed circuit with receiver T_1 at B and receiver T_2 at D, the impedance of each receiver being equal to the characteristic impedance of the disturbed line (Z_R),

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* Tuttle, W. N. Bridged T and Parallel T Null Circuits for Measurements at Audio Frequency. Proc. I.R.E. Vol. 28, p. 23. January, 1940.

then, the sound heard in T_1 is the near-end crosstalk and the sound in T_2 is the far-end crosstalk. The crosstalk attenuation is the logarithmic ratio of power delivered by source to power delivered to telephone. In the case of H.F. currents the telephones are replaced with other terminations. The crosstalk attenuation can be obtained by measuring the voltages at A and at B or D and computing the powers concerned from the relationship

$$P = \frac{V^2}{Z}$$

but it is the usual practice in making such measurements to use either some form of potentiometer network to compare the source and received voltages or some form of attenuating network to attenuate the source voltage to that of the received voltage. The former method is usually used for measurements at audio frequencies and the latter for carrier frequencies.

1.9.1. Audio cable crosstalk measurement

The circuits used for crosstalk measurements are shown in figures 23 and 24. The crosstalk meter is a potentiometer with elements as shown in figure 25.

A buzzer, designed to emit a band of frequencies similar to that used in speech, is normally used to generate the telephone currents which are applied to the disturbed line, but a fixed or variable frequency oscillator may be used if the crosstalk at a particular frequency or frequencies is required. To measure the crosstalk, the receiver switch is moved between the two positions and the crosstalk meter adjusted until equal sounds are heard irrespective of the position of the switch. The crosstalk meter then indicates the crosstalk attenuation between the circuits, provided the characteristic impedances of the disturbed and disturbing pairs are the same. Where the characteristic impedances are different e.g. Z_S and Z_R for disturbing and disturbed line respectively, the reading of the crosstalk meter has to be corrected by the algebraic addition of

$$10 \log_{10} \left| \frac{Z_R}{Z_S} \right| \text{ decibels}$$

or

$$\frac{1}{2} \ln \left| \frac{Z_R}{Z_S} \right| \text{ nepers}$$

1.9.2. Carrier pair crosstalk measurement

The circuits used are shown in figures 26 and 27, from which it will be noticed that the crosstalk is always measured between 140 ohm non-reactive terminations.

For crosstalk measurements, a high powered oscillator with a balanced 140 ohm output of 7 watts (approximately) is used, and the measuring set contains the equipment shown in the diagrams. The attenuator used has a range 0-80 db, and the 15 000 ohm resistor effectively decreases the calibrating signal by 40 db. The selective amplifier detector has an input (ladder) attenuator of 60 db in 20 db steps and is provided with a meter reading from 0 to — 30 db. The detector is capable of measuring levels of — 125 db relative to 0·374 volts, and in conjunction with the power oscillator, crosstalk attenuations up to 160 db can be measured. For the measurement of crosstalk in carrier pairs (which after network balancing usually varies between 60 and 120 db), the procedure followed is:

(a) Adjust the oscillator for measurement frequency,

(b) set the switch to position shown in diagram,

(c) set attenuator to 20 db,

(d) tune detector for maximum output,

(e) set selective amplifier input attenuator to 0 db,

(f) by adjustment of a calibrated control, set meter reading to zero,

(g) change over switch,

(h) adjust input attenuator so that a reading is obtainable on the meter,

(i) calculate crosstalk attenuation which equals 60 db plus loss in input attenuator plus meter reading plus (for far-end crosstalk only) line attenuation at the frequency of measurement.

With this arrangement the crosstalk between any one pair and all other pairs in the cable can be made with one calibration per test frequency.

1.9.3. Coaxial pair crosstalk measurement

The circuits used for measurements up to 3 Mc/s are shown in figures 28 and 29, from which it will be seen that the crosstalk is always measured between 75 ohm non-reactive terminations by an attenuator substitution method.

For crosstalk measurement, a high powered oscillator with an output of 5 watts (approximately) is used, together with the measuring equipment shown. The 7 425 ohm resistor effectively reduces the reference level by 40 db. The communications receiver has two stages of radio frequency gain and these stages have to be accurately lined up to give adequate sensitivity with a high impedance input. The output from the communications receiver is monitored either by:

(a) a D.C. micro-ammeter inserted in the diode rectifier circuit or

(b) a full-wave rectifier + D.C. micro-ammeter connected across the audio output. The A.G.C. is, of course, switched out of circuit.

For the measurement of crosstalk the procedure followed for each measurement is:

(a) adjust the oscillator to the measurement frequency,

(b) plug flexible cord in socket A,

(c) tune receiver to give greater gain at oscillator frequency,

(d) adjust the receiver gain so that the micro-ammeter pointer is at a particular point on the scale,

(e) remove flexible cord from socket A and plug into socket B,

(f) adjust attenuator until the micro-ammeter pointer is at the same point as in (d).

(g) calculate crosstalk attenuation which equals 80 db plus loss in attenuator plus (for far-end crosstalk only) line attenuation at frequency of measurement.

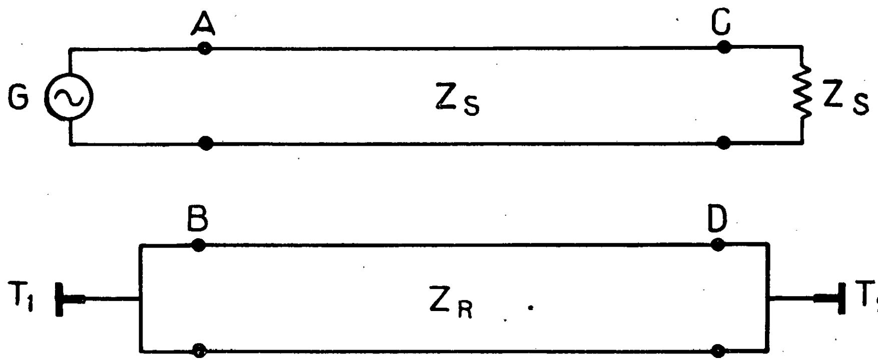
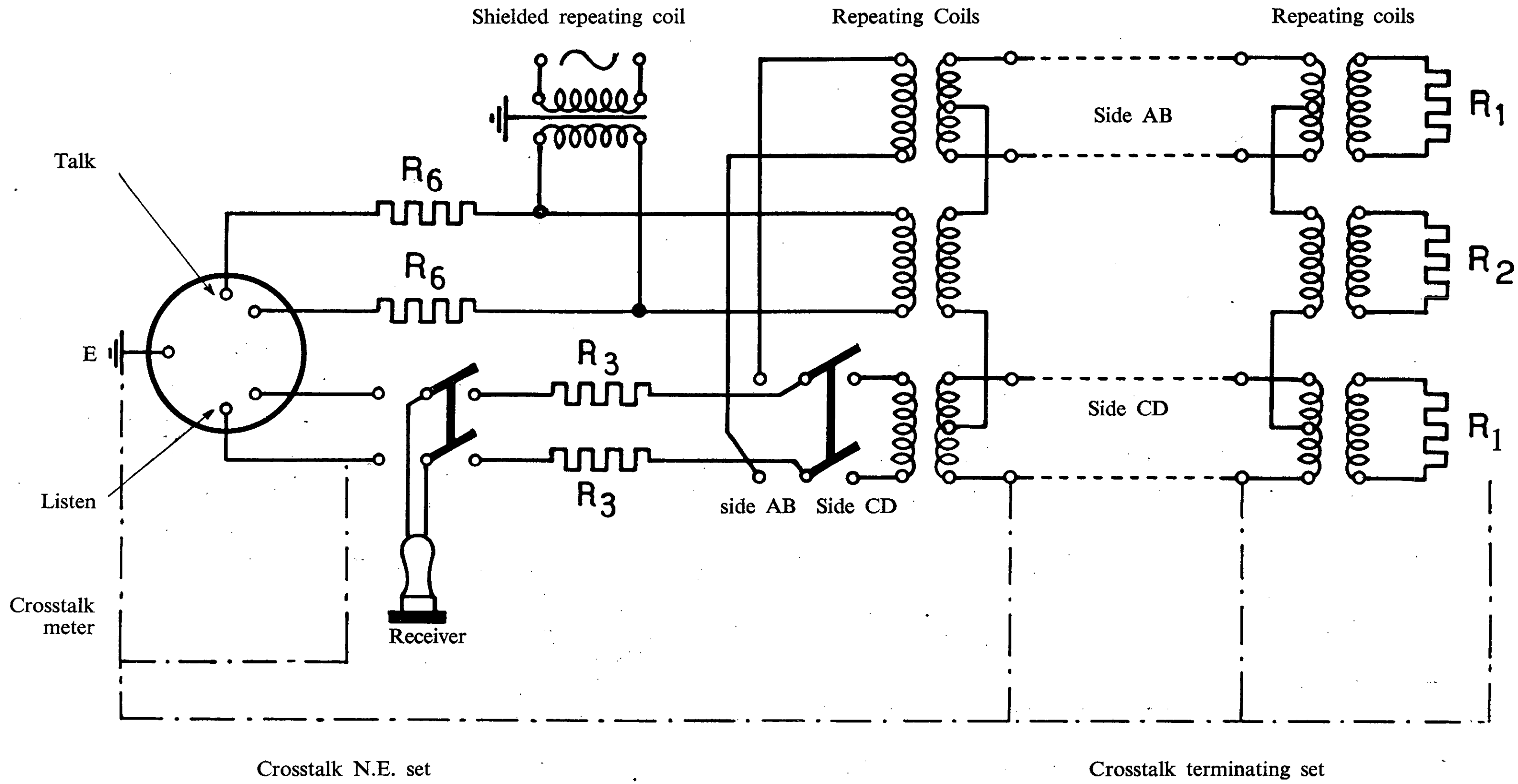
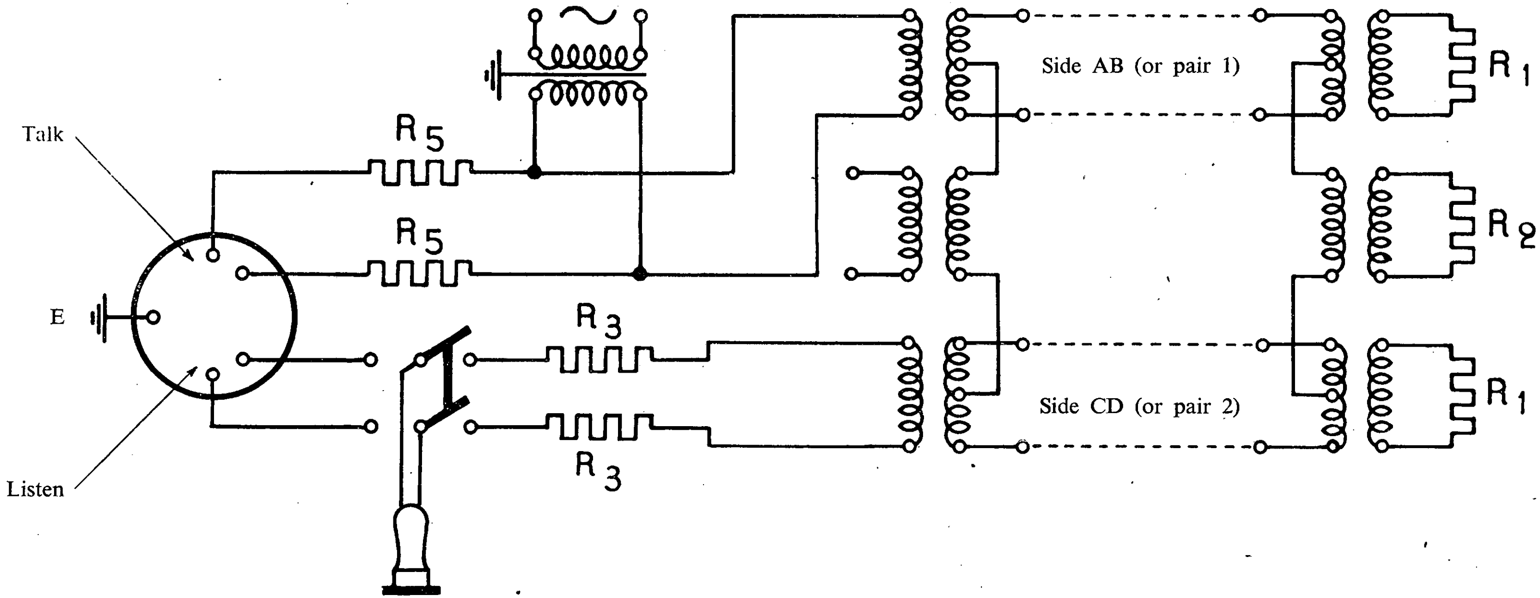


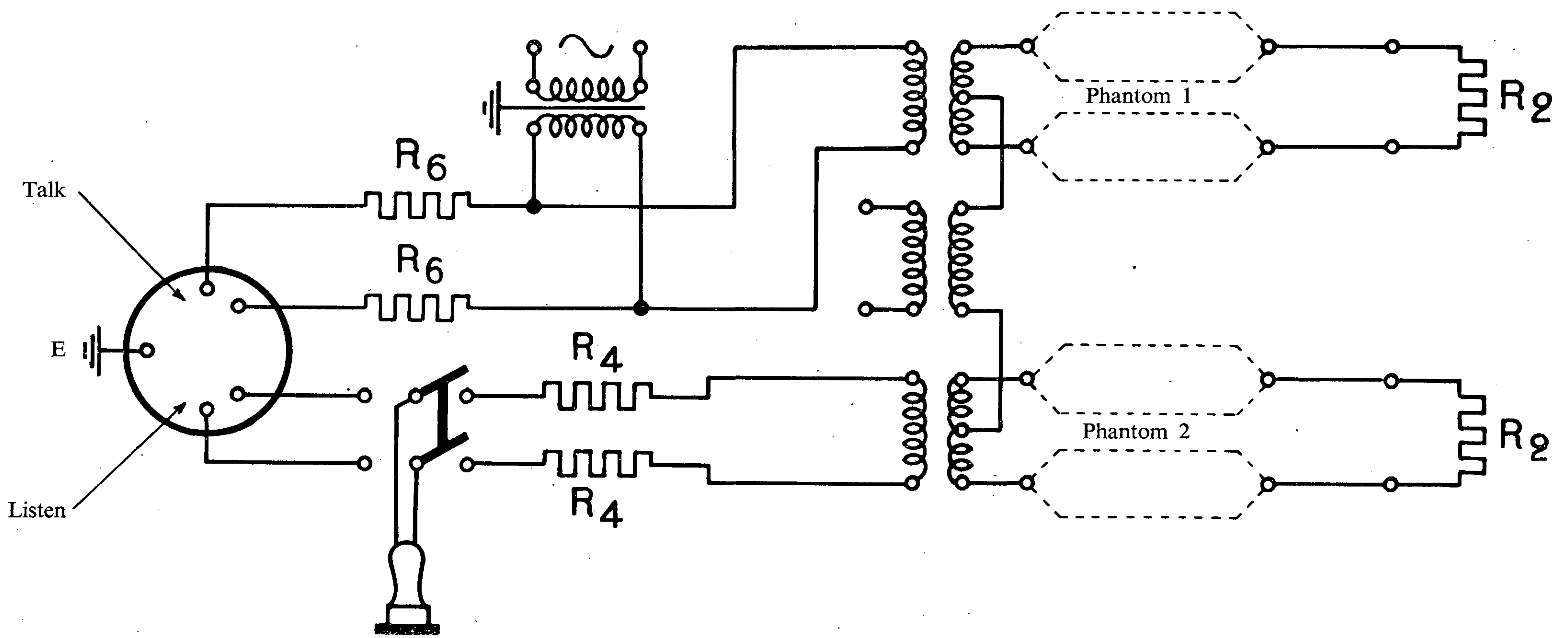
FIGURE 22



(a) Phantom to side



(b) Side to side

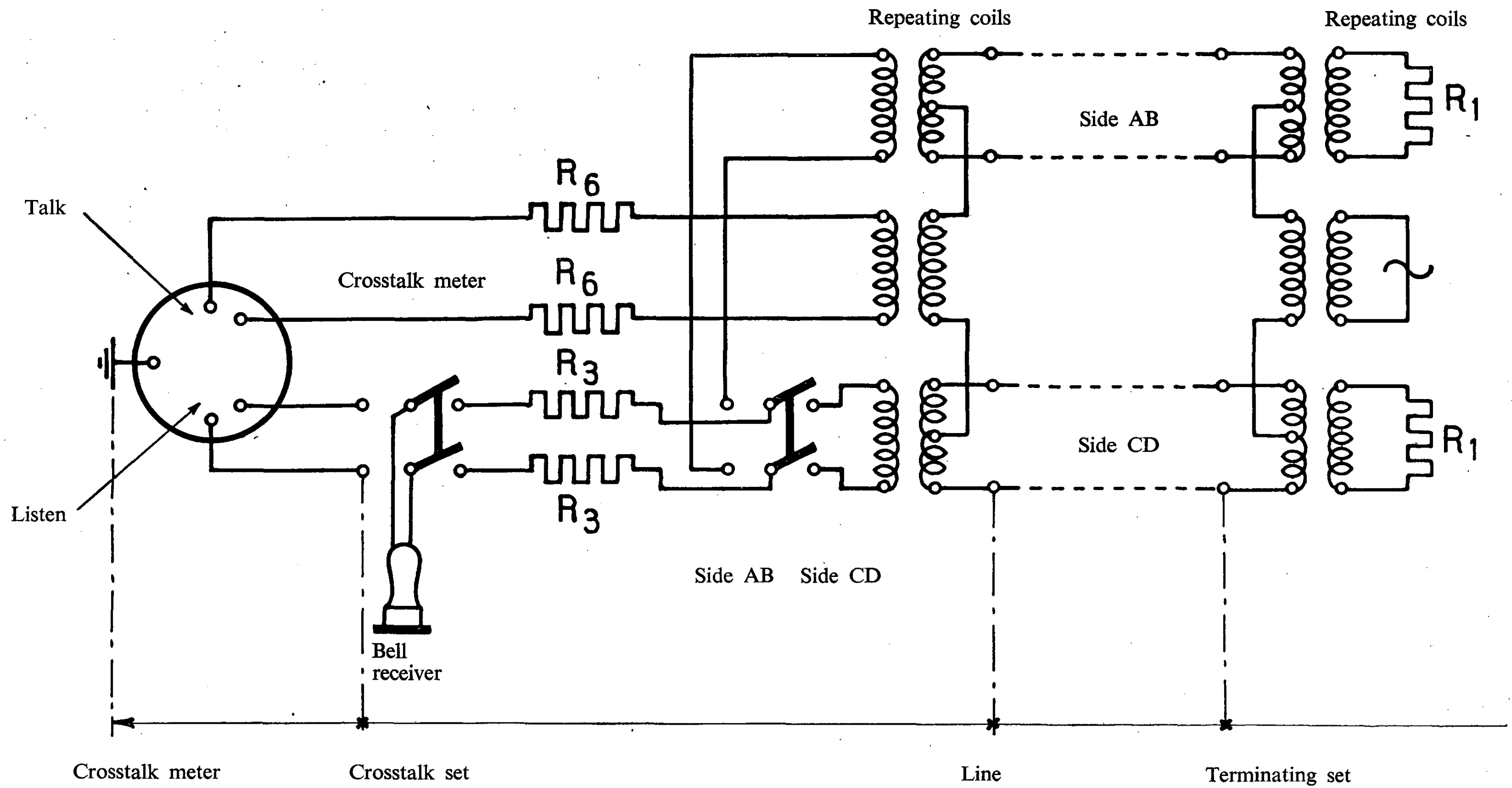


(c) Phantom to phantom

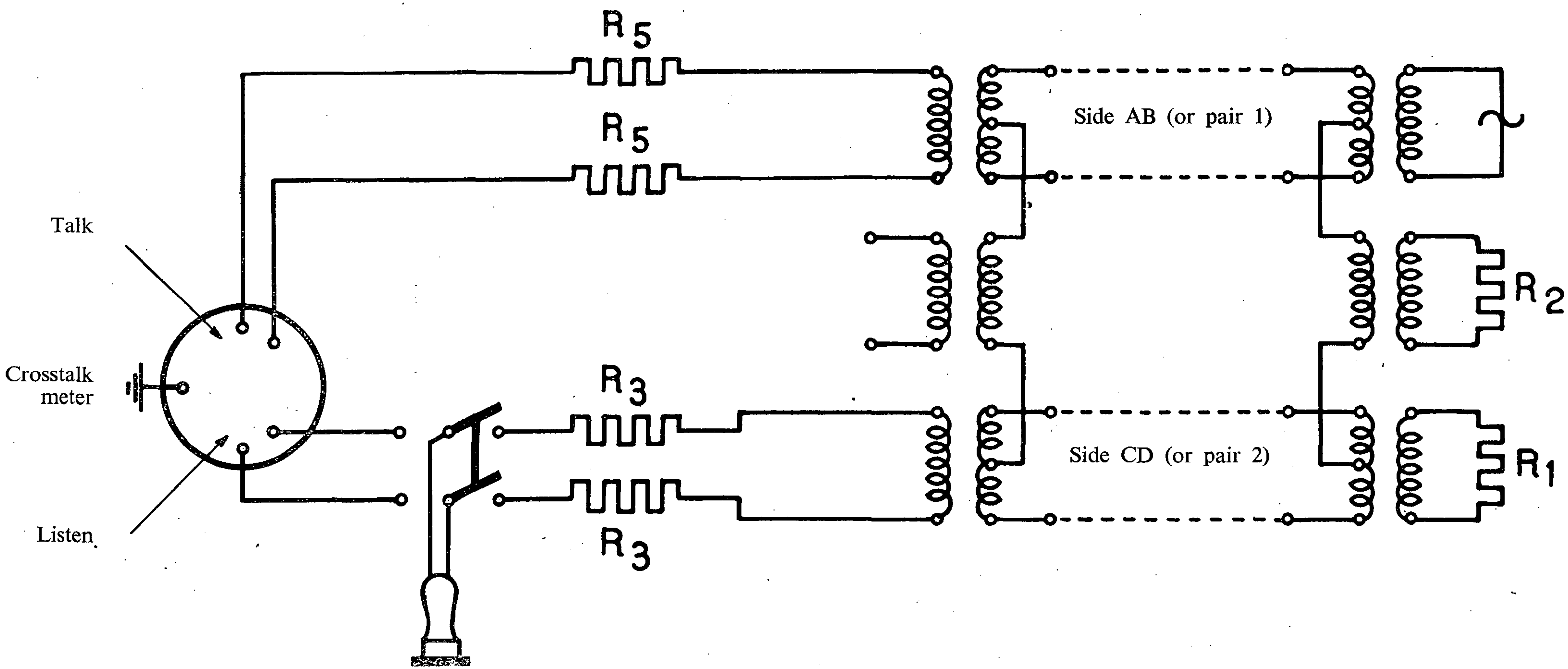
FIGURE 23. — *Schematic of circuits used for measuring near-end crosstalk in audio cables*

Notes: R_1 = Resistance suitable for terminating the side CCTS
R_2 = Resistance suitable for terminating the phantom CCTS
R_3 = Resistance added to receiver to make the receiver impedance approximate the side CCT impedance
R_4 = Resistance added to receiver to make the receiver impedance approximate the phantom CC impedance
R_5 = Resistance added to crosstalk meter to make its impedance approximate the side CCT impedance
R_6 = Resistance added to crosstalk meter to make its impedance approximate the phantom CCT impedance

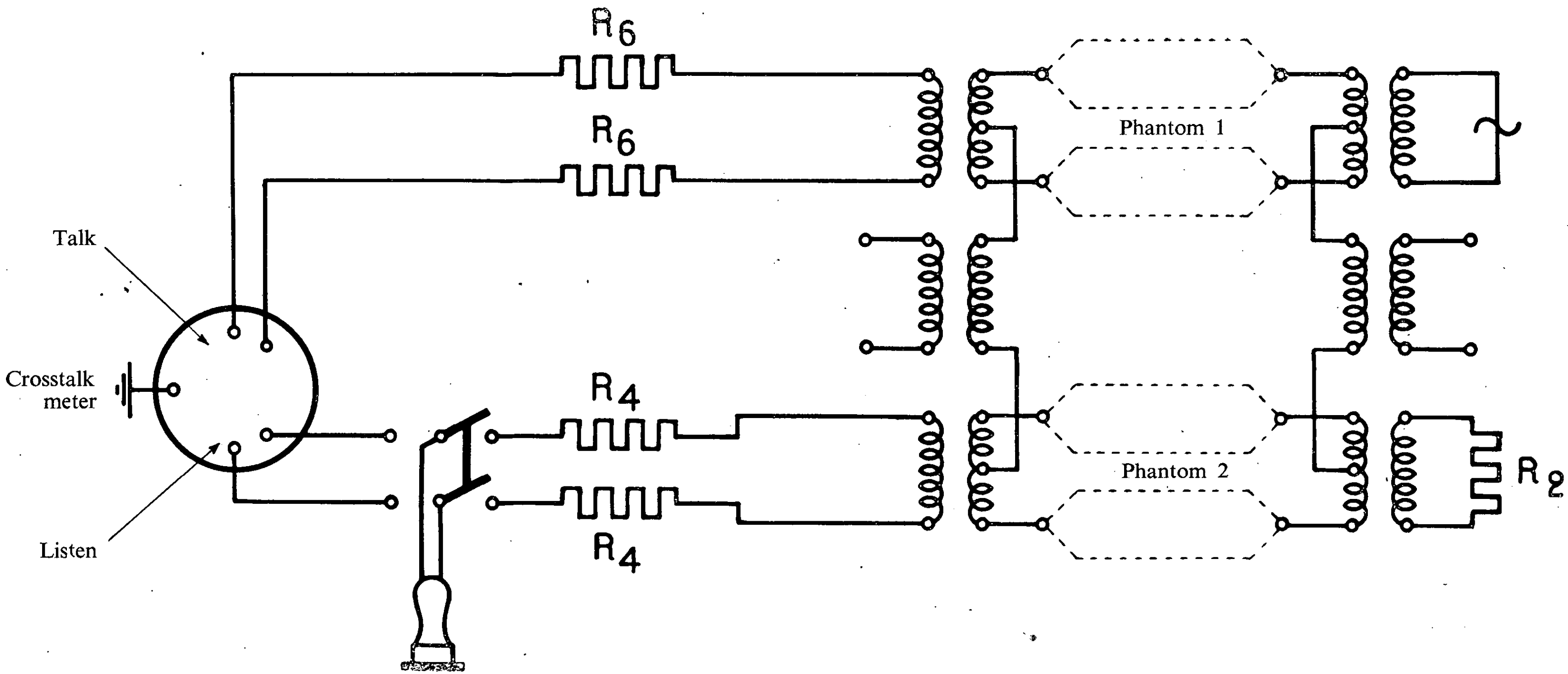
For measuring phantom-to-pair crosstalk the conditions are as shown in figure *(c)*, except that the pair is connected in place of phantom 2 and terminated with resistance R_1, R_3 being connected in series with the receiver



(a) Phantom to side



(b) Side to side



(c) Phantom to phantom

FIGURE 24. — *Schematic of circuits used for measuring far-end crosstalk in audio cables*

Notes: R_1 = Resistance suitable for terminating the side CCTS
R_2 = Resistance suitable for terminating the phantom CCTS
R_3 = Resistance added to receiver to make the receiver impedance approximate the side circuit impedance.
R_4 = Resistance added to receiver to make the receiver impedance approximate the phantom circuit impedance
R_5 = Resistance added to crosstalk meter to make its impedance approximate the side circuit impedance
R_6 = Resistance added to crosstalk meter to make its impedance approximate the phantom circuit impedance

For measuring phantom-to-pair crosstalk the conditions are as shown in figure *(c)*, except that the pair is connected in place of phantom 2 and terminated with resistance R_1, R_3 being connected in series with the receiver

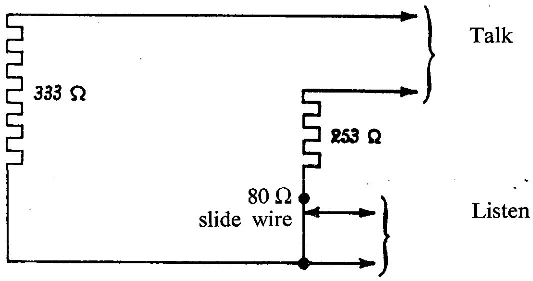


FIGURE 25. — *Schematic of audio crosstalk meter*

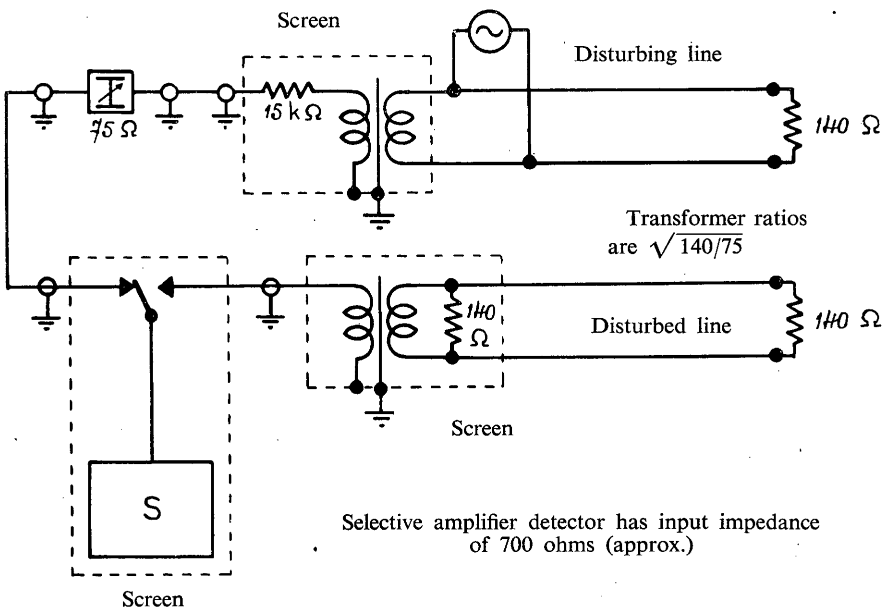


FIGURE 26. — *Near-end crosstalk measurement between symmetrical pairs for carrier systems*

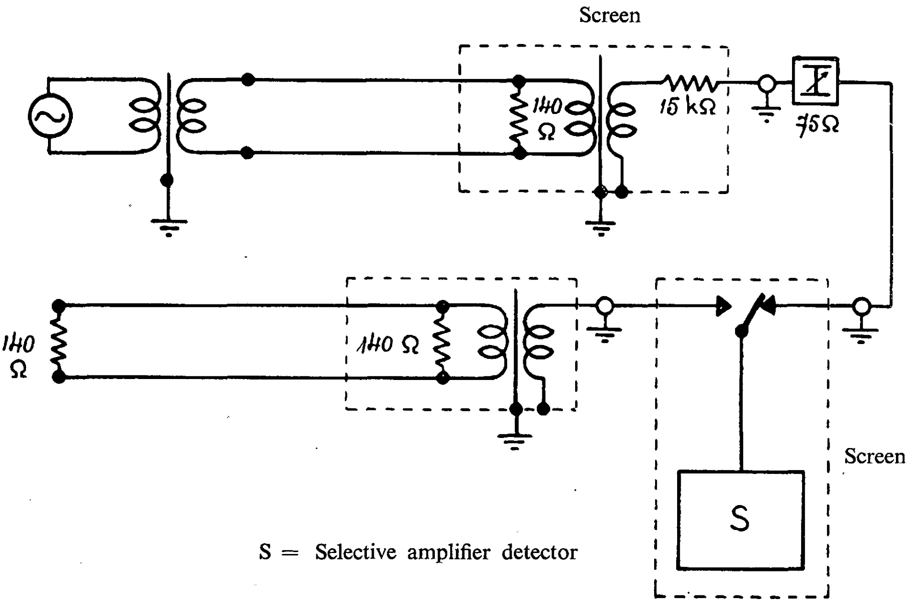


FIGURE 27. — *Far-end crosstalk measurement between symmetrical pairs for carrier systems*

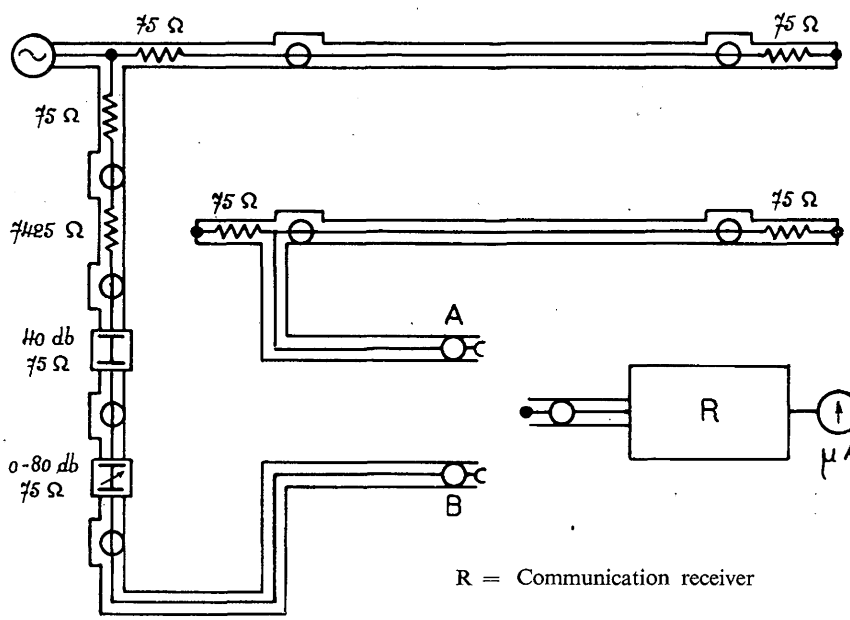
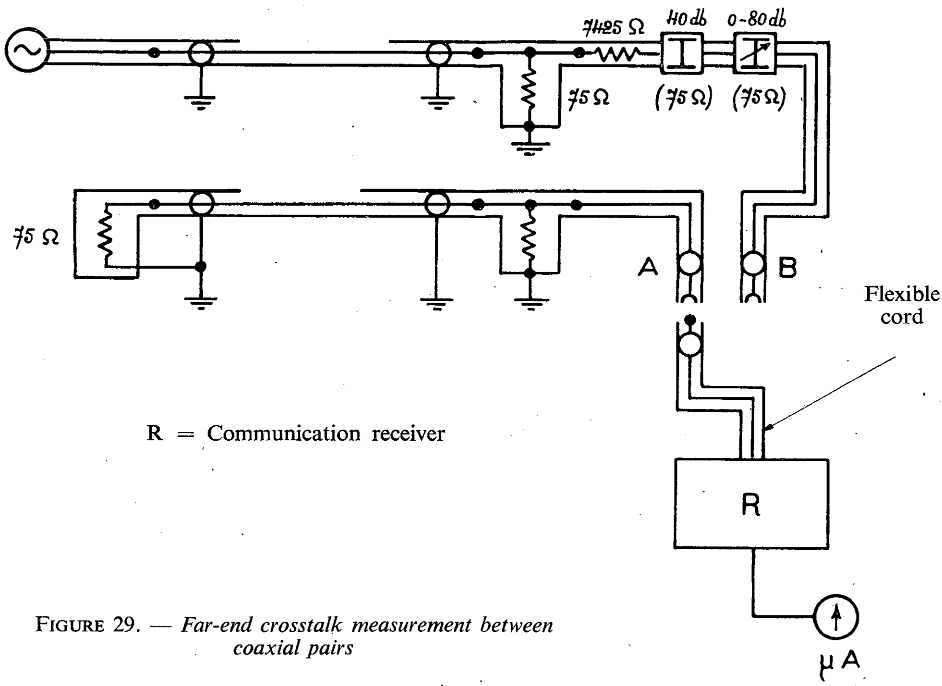


FIGURE 28. — *Near-end crosstalk measurement between coaxial pairs*



R = Communication receiver

FIGURE 29. — *Far-end crosstalk measurement between coaxial pairs*

SECTION 2

PULSE TESTING ON FACTORY LENGTHS OR REPEATER SECTIONS OF COAXIAL CABLE (TO BE USED FOR TELEPHONY OR TELEVISION) AND ON REPEATER SECTIONS OF OPENWIRE LINES

The C.C.I.F. considers that it is not necessary to standardize intentionally measurement, by means of pulses, of impedance irregularities of coaxial pairs to be used only for international telephone circuits.

The making of such measurements and the limits to be fixed is left to the discretion of Administrations or Private Operating Companies concerned with the international line in question. On the other hand such measurements are very useful on coaxial pairs to be used for television transmissions.

As regards pulse testing equipment to be used for maintenance of international circuits (for example for localizing a break in a cable or a major impedance irrugularity), this question is still being studied by the C.C.I.F. and it is too early to recommend any particular type of apparatus for such measurements.

For information, apparatuses used by the Australian Telephone Administration, the Cuban Telephone Company, the French Administration, the British Administration, and the Swedish Telephone Administration for making pulse tests either on circuits or on factory lengths of coaxial cables are described in Annexes 47 to 51 below. Apparatuses used by the American Telephone and Telegraph Company are described in the following article:

" Pulse echo measurements on telephone and television facilities " by L. G. ABRAHAM, A.W. LEBERT, J. B. MAGGIO and J. T. SCHOTT, *Transactions of the American Institute of Electrical Engineers*, volume 66, pages 541 to 548 (1947). This article has been reproduced in Bell System Monograph B-1469.

Also for information, attention is drawn to the following articles by F. F. ROBERTS, published in the *Journal of the Institution of Electrical Engineers:*

" New methods for locating cable faults, particularly on high-frequency cables " (Volume 93, IIIrd part, No. 26, November 1946, pages 385 to 405);

" A pulse test set for the measurement of small impedance irregularities in high-frequency cables " (Volume 96, IIIrd part, No. 39, January 1949, pages 17 to 24).

PART THREE

ANNEXES DEALING WITH METHODS AND APPARATUS FOR MAKING MEASUREMENTS ON LINES

ANNEX 30

METHOD USED BY THE BRITISH ADMINISTRATION FOR THE INITIAL EQUALIZATION OF COAXIAL CABLE CARRIER SYSTEMS

When lining up coaxial cable carrier systems prior to putting them in service, the British Administration uses a wide-band non-selective receiver and a continuously variable oscillator.

The method generally employed consists in first calculating the approximate values, for each repeater station, of the attenuation at a selected frequency, the variations of this attenuation with temperature and the variations of the attenuation with frequency at a particular temperature; the approximate settings for each equalizer and attenuator are then calculated and each is then adjusted temporarily to the calculated value. A series of test signals at small frequency intervals is then sent from the Coaxial Line Control Station (defined in Volume III of the *Green Book*, page 237) and the levels at the outputs of the first and subsequent repeater stations are measured. From the figures obtained the final equalizer settings are determined and the number, position and attenuation-frequency characteristics of any line residual (" mop-up ") equalizers which may be necessary are decided. This procedure is repeated for the other direction of transmission, each direction being treated independently except that the temperature equalization applied at any one station is the same for both directions of transmission.

When the final equalization of the cable has been completed, through level measurements at 7 frequencies in the band 60-4 092 kc/s are made at each intermediate station and recorded for maintenance purposes.

ANNEX 31

MEASURING APPARATUS USED BY THE SWISS TELEPHONE ADMINISTRATION FOR THE MAINTENANCE OF CARRIER SYSTEMS ON SYMMETRICAL-PAIR CABLES

1. Measuring equipment for the terminal stations of 60-circuit systems

The measuring equipment for the terminal stations enables the most complete measurements to be made. It is mounted on a trolley so that the test leads are very short. The selective portion enables measurements to be made on the individual channels without affecting the entire system.

The characteristics of the equipment are:

(a) *Oscillator*

1. Frequency band: 10 to 160 kc/s and 150 to 300 kc/s.
2. Scale: linear.
3. Length of scale: 400 millimetres for each frequency range.
4. Marking of scale: one division per kc/s, a large division with figures each 5 kc/s, a red mark on the limits of the telephone channels (12, 16. . . 252 kc/s).
5. Attenuation distortion: ± 0·02 nepers from 10 to 300 kc/s.
6. Output voltage (balanced or unbalanced).
   α) constant voltage: 2·1 V, 1·55 V, 0·775 volts;
   β) 0, — 1, — 2, — 3, — 4, — 5 and — 6 nepers relative to 1 mW in 600 ohms, 150 ohms or 75 ohms.
7. Non linearity distortion: less than 1% for 2·1 volts in 75 ohms.
8. Power supply 220 volts 50 c/s. Mains voltage variations of 10% (or 2% in frequency) do not produce more than ± 0·02 nepers variation in the output voltage.
9. Calibration; internal thermocouple by means of a d.c. source (maximum error: ± 0·02 nepers).

(b) *Measuring instrument*

1. Frequency band: 10 to 300 kc/s with an error of ± 0·02 nepers.
2. Range of measurement: + 4 to — 8 nepers relative to 1 mW in 600, 150 and 75 ohms.
3. Input impedance: for level measurements 710 000 ohms; for attenation measurement 600, 150 and 75 ohms.
4. Input: balanced.
5. Supply voltage: 220 V, 50 c/s.

6. Accuracy (for ± 10% mains voltage or for ± 2% frequency variation ± 0.02 nepers.
7. Calibration: by means of the oscillator described above.

(c) *Selective filter*

1. Frequency band: 12-300 kc/s.
2. Attenuation distortion in pass band: ± 0·02 nepers.
3. Pass band attenuation: 0 nepers.
4. Selectivity: approximately 6 nepers for a deviation of ± 700 c/s.

Dimensions:

Height	1 330 millimetres
Length	480 ,,
Distance between wheel axles	600 ,,
Depth	840 ,,
Weight	100 kilogrammes

2. Measuring equipment for intermediate repeater stations for 48 circuit systems

The measuring equipment for intermediate repeater stations is more simple and is in portable form. It measures (amongst others) the level of the 60 kc/s pilot which, in Switzerland, is transmitted on each carrier system; as it has a selective circuit of 60 kc/s to make this measurement, arrangements are made to measure the non-linearity distortion (third harmonic) at the frequency of 20 kc/s.

The principle characteristics are the following:

Level Measurements

(a) *Non-selective*

1. Frequency band 10 to 204 kc/s.
2. Attenuation distortion in this band: ± 0·04 nepers.
3. Characteristic " attenuation-frequency " uniform.
4. Measuring range: — 5 to + 4 nepers (relative to 1 mW in 150 ohms).
5. Balanced input.
6. Input impedance > 10 000 ohm.

(b) *Selective*

1. Selective to 60 kc/s.
2. Selectivity: — 3 nepers for ± 1·5 kc/s.
3. Accuracy ± 0·04 nepers.
4. Calibration: internal oscillator of 60 kc/s.
5. Input impedance > 10 000 ohms.

Measurement of non-linearity distortion

Measurement of the relative value of the third harmonic as under *(b)* (selective to 60 kc/s); internal oscillator of 20 kc/s; output level from + 2 to — 4 nepers.

ANNEX 32

DESCRIPTION OF A METHOD FOR SELECTIVE MEASUREMENTS ON 12-CHANNEL CARRIER CABLE TELEPHONE SYSTEMS USED IN MEXICO BY THE SOCIEDAD TELEFONOS DE MEXICO

Figure 1 shows a block schematic of the selective level measuring set. It consists of a transformer followed by a band-pass filter B, a negative feedback amplifier and a measuring instrument E which includes a rectifier D. The 60 kc/s pilot first passes through the transformer and then the band-pass filter B which is a crystal filter with a very narrow pass-band in order to reject the pilots of adjacent telephone channels. The pilot is then rectified after amplification by amplifier C.

The magnitude of the rectified current is a function of the level of the pilot and can be used to indicate this level.

In order to facilitate maintenance means are provided to enable an attended station to measure the levels of the pilots at associated unattended stations. The equipment described above is used together with a switch and a remote control relay device operated from the attended station. The measuring set can be connected to the output terminals of any of the repeaters in the unattended station and the direct current from the measuring set transmitted over one of the cable pairs to the attended station where it can be measured.

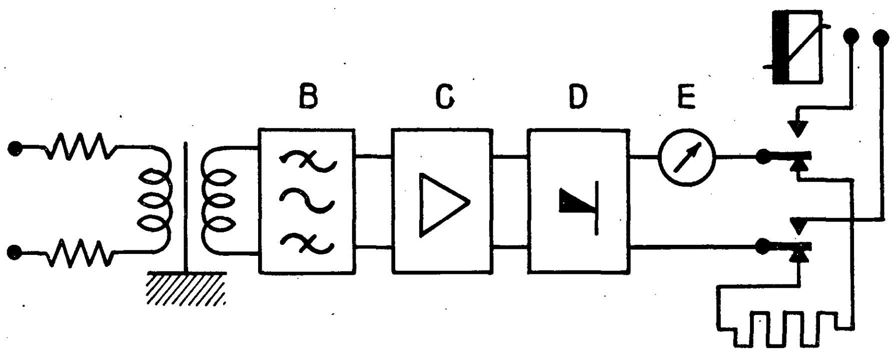


FIGURE 1

ANNEX 33

NOTE BY THE FRENCH TELEPHONES ADMINISTRATION ON MEASURING APPARATUS FOR THE MAINTENANCE OF CARRIER SYSTEMS

The French Telephone Administration use for the maintenance of carrier systems the following apparatus:

— portable apparatus for the measurement of pilots in basic group A or B.
— fixed apparatus for the measurement of the pilot in the supergroup.
— selective level indicator (12-312 kc/s).
— wideband level indicator (0,3-4 000 kc/s).
— maintenance group of 10 frequencies for symetrical pairs.
— maintenance group of 16 frequencies for 16 supergroups on coaxial pairs.

This apparatus is described below:

Apparatus for the measurement of pilots in basic group A or B

I. General

The apparatus enables the measurement of pilots in basic groups A or B to be made.

In the case of basic group B the pilot of frequency 84 140 kc/s is filtered, amplified and detected.

In the case of basic group A the pilot, of frequency 35-860 kc/s is modulated by 120 kc/s, the product of this modulation 84-140 kc/s is then treated as the pilot of basic group B.

II. Electrical characteristics

Selectivity of the crystal filter

Frequency transmitted 84 140 kc/s

Selectivity { at 84,140 $\pm$ 0·140 kc/s $>$ 6·5 N
at 84,080 kc/s: $>$ 5 N.

Input impedance: 150 ohms in the position " measure pilot "
$>$ 5 000 ohms in the position " monitor pilot ".

Measuring range:

— Power level of measuring pilot: between — 2·7 and — 7·3 N in 150 ohms.
— Voltage level of measuring pilot: between — 1·2 and — 5·8 N high impedance.

Accuracy: The reading is made on a meter graduated from — 0·3 to + 0·3 N with an accuracy of ± 0·02 N.

Fixed apparatus for measurement of the supergroup pilot

I. General

The apparatus enables the measurement of the supergroup pilot at specified points in the supergroup modulation and demodulation equipments.

The pilot of frequency 411,860 kc/s is modulated with 496 kc/s. The product of this modulation 84 140 kc/s is filtered, amplified and detected.

II. Electrical characteristics

Selectivity of the crystal filter

Frequency transmitted: 84 140 kc/s.

Selectivity { at 84 140 ± 0·140 kc/s: > 6·5 N
at 84 080 kc/s > 5 N.

Input impedance: 300 ohms.

Measuring level: — 2·3 N or — 2·9 N below the relative level at the point of measurement i.e. — 7·45 and — 8·05 N (voltage level).

Accuracy: The reading is made on a meter graduated from — 0·3 to + 0·3 N with an accuracy of ± 0·02 N.

Selective level indicator 12-312 kc/s

I. General

This apparatus of the heterodyne types enables the measurement of absolute voltage level between — 8 N and + 2 N in the band 12-312 kc/s without stopping the voice channels adjacent to that which is measured.

II. Electrical characteristics

Frequency band: 12 to 312 kc/s.

Accuracy of internal oscillator: The frequency is correct to approximately 500 c/s throughout the band of frequencies.

The scale of the variable condenser of the internal oscillator permits a reading of the frequency close to 200 c/s from 12 to 312 kc/s.

Intermediate frequency: The apparatus includes a crystal filter of 360 kc/s followed by 2 stages of amplification at intermediate frequency also at 360 kc/s.

Selectivity: 4 N at ± 1 250 c/s.

Measuring range: from — 8 N to + 2 N.

Accuracy of measurement: Of the order of 0.1 N. The apparatus includes an internal arrangement for standisation.

Input impedance: 10 000 ohms.
or 600 „
or 150 „
or 75 „

The apparatus enables the measurement of balanced and unbalanced voltages.

Power supply: The supply to the apparatus is from the mains.

Wideband level indicator for maintenance 0·3 kc/s-4 Mc/s

This apparatus enables the measurement of absolute voltage levels in the band of frequencies 0·3-160 kc/s and 60-4 000 kc/s. It does not include electronic valves.

Its characteristics are the following:

— Band of frequencies 0·3-160 kc/s, 60-4 000 kc/s.

— *Range of measurement:* — 1·5 N to + 1·5 N.

— *Input impedance:* band 0·3-160 kc/s: 150 ohms or 600 ohms or > 1 000 ohms (2 000 ohms from 0·3 to 110 kc/s); band 60-4 000 kc/s: 75 ohms or > 800 ohms.

Amplifier for level indicator 60-4,000 kc/s

This apparatus extends the range of measurement of the wideband maintenance measuring indicator described above from — 4·5 N to + 1·5 N. Its characteristics are the following:

— Frequency band: 60-4 000 kc/s.

— *Gain:* 3 N.

— *Input impedance:* 75 ohms or > 800 ohms.

The power supply is from the mains.

Group of maintenance frequencies for symmetrical pairs

I. General

This apparatus enables maintenance measurements to be made on the symetrical pair lines used with 12, 24 or 36 telephone channels.

For this purpose the following ten interstice frequencies are used: 11 860 — 23 860 — 39 860 — 55 860 — 80 140 — 96 140 — 108 140 — 128 140 — 144 140 — 156 140 kc/s.

The apparatus consists of two parts:

— the sending part which generates and transmits these frequencies,

— the receiver which measures their level in association with the " portable measuring apparatus of the basic group pilot ".

The power supply is from the mains.

II. Electrical characteristic

2.1. *Transmission*

The sending is in the form of a generator with an internal impedance of 6 000 ohms able to deliver a level of voltage — 10 or — 9 N between the ends of a resistance of 750 ohms (input of line repeaters). The accuracy of transmitted frequencies is ± 3 c/s.

2.2 *Reception*

2.2.1. The receiver transposes in frequency and level the received interstice signals to enable their measurement by the " portable apparatus for measuring the pilots of the basic group " described above.

The frequency obtained after transposition is 84,140 kc/s.

The transposition in level is made in the following conditions:

— nominal voltage level at input — 2·5 N;

— nominal voltage level at the output across an impedance of 150 ohms: — 5·5 N.

An attenuator inserted in the circuit enables the sensitivity of the receiver to be varied by ± 1 N about its nominal value.

— Variation of level as a function of received frequency: 0·05 N.

— Accuracy of variation of level: ± 0·05 N.

2.2.2. Input impedance: 150 ohms and high impedance.

2.2.3. Output impedance: 150 ohms.

Note. — The combined use of interstice frequencies on the one hand and of a selective receiver on the other enables maintenance measurements to be made without interuption of traffic.

Group of 16 maintenance frequencies for 16 supergroup coaxial pairs

I. General

This apparatus enables maintenance measurements to be made on 16 supergroup coaxial pairs.

For this purpose it uses the following 16 insterstICial frequencies:

60, 556, 808, 1 056, 1 304, 1 552, 1 800, 2 048, 2 296, 2 544, 2 792, 3 040, 3 288, 3 588, 3 784, 4 032 kc/s.

The apparatus consists of three parts:

— the transmitter to generate and send these frequencies. This generator is based upon quartz crystal oscillators;

— the receiver which enables measurements to be made of their level as well as that of the pilots 308 and 4 092 kc/s;

— a carrier frequency generator which supplies the carrier voltage necessary to the transmitter and receiver.

The power supply is from the mains.

II. Electrical characteristics

1. *Transmission*

1.1. *Frequencies*

Frequencies transmitted: 60 — 556 — 808 — 1 056 — 1 304 — 1 552 — 1 800 — 2 048 — 2 296 — 2 544 — 2 792 — 3 040 — 3 288 — 3 536 — 3 784 — 4 032 kc/s.

Accuracy of transmitted frequencies ± 75 c/s.

Spurious frequencies: ratio, signal transmitted to spurious frequencies, 3·5 N.

1.2. *Level*

Matched transmission: Power level in 75 ohms: variable from — 8 to — 1 N by steps of 1 N.

Accuracy of transmitted level: ± 0·025 N.

1.3. *Output impedance*

Matched transmission: 75 ohms.

A coaxial attenuator of 0·4 N loss and characteristic impedance 75 ohms is connected to the output. It enables matched sending of a variable power level from — 8·4 to — 1·4 N by steps of 1 N in an impedance of 75 ohms.

2. *Reception*

2.1. *Frequency*

The receiver is able to measure level:

— of the frequencies from the oscillator,

— of the pilot frequencies 308 and 4 092 kc/s.

2.2. *Measuring range*

— Matched: absolute power level in 75 ohms — 2 to — 7 N (if required — 8 N.

— High impedance: absolute voltage level: 0 to — 5 N (if required — 6 N).

2.3. *Measuring accuracy*

— When matched, ± 0·02 N after calibration stability of level for a variation of ± 10% of the mains voltage: ± 0·03 N.

2.4. *Input impedance*

Matched input: 75 ohms and high impedance.

2.5. *Selectivity*

6 N at ± 300 c/s.

Note. — The use of combined interstice frequencies with a selective receiver enable maintenance measurement to be made without interupting service.

ANNEX 34

MEASURING SETS USED BY THE CUBAN TELEPHONE COMPANY FOR MAINTENANCE OF CARRIER SYSTEMS ON COAXIAL CABLES

1. Types of sets described in this annex

The transmission testing apparatus mentioned in this paper is usually supplied with coaxial line and terminal equipment to the following scale:

Repeater test equipment	One only—but where the coaxial system involves more than one maintenance area, one set may be supplied to every maintenance area.
Selective measuring set for inter-supergroup and line pilots	Normally one per terminal station, but on long routes where a single coaxial link exceeds say 300 km, more may be required.
Group reference pilot test set	One for every station where coaxial groups are distributed (normally where a group distribution frame is provided).
Supergroup reference pilot test set	One for every station where coaxial supergroups are distributed (normally where a supergroup distribution frame is provided).

The main purpose of the above equipment is to enable routine maintenance measurements and adjustments to be carried out while the coaxial system is in traffic. However, it is not suitable for the extended tests which are usually necessary for the location of faults in either line or terminal equipment. For this purpose a high-frequency transmission measuring set is usually provided. This set comprises a power unit, an oscillator and send unit, and a receive unit, all in portable form. The oscillator unit is capable of sending any one of a number of discrete frequencies from a 75 ohm unbalanced source at any level in the range + 5 db to — 65 db, referred to one milliwatt. The power unit has been specially designed so that the set is equally suitable for use at either terminal stations or at dependent repeater stations where, under certain conditions, no A.C. mains power may be available; it is operated from either 200-250 volts or 100-150 volts A.C. mains, or from a portable 12 volt battery.

The facilities of this set are greatly extended by using an external variable-frequency oscillator, and the provision of such an oscillator, continuously variable from 10 kc/s to 5·2 Mc/s is strongly recommended.

The two transmission measuring sets mentioned above are usually supplied with coaxial lines and terminal equipment to the following scale:

High-frequency transmission measuring set	One per terminal station or maintenance department.
Variable-frequency oscillator	One per terminal station or maintenance department.

2. Repeater test equipment

This is the equipment used for the maintenance of line amplifiers and gain control units.

It is capable of measuring gains and losses in the following ranges:

Frequency	50 kc/s-5·2 Mc/s continuously variable.
Gain	0-89 db.
Loss	0-23 db.
Accuracy	± 0·1 db on loss, ± 0·1 db for 0 to 50 db gain.

The method of measurement involves a comparison between the loss of calibrated attenuators and the loss or gain of the equipment under test.

Additional facilities are provided for checking gain control units. Briefly, these comprise:

(a) A five-frequency crystal controlled pilot simulator.

(b) Means for measuring the 2 kc/s output from the thermistor feed circuit, and the current from the deviation relay circuit.

(c) A 50 c/s generator and a monitor for checking thermistors.

Power supplies

200-250 volts A.C., 40-60 c/s.

Maximum power consumption: 220 watts.

It should be noted that the panel under test is supplied with high and low tension from a mains unit mounted on the repeater test equipment.

Mechanical construction. — The repeater test equipment is mounted on two separate 3 ft bays. A test-jig is also supplied for holding a panel under test. The whole equipment is intended to be set up on a convenient table or bench.

3. Transmission measuring equipment type 74610

This is the portable equipment used for measuring the line control and inter-supergroup pilots.

It measures selectively, in the presence of traffic, through and terminated levels at the following frequencies:

60 kc/s	Line regulation pilots	308 kc/s	2 296 kc/s	Intersupergroup pilots.
2 604 „		808 „	2 544 „	
2 792 „		1 056 „	3 040 „	
4 092 „		1 304 „	3 288 „	
		1 552 „	3 536 „	
		1 800 „	3 784 „	
		2 048 „	4 032 „	

The level range is — 5 db to — 45 db relative to 1 mW in 75 ohms, with an accuracy of ± 0·5 db, and — 45 db to — 65 db referred to 1 mW in 75 ohms, withan accuracy of ± 1·0 db.

Power supplies

220 volts H.T., 70 mA, and 12.6 volts A.C. centre-tapped filament supply, both obtained from normal system supplies via a special separately fused outlet on the spare amplifier positions on the repeater bays.

Mechanical construction

Contained in one light portable aluminium-alloy box. Size $19^1/_8 \times 10^5/_8 \times 9^7/_8$ (486 × 270 × 250 mm). Weight approximately 30 lb (13·5 kg).

4. Selective level measuring set

This is the portable equipment used for measuring the group reference pilot 84.080 kc/s pilot in the presence of speech, signalling and the 84,140 kc/s pilot.

The levels are measured with reference to 1 mW in 75 ohms and are selected by means of a switch on the front panel. The switch positions are as follows:

Group distribution frame. Receive . . . . { — 28 terminated
— 27 through

Group distribution frame. Transmit	— 57 terminated — 57 through
Measure Group Pilot	— 52 terminated
Measure Supergroup Pilot	— 52 terminated
Pilot	— 5
Pilot	+ 5

Normally measurements are made on the " measure Group Pilot, — 52 Terminated " position, at various points in the injection and distribution circuits. The nominal level at all these points is arranged to be — 52 db referred to 1 mW.

Measurements at the group distribution frame (G.D.F.) will only be made under two conditions:

(a) during initial lining-up when the " terminated " position will be used;

(b) under fault conditions when only an indication of the presence or absence of the pilot is required, and when the " through " position will be used.

The " Measure supergroup pilot " position is required only when the set is used in conjunction with the selective level measuring attachment for measuring the supergroup pilot (see paragraph 5 below).

The " Pilot — 5 " and " Pilot + 5 " positions are used in connection with the lining-up of the meter circuit.

Power supplies

200-250 volts A.C. 40-60 c/s.

Mechanical construction

Contained in one portable aluminium-alloy box.
Size: $17^3/_4'' \times 9^1/_8'' \times 9''$ (451 × 232 × 229 mm).
Weight approximately 20 lb (9 kg).

5. Selective supergroup pilot level measuring attachment

This, is used with the group level measuring set (paragraph 4 above) for the measurement of the supergroup reference pilot.

The attachment consists basically of a demodulator unit together with associated amplifiers. The 411·920 kc/s signal is mixed with 496 kc/s derived from the system, and the resulting 84,080 kc/s signal is measured by the group level measuring set in the position " measure supergroup pilot ".

Power supplies

200-250 volts A.C. 40-50 c/s
Power consumption: 15 watts.

Mechanical construction

Contained in one portable aluminium-alloy box.
Size: $17^3/_4'' \times 9^7/_8'' \times 9''$.
Weight approximately 20 lb.

6. High Frequency Transmission measuring set

This is the set used for tests of a general nature on line and terminal equipment. It cannot normally be used while the system is in traffic. It comprises a sending unit, a receiving unit and a power unit.

The send unit will transmit (into 75 ohms unbalanced circuits) any level between + 5 db and — 65 db referred to 1 mW at any one of the following frequencies: 60, 84, 300, 412, 808, 1 500, 2 000, 2 500, 3 000, 3 400, 3 800, 4 000 kc/s.

The sending level accuracy is ± 0·25 db at a sending level of 0 db and ± 0·5 db at all other levels.

The receive unit will measure through and terminated levels on 75 ohms on unbalanced circuits in the range + 25 db to — 65 db, referred to 1 mW. Its frequency range is 60-4 500 kc/s.

The measuring accuracy is ± 0·25 db for meter readings of + 5 db to — 5 db, and ± 0·5 db for meter readings below — 5 db.

Power supplies

either 100-150 volts A.C.: 40-60 c/s
or 200-250 volts A.C.: 40-60 c/s
or 12 volt D.C.

Mechanical construction

Contained in three portable metal boxes, each $17\frac{1}{2}'' \times 9^1/_8'' \times 8^7/_8''$.

7. Variable frequency oscillator

This is the variable frequency oscillator which can be used in conjunction with the high frequency transmission measuring set.

Its frequency range is 10 kc/s-5·2 Mc/s, continuously variable.

Power supplies

200-250 volts A.C.: 40-60 c/s.

Mechanical construction

Contained in one portable metal box.

ANNEX 35

MEASURING EQUIPMENT USED BY THE DUTCH TELEPHONE ADMINISTRATION FOR THE MAINTENANCE OF CARRIER SYSTEMS

The Dutch Administration has portable high frequency equipment to make maintenance measurements in service in the high frequency part of the carrier systems and of groups on lines. This portable equipment may also be used for the localization of faults.

The measuring equipment is for use on systems where the channel spacing is 4 kc/s (following the recommendations of the C.C.I.F.). It might be added that this equipment might also be used for carrier systems with a spacing of 6 kc/s between channels, systems which are used on a large scale in the Dutch National Network.

Because of its special arrangement this equipment is particularly easy to operate and in the event of mis-operation it will not send a disturbing signal on the channels of the links being measured.

Description

The equipment consists of a sending part and a receiving part. For transmission measurements two equipments are used one at each end of the link; one equipment then sends the required signals into the system or cable, whilst the other measures the signals received. The equipment continues to function normally during measurements which do not affect traffic.

The sending part of the measuring equipment is so arranged that it can only produce frequencies situated between two successive channels. The spacing between the virtual carrier frequencies is, in the systems to be measured, 4 kc, and between the signal to be measured and the carrier frequencies is 80 c/s. The frequencies do not cause disturbance in the voice channels, and the signals may be measured in so selective a manner that neither the carrier leaks nor speech signals interfere with the measurement.

Since the channel to be measured is situated either in the lower sideband or in the upper sideband the measuring frequency may be displaced by 80 c/s, either upwards or downwards.

There may therefore be transmitted a series of frequencies of $n \times 4$ kc/s — 80 c/s and $n \times 4$ kc/s + 80 c/s and in no circumstances any other frequencies. The selection between " the lower sideband " and " upper sideband " is made by means of a key which may be placed in the position " — 80 c/s ", or " + 80 c/s ". When the key is in the position " C.C.I.F. " the selection is made automatically (basic group A in the upper sideband and the other basic groups in the lower sideband).

The selection of the required frequency is very simple. One only sets the equipment to the required channel; an indicator shows when the setting is correct.

The range of frequencies lies between 12 and 300 kc/s. The measuring signals which are multiples of 4 kc/s and 6 kc/s are transmitted automatically when required. For measuring signals which are not multiples of 6 kc/s a button should be pressed to ensure that disturbing signals are not applied to systems which have 6 kc/s spacing.

The *receiving part* consists of a level measuring set enabling the selective measurement of signals. The selective measuring set, for convenience, is coupled to the oscillator so that it is automatically in agreement with the frequency sent to line.

It is possible to measure these types of signal:

(a) the frequencies displaced by 80 c/s in the positive or negative sense from the carrier frequencies (80 c/s in the channel in question),

(b) the frequencies displaced by 800 c/s in the positive or negative sense from the carrier frequency (800 c/s in the channel),

(c) the carrier frequencies.

Case (a) is for the measurement of the signal level sent from the equipment in the same station and the measurement made on a link on which a second equipment sends similar frequencies at the distant end.

The signals measured in *case (b)* are obtained when 800 c/s signals are sent on each channel at audio frequency by a separate oscillator.

This arrangement is used for the localization of faults on the carrier system. The *case (c)* is for the measurement of carrier leak.

In the positions " 800 c/s " and " carrier leak " the output of the sending equipment is blocked so that it is not able to send any signals.

The input of the selective measuring set has a high impedance and is balanced so that the equipment might be connected at all points of the system in service without causing faults or additional loss.

The equipment for high frequency measurements is equipped with a telephone to allow the establishment of telephone communication between two measuring equipments in different repeater stations: these communications are established on a 2-wire speaker circuit.

Technical data

A. Sending part

Frequency band

In the band of frequencies from 12 to 300 kc/s all multiples of 4 kc/s ± 80 c/s may be transmitted with the exception of 60 kc/s ± 80 c/s. (Assuming the existance of a pilot frequency of 60 kc/s.

Accuracy of transmitted frequency

The maximum deviation of the transmitted frequency relative to its nominal value is $1{\cdot}0 + f \,.\, 10^{-5}$ c/s (f is the frequency transmitted in c/s).

Output impedance

Around 7 000 ohm balanced with a parallel capacitance of the order of 350 p f. of the connecting leads.

Output power

(Closed by 75 ohms.) Adjustable between — 60 db and 0 db relative to 1 mW in 150 ohms (0·387 V).

B. Selective measuring set

Frequency band

It is possible to make measurements in the frequency band of 12 to 300 kc/s for the following cases.

(a) Measure the 80 c/s on the channels in the form of multiples of 4 kc/s ± 80 c/s.

(b) Measure the 800 c/s on the channels in the form of multiples of 4 kc/s ± 800 c/s.

(c) Measure the carrier leak in the form of multiples of 4 kc/s.

Bandwidth

For the cases *(a)* and *(c)*: around 20 c/s. For case *(b)*: around 40 c/s.

Sensitivity

The installation enables the reading of levels between — 70 db and + 20 db relative to 1 mW in 150 ohms (0·387 V). The sensitivity may be adjusted in steps of 10 db.

Accuracy

The absolute error of measurement including the characteristic of the frequency is:

for the case *(a)* and *(c)* $<$ 0·5 db
for the case *(b)* $<$ 1 db.

C. General

Power Supply

220 V, 50 c/s approximatively 365 VA.

Dimensions and weights

Depth 600 mm (not including projections)
Width 540 mm (not including projections)
Height 1 400 mm (total)
Weight, approximately 390 lb.

ANNEX 36

METHOD USED BY THE TELEPHONE ADMINISTRATION OF THE FEDERAL GERMAN REPUBLIC FOR THE MEASUREMENT OF ATTENUATION DISTORTION ON UNLOADED SYMMETRICAL PAIRS WITH CARRIERS SYSTEMS

For reference measurements as well as for maintenance measurements on carrier systems on unloaded symmetrical cable pairs, the Telephone Administration of the Federal German Republic use the following measuring apparatus:

(a) for reference measurements:

test current generators,
wideband and selective level measuring sets
level oscilloscopes.

(b) for maintenance measurements:

apparatus for measuring interstice frequencies.

The use of this apparatus is discussed briefly below and the principal characteristics of the level oscilloscopes and of the arrangement for measuring the interstice frequencies are given.

A. To verify the *reference values* of a carrier system two different methods may be used:

First Method: The various measuring pilots at discrete frequencies are transmitted successively, all frequencies chosen being set and adjusted manually at the transmitting station: at the receiving station these are measured by means of a selective or wideband measuring set. The measuring apparatus is connected to the line as in figure 1.

Characteristics

Frequency band	Measuring range (absolute voltage level)
Generator of 4 up to at least 620 kc/s	— 7·5 to + 2 N
Measuring set of 4 up to at least 620 kc/s	— 13 to + 3 N

Second Method: To verify and correct the attenuation distortion in a more rapid and simple manner the measuring apparatus used indicates directly the curve " level-frequency " on an illuminated screen.

For this application the measuring frequency is varied continuously and periodically between arbitrary limits, this variation being effected by a supplementary arrangement.

On the receiving side a portable oscilloscope is used. The horizontal trace of the beam is obtained automatically from the received frequency by means of a frequency descriminator. This may be varied depending upon the frequency band used (see " characteristics "). In order to obtain a record, the curve on the screen of the oscilloscope may be traced by hand or photographed. Measurements are also made as shown in figure 1.

Characteristics of the measuring oscilloscope

Size of image on the luminous screen: width 60 mm, height 50 mm. The screen has some after glow.

Band of frequencies used:	0·3	to	20 kc/s
	4	to	60 kc/s
	4	to	300 kc/s
	4	to	600 kc/s
	600	to	1 200 kc/s.

To study a restricted frequency band, a special arrangement enables any part of these bands up to a decade to be expanded.

Measuring range . . . . — 7·5 to + 2·9 N
(absolute voltage level)

Recording range . . . . 2·4 N
It is possible to expand of 0·7 N up to the maximum height.

Range switch: The total range of — 5 N to + 2 N may be covered in steps of 1 N or 0·1 N.

Average acuracy of measurement . . . . ± 0·02 N.
in the band from 10 to 600 kc/s
and for levels greater than — 5·5 N.

Variation of level just noticeable when in most sensitive condition ± 0·01 N

Input impedance

below 10 kc/s . . . . greater than 30 000 ohms
above 10 kc/s . . . . ,, ,, 5 000 ohms
suitable to values of . . . . 600, 150 or 75 ohms.

Power Supply: 110/220 V; 40 to 60 c/s; approximated 95 VA.

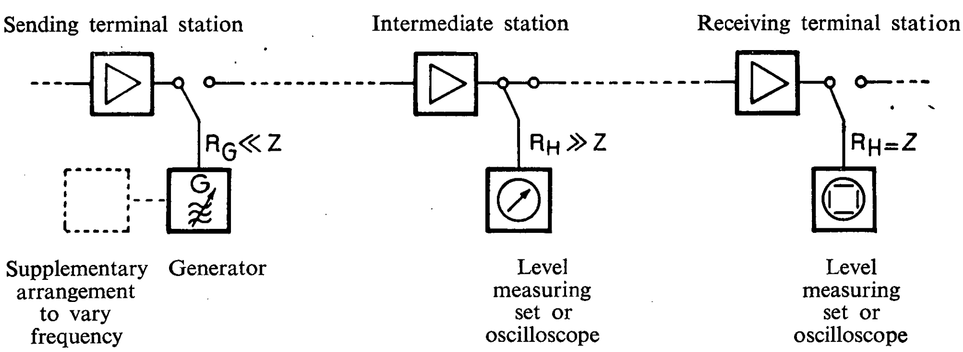


FIGURE 1. — *Reference measurements carried out on a carrier system line*

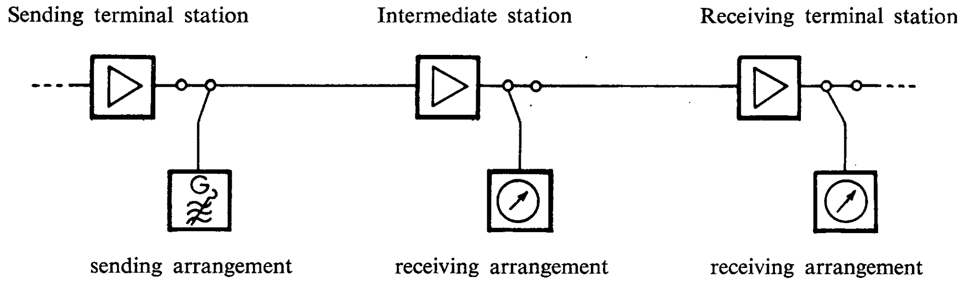


FIGURE 2. — *Maintenance measurements made on a carrier system line in service by means of apparatus for measuring interstice frequencies*

Note: The apparatus is also used to measure the following:

Impedances	between 30 and 3 000 ohms
return losses	less than 6 N.

B. For *the maintenance* of carrier systems the apparatus is used to measure interstice frequencies. Measurements of line attenuation distortion can be made —as shown in figure 2—without the necessity of taking channels out of service: in such cases the reference values are checked.

Measuring frequencies of a suitable range are applied successively at the sending point, that is to say at the point where the amplifier of the sending station is connected to the line, the impedance of the sending source being high compared to that of the line. The voltage level at the sending point is automatically maintained to a constant value independant of variations with frequency of this impedance.

The voltage level at the output of intermediate repeaters and of the terminal repeaters are checked by means of a special selective measuring set.

All interstice frequencies chosen correspond to a frequency of 80 c/s in a telephone channel. In conformity with scheme 2 (see fig. 15 of Volume III of the *Green Book*) recommended for systems of 5 basic groups and also for the schemes of basic supergroup (see fig. 17 of Volume III) proposed for systems of 10 basic groups (system still under study) the interstice frequencies deviate from the virtual carrier frequencies by

— 80 c/s in the band of 12 to 252 kc/s and
+ 80 c/s in the band of 312 to 552 kc/s.

The interval between the interstice frequencies is 12 kc/s the supplementary frequency of 15,920 c/s being interposed.

The absolute voltage level intended for the measurements corresponds to a level of power of — 1·2 N reference to a relative level of zero.

Figure 3 represents the simplified arrangement of the apparatus: the sending apparatus and the receiving apparatus are together in one carrying case.

Characteristics

Sending equipment

Frequency available:

11 920	15 920	23 920	35 920	47 920	59 920	71 920	83 920	95 920
107 920	119 920	131 920	143 920	155 920	167 920	179 920	191 920	203 920
215 920	227 920	239 920	251 920 c/s					
312 080	324 080	336 080	348 080	360 060	372 080	384 080	396 080	408 080
420 080	432 080	444 080	456 080	468 080	480 080	492 080	504 080	516 080
528 080	540 080	548 080	552 080 c/s.					

Note: All the interstice frequencies above are used on the telecommunications network of the Federal German Telephone Administration without affecting service. There is also the possibility of suppressing certain frequencies which might disturb a programme circuit for example which is routed on a carrier system.

Level of voltage at sending point:

in the case of a 75 ohms impedance . . . . . — 6·5 to — 1·5 N
in the case of a 37·5 ohms unbalanced impedance . . . — 6·5 N
(for example at the input of the basic supergroup equipment)

Accuracy of sending level (the impedance at the sending point having its nominal value) . . . . ± 0·02 N

Variation of sending level
if the variations of this impedance does not exceed ± 15% ± 0·01 N

Shunt loss
caused on a line of nominal impedance of 150 ohms less than 0·02 N

Receiver

Frequencies available: see arrangement of sending equipment.

Measuring range . . . . — 8·0 to 0 N

Range switch: The total range may be covered in steps of 1.0 N.

Accuracy of measurement
at the point of maximum deflection. . . . . less than ± 0·02 N
Input impedance . . . . greater than 10 000 ohms

Selective filter
Distortions in the pass band of ± 20 c/s . . . . less than 0·02 N
Attenuator up to ± 170 c/s . . . . greater than 5 N

Power Supply: 110/220 V; 40 to 60 c/s approximately 70 VA.

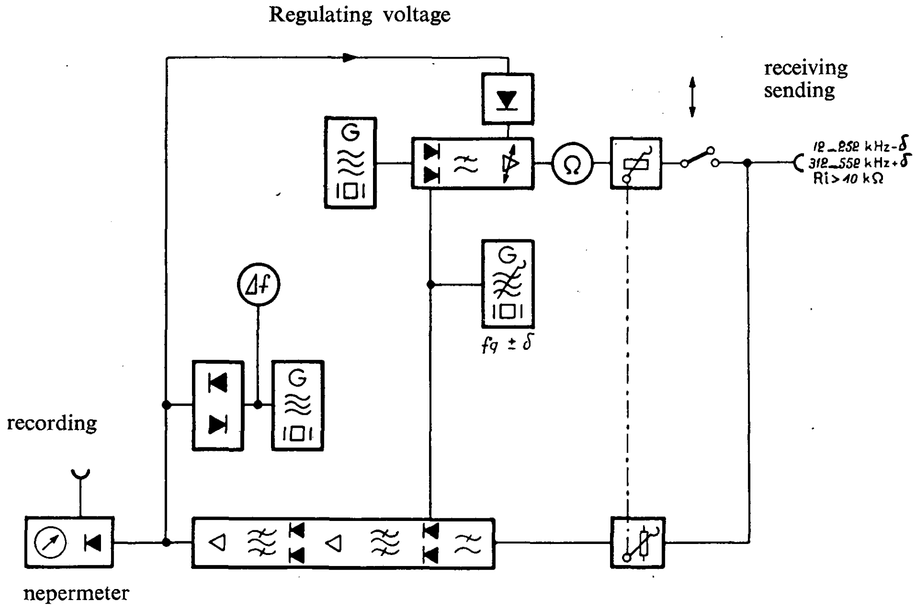


FIGURE 3. — *Apparatus for measuring interstice frequencies*

Note: The apparatus which measures the interstice frequencies is also used for the localization of faults affecting the carrier equipment. Complete with a recorder, this arrangement enables variations in level along the line to be recorded.

With the aid of the arrangement in figure 3 it is also possible to measure the modulus of the input impedance at the sending point as a function of frequency.

ANNEX 37

METHOD OF MEASURING CHARACTERISTIC IMPEDANCE OF A COAXIAL PAIR TERMINATED BY A RESISTANCE ROUGHLY EQUAL TO ITS CHARACTERISTIC IMPEDANCE

(Memorandum prepared by Standard Telephones and Cables Ltd)

Object of the memorandum

To describe the method of measuring the characteristic impedance of coaxial cores at frequencies of the order of 1 Mc/s by measuring the sending end impedance with the core terminated at its distant end by a resistance of the same order as the characteristic impedance of the pair.

Need for the method

For some time past it has been customary to evaluate the attenuation and characteristic impedance of coaxial pairs, at frequencies of the order of 1 Mc/s, from measurements of the sending-end impedance with the distant end of the core (1) open-circuited, and (2) closed-circuited, using a radio frequency impedance bridge. Although the attenuation obtained from this test can be relied upon in the normal way to within about $1^0/_{00}$ which is satisfactory, the characteristic impedance is subject to much greater uncertainties. In the consideration of the value of coaxial circuits for the transmission of carrier telephony, the reflections due to impedance irregularities which have been found to occur in practice have not given undue concern; but for good television working higher quality in the final circuits is desirable, and a more accurate knowledge of the characteristic impedance of individual lengths of cable is desirable to this end. The terminated method of test described herein can be relied upon for a sufficiently accurate determination of characteristic impedance provided that adequate care is taken in its application. A means of assessing the probable accuracy of the result obtained on any pair is described herein.

The terminated test cannot be used for the determination of attenuation with any reasonable degree of accuracy. For this the open and closed circuit test must be retained. Furthermore, when employing the terminated test for the measurement of characteristic impedance, the quarter wavelength frequencies must be found with the distant end of the pair open or closed.

Description of the terminated tests

The terminated test necessitates the measurement of the sending end impedance of the coaxial pair at two adjacent quarter-wavelength frequencies with the distant end terminated with a resistance approximately equal to the characteristic impedance of the pair. The characteristic impedance is the mean of the two readings. Bridge errors are reduced to a minimum by using a termination of such value that both readings involve the same tens decade of the bridge.

Precautions to be observed

Provided that the quarter wavelength frequency is accurately determined and that the bridge readings both involve the same tens decade, the main sources of possible errors are (1) unsuitability of the termination (2) faulty testing (3) irregularities within the pair under test. In order to get the desired accuracy in the result the first two sources must be eradicated. Then any irregularity will be apparent.

1. *Terminating Resistance.* — The terminating resistance must be of such a type that when fitted into the distant end of the pair its value at high frequencies is substantially equal to its D.C. resistance. A criterion of this is how the sending end impedance readings on homogenious pairs correspond with those to be expected according to the theoretical considerations given in the next paragraph and in figure 2. A type SR 1192 resistance plugged into a type C 15 adaptor has been found to be suitable. It is useful to use the same resistance for balancing the impedance bridge initially.

2. *Testing errors.* — To some extent it is not easy to distinguish testing errors from the effects of pair irregularities; but when the cable is one known to be normally of good quality, erratic discrepancies from the results to be expected from theory would suggest the presence of testing errors. As the characteristic impedance can be so easily worked out from the bridge readings at a glance, it is a very simple matter to check suspected errors without delay.

3. *Pair irregularities.* — If the terminating resistance is satisfactory and the testing faultless, any remaining discrepancies must be attributed to irregularities in the pair under test.

Theoretical considerations

In a uniform transmission line of length l, having propagation, attenuation and phase constants of γ, α and β, and characteristic impedance Z_C, and terminated with an impedance Z_R, the sending-end impedance is given by:

$$Z_E = Z_C \frac{Z_C \sinh pl + Z_R \cosh pl}{Z_R \sinh pl + Z_C \cosh pl} \qquad (1)$$

$$= Z_C \frac{\dfrac{Z_R}{Z_C} + \text{th}\, pl}{1 + \dfrac{Z_R}{Z_C}\, \text{th}\, pl} \qquad (2)$$

where

$$\text{th}\, pl = \text{th}\,(al + j\,bl) = \frac{\text{th}\, al + j\,\text{tg}\, bl}{1 + j\,\text{th}\, al\, \text{tg}\, bl} \qquad (3)$$

$$= \frac{\coth al - j \cot bl}{1 - j \coth al \cot bl} \qquad (4)$$

At even $\frac{\lambda}{4}$ *wavelengths,* $\tan \beta l = 0$, so, from (3): $\tanh \gamma l = \tanh \alpha l$

$Z_R + \tanh \alpha l$

$$\text{Hence} \quad Z_E = Z_C \frac{\dfrac{Z_R}{Z_C} + \text{th}\, al}{1 + \dfrac{Z_R}{Z_C}\, \text{th}\, al}$$

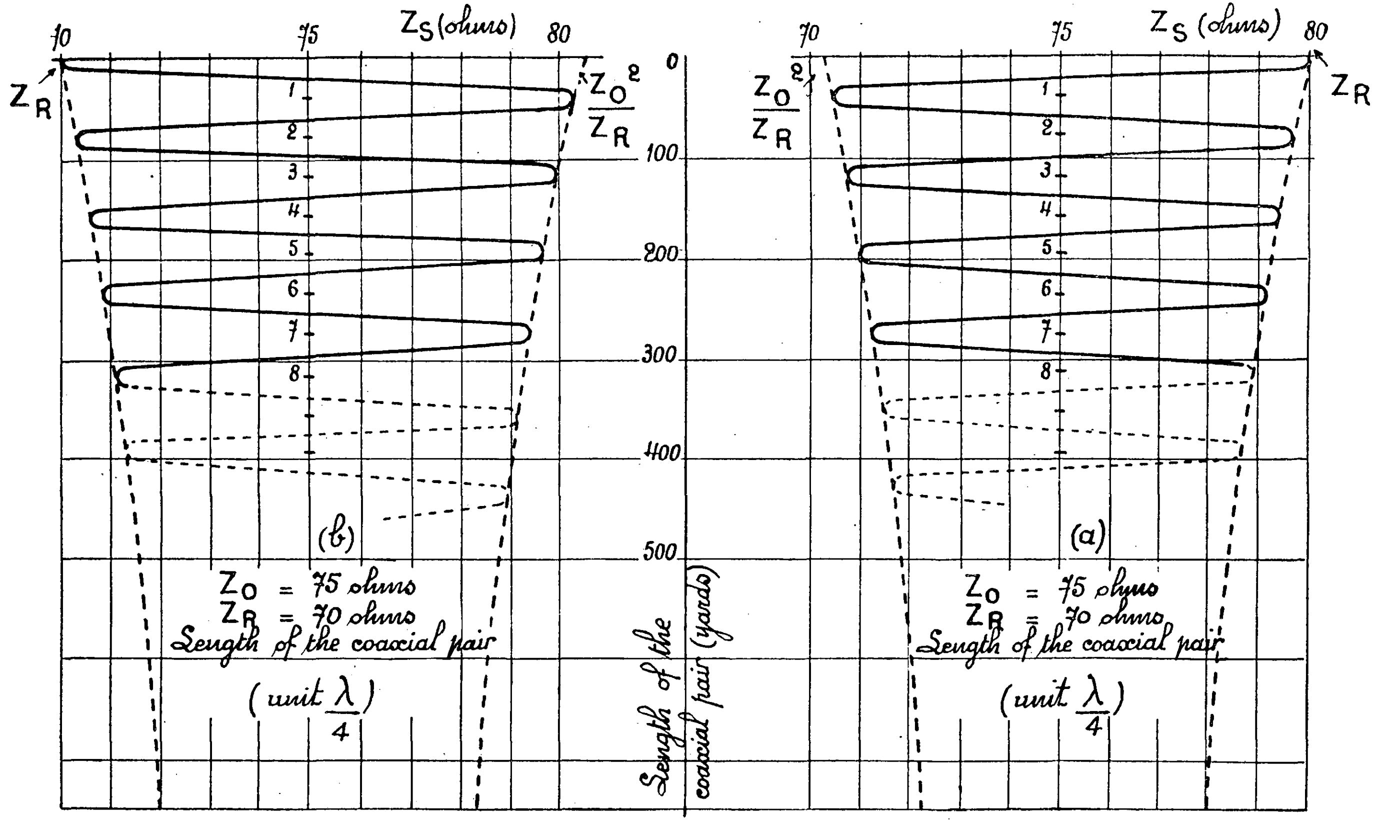


FIGURE 1. — *Variation of real part of Zs as a function of the length of a coaxial pair at 2 Mc/s (coaxial pair type 370 DS)*

and as αl *wa* 0, Z_E — Z_R.

At odd $\frac{\lambda}{4}$ *wavelengths,* $\cot \beta l = 0$, so, from (4): $\tanh \gamma l = \coth \alpha l$

$$\text{d'où} \quad Z_E = Z_C \frac{\frac{Z_R}{Z_C} + \coth al}{1 + \frac{Z_R}{Z_C} \coth al} = Z_C \frac{\frac{Z_C}{Z_R} + \text{th } al}{1 + \frac{Z_C}{Z_R} \text{th } al}$$

and as αl *wa* 0, Z_E *wa* $\frac{Z_C^2}{Z_R}$.

The results above are only true when Z_C and Z_R are purely resistive. This is nearly enough so for the present purpose when considering coaxial cable at frequencies of the order of 1 Mc/s.

Figure 1 shows the variation of the real part of Z_S with length for coaxial pair type 370 DS at a frequency of 2 Mc/s assuming $Z_C = 75$ ohms, for two cases, 2_R equals 80 ohms (curve *a*) and Z_R equals 70 ohms (curve *b*). The envelopes of the curves are shown dotted. The effect of attenuation in bringing the envelope of Z_S in towards Z_C as the length increases is to be observed, also that Z_S tends towards Z_R at even $\frac{\lambda}{4}$ wavelengths.

Figure 2 shows the upper side of the envelope for frequencies of 1, 2 and 2·5 Mc/s, and for terminations of 15, 5 and 2 ohms more than Z_0, assuming Z_0 to be of the order of 75 ohms. From this graph the theoretical value of Z_S can be obtained sufficiently accurately for checking actual measurements at *even* quarter wavelengths for all lengths up to 1 250 yards and all frequencies between 1 and 2·5 Mc/s. Thus a length of 379 yards of coaxial pair with a value of $\frac{v}{c} = 0{\cdot}965$ where v is the velocity of propagation on the pair and c is the velocity of propagation of an electromagnetic wave in free space would have an even quarter wavelength at 2·5 Mc/s. If on terminating it with 78 ohms the measured value of Z_S at 2·5 Mc/s were 77·3 ohms, and at the adjacent quarter wavelength frequency (2·3 Mc/s) 74·8 ohms, then $Z_0 = 76{\cdot}0$ ohms, the mean of the two readings. The higher reading can be checked from the graph (fig. 2) in the following way: Since $Z_R = 78$ and $Z_0 = 76$, $Z_R - Z_0 = 2$. Hence, from the graph, a length of 379 yds projected up to the line for $Z_R - Z_0 = 2$ at 2·5 Mc/s, gives a corresponding value of $Z_S - Z_0$ of

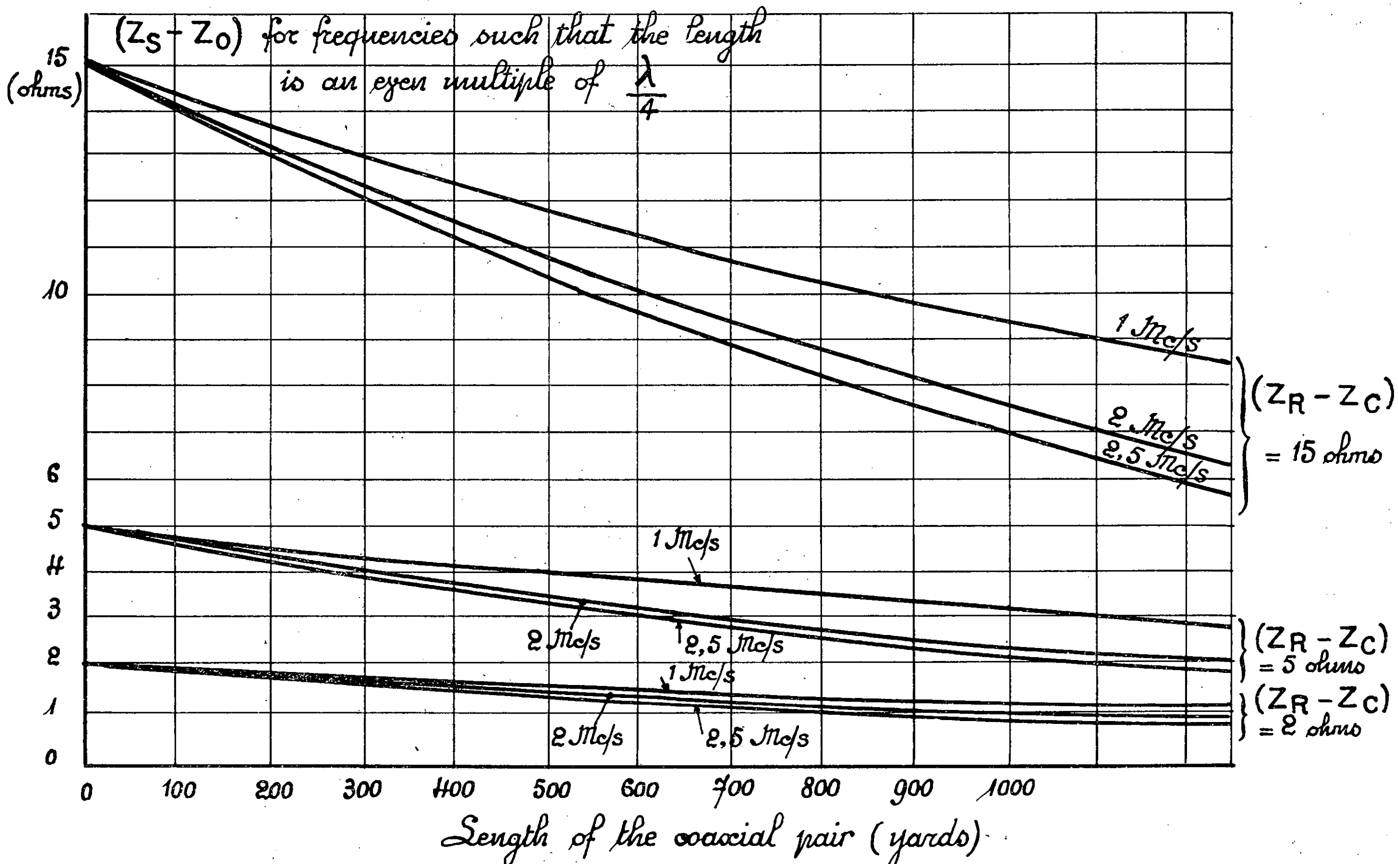


FIGURE 2. — *Graph for checking even quarter wavelength readings of sending end impedance (coaxial pair type 370 DS)*

1·5 ohms. $S_0 Z_S = Z_0 + 1{\cdot}5 = 77{\cdot}5$ ohms, which checks near enough with the measured value (77·3 ohms). Interpolation must be adopted when necessary in using the graph for intermediate values of $Z_R - Z_0$ and frequency. The graph can be used when Z_R is less than Z_0 by reading $Z_0 - Z_R$ for $Z_R - Z_0$ and $Z_0 - Z_S$ for $Z_S - Z_0$. It then applies only to the lower of the two bridge readings.

ANNEX 38

MEASUREMENT OF PHASE DISTORTION ON A LOOPED TELEVISION CIRCUIT

(Note by the British Broadeasting Corporation)

The principle adopted was to determine the points at which phase angle a rotation of π radians occurred and then to determine very accurately the frequency of these points. The signal was applied to the loop and to a local attenuation network through a dividing amplifier which had very low phase distortion and the output from the loop circuit was opposed in a hybrid coil to the output of the attenuator. The attenuation and frequency were varied until null points were achieved. A sensitive, tuned detector, was employed in order to obtain a sensitive indication of any difference between the two opposing signals. The frequency of the tone source was then measured with a crystal-type frequency measuring circuit and it is believed that the π points were determined at frequencies which were accurate to within 0·1 %.

This was used on a loop where total delay was 25 microseconds; and an accuracy of 0·025 microseconds was therefore achieved.

ANNEX 39

METHODS PROPOSED FOR THE MEASUREMENT OF PHASE DELAY IN TELEVISION EQUIPMENTS AND IN TELEVISION TRANSMISSION SYSTEMS

(Note by the British Telephone Administration)

Introduction

The phase delay (in seconds) in a linear network or transmission system is the ratio of the total phase shift in radians (usually insertion phase shift) at the frequency under consideration to the angular frequency in radians per second. It can therefore be measured by measuring the total phase shift, but difficulty arises in the following cases:

(a) When the two ends of the circuit are not available at the same place, e.g. in a one-way relay system.

(b) When the total transmission time on the system is very large compared with the small variations in phase delay with frequency which it is desired to measure and equalise. This occurs, for example, in a long coaxial cable system.

A new method is proposed to overcome these difficulties.

Principle of method

The phase delay of a transmission system at harmonics of a frequency f_1, say, relative to the phase delay at this frequency, can be determined by transmitting a known periodic waveform with this fundamental frequency f_1, rich in harmonics, and recording and analysing the received waveform by Fourier analysis. For example, suppose the following voltage is transmitted:

$$a_1 \sin \omega_1 t + a_2 \sin 2 \omega_1 t + a_3 \sin 3 \omega_1 t + \ldots$$

and the received voltage is:

$$b_1 \sin \omega_1 (t - \mathrm{T}) + b_2 \sin [2\omega_1 (t - \mathrm{T}) - \varphi_2] + b_3 \sin [3\omega_1 (t - \mathrm{T}) - \varphi_3] + \ldots$$

Then the phase delay at $f_1 = \mathrm{T}$

$$\text{at } 2f_1 = \mathrm{T} + \frac{\varphi_2}{2\,\omega_1}$$

$$\text{at } 3f_1 = \mathrm{T} + \frac{\varphi_3}{3\,\omega_1} \text{ and so on,}$$

The value of T cannot be determined unless a loop circuit is available but this is usually unimportant compared with a knowledge of the variation of phase delay with frequency which it is desirable to equalise to make the received waveform a true reproduction of the transmitted waveform.

An electrical method for analysing the received waveform

The recording and Fourier analysis of the received waveform is rather cumbersome and the following electrical method of analysis is proposed instead.

Referring to figure 1, at the sending end an oscillator set to frequency f_1 feeds a unit A which will produce a waveform of accurately reproducible type such as a narrow pulse, a square waveform, a half-sine waveform, etc. The narrow pulse waveform is probably the best as harmonics in such a waveform are of nearly uniform amplitude up to a high frequency the value of which depends on the pulse width. This signal is transmitted to the circuit under test. At the receiving end the signal is passed through a low-pass or band-pass filter to filter out the fundamental component at frequency f_1 free from the harmonics. The sine wave signal at frequency f_1 is fed through a variable phase shifter, which can be any known convenient type, to a Unit B identical as far as possible with the Unit A at the transmitting end. The level fed to Unit B would be the same as that fed to Unit A.

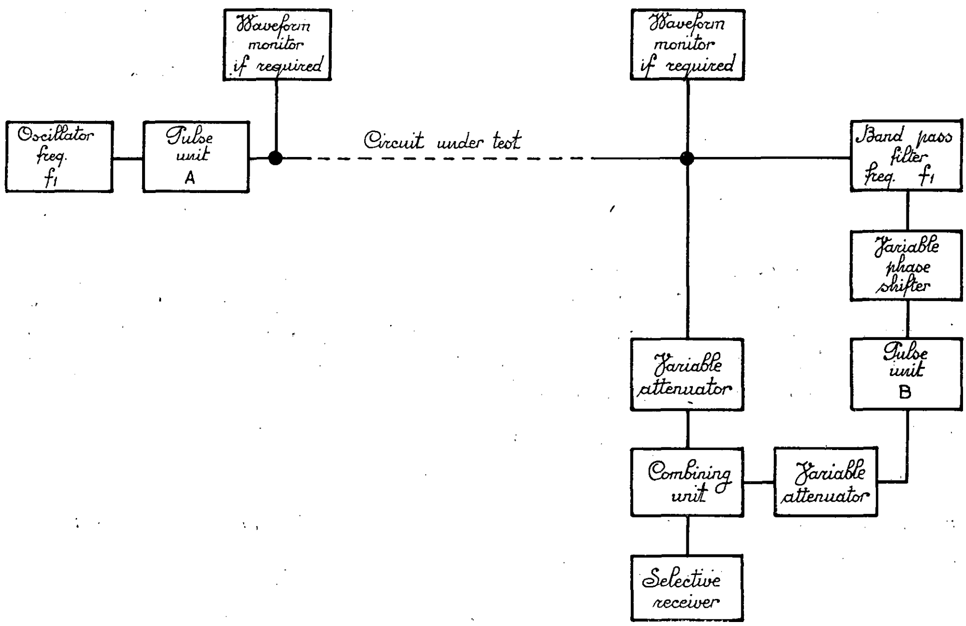


FIGURE 1. — *Method proposed for measuring " attenuation-frequency " and " phase delay-frequency " characteristics of a circuit*

The pulse output from Unit B is then fed via a variable attenuator to a combining Unit and here it is combined with the signal received over the circuit under test after the latter has passed through a variable attenuator. The combining unit may consist, for example, of two valves feeding a common anode load, the two pulse signals being applied to the grids. The output of the combining unit is then fed to a selective receiver which might be a normal communications type receiver.

The method of operation would be as follows:

The selective receiver would be tuned to frequency f_1 and the variable phase shifter and one or both of the variable attenuators adjusted to obtain zero output from the combining unit, and the positions of the attenuators and phase shifter would be noted. The selective receiver would then be tuned to frequency $2f_1$ and the same process repeated. This would then be repeated at $3f_1$, $4f_1$, etc. The phase shifter could, if desired, be directly calibrated in phase delay at frequency f_1, although a different calibration would then be required for each value of f_1 used. If it was calibrated at frequency f_1, the phase delay at frequency $2f_1$ relative to that at f_1 would be given directly by the change in the setting of the phase shifter in going from f_1 to $2f_1$ and the relative gain or loss in the circuit under test at $2f_1$, relative to f_1, could be obtained from the attenuator settings at the two frequencies. The same applies for $3f_1$, $4f_1$, etc.

It will be noted that the system is applicable when the transmitting and receiving ends are separated and when the total delay, as distinct from the variation of delay with frequency, is large.

It should be noted that the frequency f_1 is quite arbitrary but the lower it is made the larger will be the number of frequencies of measurement in a given frequency band. If it is desired to cover the whole frequency range from say 50 c/s to 4 Mc/s or higher, a number of values of f_1 would be required and two separate sets of equipment for different values of f_1 might be more convenient than combining all values of f_1 in one set.

A square wave rather than a narrow pulse wave might be more convenient for the lower value or values of f_1, as visual information on square wave response may be useful for other purposes. Monitoring waveform oscilloscopes are shown in figure 1 and would be useful if the interest is in the shape of the waveforms rather than amplitude/frequency and phase/frequency response of the circuit. If a loop circuit is being measured the second Unit B is not necessarily required. Unit A could then serve the dual purpose of producing the transmitted signal and the comparison signal but the latter would have to be produced by passing the transmitted signal through a variable delay network having constant loss and delay independent of frequency.

Conclusion

The proposed method of measuring the phase delay/frequency characteristic, and if desired the amplitude/frequency characteristic of a television circuit appears to have several advantages over previously proposed methods, particularly where a loop circuit is not available. The equipment required is simple in form and the accuracy of the method will largely depend on the reproducibility of identical characteristics in the Units A and B.

The equipment could be used to give information of the square waveform or pulse response of the circuit at the same time as the amplitude/frequency and phase/frequency response, and this combination of facilities to measure time response and amplitude and phase response in the same equipment may prove very useful.

The method outlined above was first considered by the British Administration in 1939 but was not then developed owing to the intervention of the war.

Note. — The British Administration has recently constructed and tested apparatus, of the type described in this annex, for measuring phase delay. Satisfactory results have been obtained in the field; with a pulse length of 0·1 microseconds the phase delay of quadripoles may be measured with an accuracy of 0·01 microsecond when both pairs of terminals of the quadripole are accessible at the same point. Satisfactory results have also been obtained when the two pairs of terminals are not at the same point but with somewhat less accuracy.

It is necessary for further experience to be obtained using this apparatus (and apparatus for measuring group delay) on complete television systems before a firm recommendation can be made.

The effect of non-linear elements in the transmission system, such as devices for restoring the direct current component, have not yet been studied, but it is thought that measurement of this type should be made, whenever possible, only on the linear parts of the system, in case it does not prove possible (in the course of time) to correctly interpret the results of measurements made on the non-linear parts.

ANNEX 40

METHOD OF MEASUREMENT OF GROUP DELAY BETWEEN THE DISTANT ENDS OF A CONNECTION

(Note by the French Telephone Administration)

The reference frequency F_0 (see fig. 1) and the variable frequency F are amplitude modulated by the frequencies f_0 and f respectively.

f_0 and f have a low value so that in the largest intervals $F_0 - f_0$, $F_0 + f_0$ or $F - f$, $F + f$ the variations of attenuation and group delay are negligible. In order to ensure a constant phase relation between the two modulating frequencies f is obtained by the multiplication of f_0; in other terms $f = f_0 \times n$.

The two modulated waves are applied to the line to be measured. At the receiving end the two waves are detected, the modulating frequencies f_0 and f separated by filters and the frequency f_0 is multiplied by the factor n. The phase difference $\Lambda\varphi$ between the two waves of the same frequency is then measured.

If the envelope of the frequency F_0 at the input to the line is in the form $I_0 \sin (\omega_0 t + d)$ where $\omega_0 = 2\pi f_0$ that at the output after detection and filtering in the form $I'_0 \sin (\omega_0 t + \alpha + \beta - \theta_0)$ the group delay for this frequency is $\tau_0 = \frac{\theta_0}{\omega_0}$.

The multiplication that is made on the frequency f_0 after detection produces a current

$$I''_0 \sin [n (\omega_0 t - \theta_0) + n (\alpha + \beta)] = I''_0 \sin (\omega t - \varphi + \gamma)$$

where γ is the phase shift introduced by the various apparatus

$$\omega = n\omega_0 = 2\pi f, \qquad \varphi_0 = n\theta_0$$

The group delay pertaining to the frequency F_0 is thus expressed by the formula

$$\tau_0 = \frac{\varphi_0}{\omega}$$

The envelope of the frequency F is present at the input to the line in the form:

$$I \sin n (\omega_0 t + \alpha) = I \sin (\omega t + n\alpha)$$

At the output after detection and filtering it is expressed by:

$$I' \sin (\omega t - \varphi + \delta) \ .$$

The group delay corresponding to the frequency F expressed by:

$$\tau = \frac{\varphi}{\omega}$$

The phase difference between the two currents is equal to $(\varphi - \varphi_0 + \gamma - \delta)$. The magnitude can be measured. The phase shift $(\gamma - \delta)$ is constant for all values of F_0 or of F.

In the limit $$\Delta\tau = \frac{\Delta\varphi}{\omega}.$$

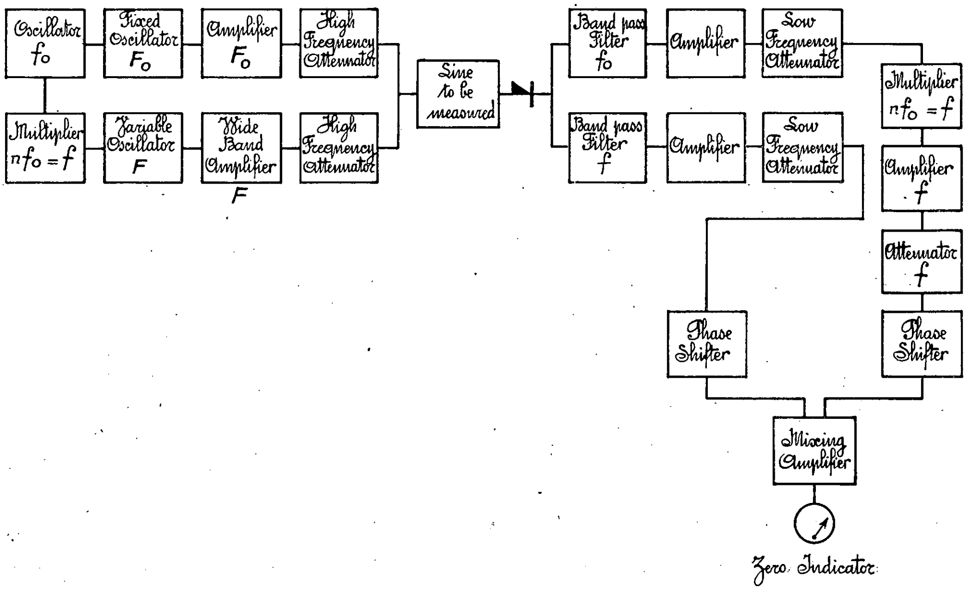


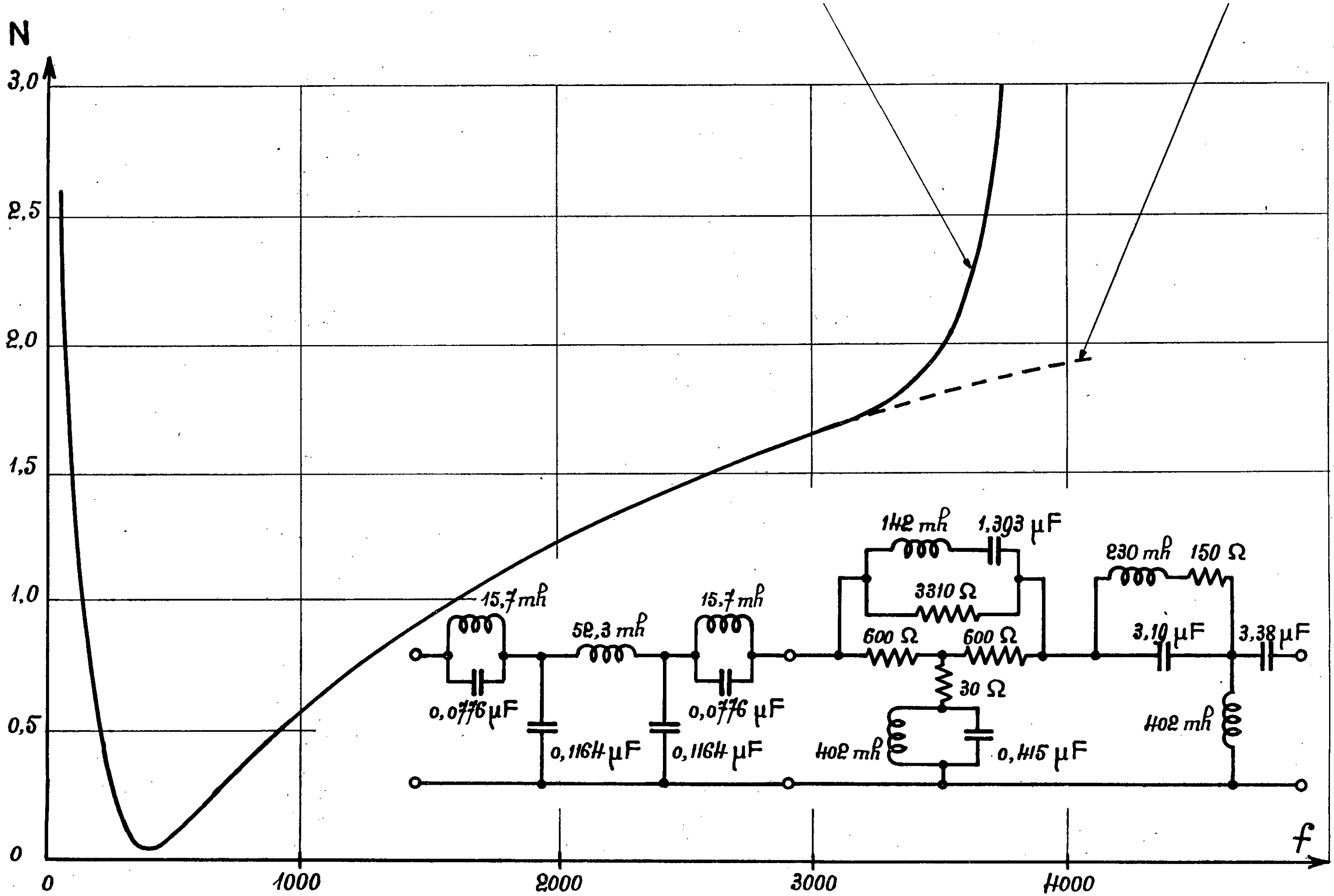
FIGURE 1. — *Measurement of the differences of group delay on a line*

ANNEX 41

MEASURING APPARATUS USED BY THE SWISS TELEPHONE ADMINISTRATION TO MEASURE NON-LINEARITY DISTORTION OF LINE REPEATERS AND OF 12, 24, 36 AND 48 CHANNEL CARRIER TELEPHONE SYSTEMS ON SYMMETRICAL PAIR CABLES

A. Measurement of non-linearity distortion of line repeaters

The measuring equipment for intermediate repeater stations described in annex 31 above (entitled " Measuring apparatus used by the Swiss Telephone Administration for the maintenance of carrier telephone systems on symetrical pair cables ") enables the measurement (amongst others) of the level of the 60 kc/s pilot which, in Switzerland, is transmitted on each carrier system; since it requires a 60 kc/s selective circuit to make this measurement arrangements are made to



f = Frequency in cycles per second

Filter producing the waveform of a conversation current Z^o = *600 ohm* measure the non-linearity distortion (3rd harmonic) at the frequency of 20 kc/s. This frequency of 20 kc/s is generated by an internal oscillator the output level of which may be varied from + 2 to — 4 neper. The 3rd harmonic is measured by means of selective equipment for the specified measurement which has the following characteristicss.

Selectivily: — 3 nepers for ± 1·5 kc/s deviation from 60 kc/s.

Accuracy: ± 0·04 nepers.

Calibration by means of 60 kc/s internal oscillator input impedance > 5 000 ohms.

B. Measurement of non-linearity distortion of 12, 24, 36 or 48 channel systems

The method of measuring the non-linearity distortion of systems consists of sending on one or more channels of a system a band of frequencies from a noise generator and measuring the psophometric electromotive force in the other channels of the system.

To reproduce (in the channels) a frequency spectrum resembling that of a telephone conversation the noise source consists of a " white noise " generator followed by a band pass filter with a characteristic as represented by the figure below.

The test consists of sending (with a power of 1 mW in one of any four channels connected together) the group of frequencies from the band pass filter and measuring the psophometric electromotive force in the other channels of the system; this value should not exceed certain limits fixed by the specification.

ANNEX 42

METHODS EMPLOYED BY VARIOUS ADMINISTRATIONS AND PRIVATE OPERATING COMPANIES FOR THE MEASUREMENT OF NON-LINEARITY DISTORTION OF A CARRIER SYSTEM ON UNLOADED SYMMETRICAL PAIR CABLES

A method used by various Administrations and Private Operating Companies consists of 800 c/s test tones on channels 11 and 12 of each basic group and measuring on channel 10 the modulation product of the 2 A-B frequency, A corresponding to the frequency of the wave transmitted on channel 11 and B to the frequency transmitted on channel 12.

Other Administrations prefer to apply 800 c/s tones on channels 6 and 4 of each basic group and measuring on channel 8 the 2·A-B modulation product, A corresponding to the frequency transmitted on channel 4.

To make the measurements on the principle outlined above a more or less selective voltmeter should be connected to the output of channel 10 (or channel 4). For instance one might use.

(1) the psophometer of the C.C.I.F. for commercial telephone circuits with the old type weighting network which has a resonance point between 800 and 1 200 c/s.

(2) the psophometer with the new weighting network associated with a band pass filter of which the mean frequency is 800 c/s and which gives a supplementary attenuation of 20 decibels for 800 — 400 = 400 c/s and for 800 + 400 = 1 200 c/s.

(3) a very narrow band pass filter followed by an ordinary voltmeter.

If a psophometer is used, or a voltmeter which is not very selective it is recommended to measure firstly the basic noise of the system before applying the 800 c/s tones.

Remark 1. — The above directions concerning these methods suppose that no basic group is placed in service before the others. If it is desired to place in service at different times the various groups of a 24, 36, 48 and 60 circuit system it is adviseable to choose, if possible, the two channels of each group on which to apply the 800 c/s test frequencies, such that the test of non-linearity distortion does not affect the carrier channels already in service.

Remark 2. — The measurement of the (2 A-B) third order produce is considered above. Nevertheless it may also be useful in certain cases to measure the (A-B) 2nd order intermodulation product in order to have a more complete picture of the non-linearity distortion conditions.

ANNEX 43

METHODS AND APPARATUS USED BY THE BRITISH TELEPHONE ADMINISTRATION FOR THE MEASUREMENT OF NON-LINEARITY DISTORTION OF A COAXIAL LINE

The British Administration has used various methods of measuring the non-linearity distortion of a coaxial line. These methods include:

1. the direct measurement of the 2nd and 3rd harmonics.
2. the measurement of the intermodulation between the test signal and the two pilots.
3. the measurement of intermodulation between test signals.

Apparatus used

When a terminal equipment is not available the following apparatus is used:

For method 1: a continuously variable oscillator in the frequency band 60 to 4 902 kc/s, a series of low pass filters to ensure a high degree of purity of the transmitted frequency and a selective amplifier-detector. This latter may be in the form of a superheterodyne radio receiver with a built in attenuator and detector.

For the methods 2 and 3: the same apparatus as for method 1 with the exception of the filters. When a terminal equipment is available audio frequency measuring apparatus only is needed. Audio test frequencies are applied to the chosen telephone channels and the intermodulation product is measured on the third telephone channel. The sending frequencies are so chosen that the intermodulation product always corresponds to the frequency of 800 c/s on the telephone channel used as the receiving circuit to which is connected a simple 800 c/s band pass filter.

ANNEX 44

METHODS AND APPARATUS USED BY THE CUBAN TELEPHONE COMPANY FOR THE FREQUENCY CONTROL OF CARRIER TELEPHONE SYSTEMS ON COAXIAL PAIRS

It is proposed that the master oscillators at the terminals of a coaxial system be compared in frequency by applying appropriate multiples of the basic frequency (4 kc) to the horizontal and vertical plates of a cathode ray tube, and timing the movement of the figure relative to a reference mark on the tube. When the interval indicates the need, readjustments will be made to the oscillators until the synchronisation requirements are met, as shown by observations on the tube.

Method of frequency comparison

At the controlled (or dependent) terminal the local frequency is compared with the incoming pilot frequency, which is transmitted from the controlling station and related therefore to the controlling oscillator.

The incoming pilot frequency 60 kc/s is applied to the horizontal sweep of the cathode ray tube. The local frequency 1 860 kc/s (super-group 6 carrier supply on the working generating set) is applied to the vertical plates. This gives a display on the tube which would move 1 cycle in less than 6 seconds for a frequency difference between the two master oscillators of 1 part in 10^{-7}. Consequently, it is reckoned that observation of the tube for less than half a minute should suffice to set the frequencies to ensure the required degree of synchronisation. By observing the direction of movement of the display on the cathode ray tube it is possible to determine readily whether the local frequency should be increased or decreased.

For a number of links, in tandem, frequency adjustment should be progressively away from the control station so that the nearest links are synchronised first.

Where a national standard of frequency exists with the required stability and absolute accuracy, such standard can be used for setting the system controlling oscillator. When working across national borders the pilot can be used as a means of comparing the national Standards.

Where no national Standard exists, one oscillator at the controlling terminal is accepted as the reference oscillator. It is considered that observation of all other oscillators relative to this controlling oscillator will suffice as an indication of its frequency stability. If the body of other oscillators changes frequency relative to the controlling oscillator, the latter should be rejected as the reference oscillator.

The absolute accuracy required for an isolated network is not nearly so stringent as the synchronisation requirements, and is readily met by the basic design of the oscillators.

The two 60 kc/s supplies from the duplicated generating equipment are also fed into the frequency comparison panel and can be compared with the local 1 860 kc/s. One of these, being derived from the same source as the 1 860 kc/s, will be in synchronism but the other one will serve as a comparison between the working and standby oscillators. Thus, it is possible to make any necessary adjustments on the standby oscillator and ensure the required degree of synchronisation when the supplies are changed over.

Measuring Equipment

The apparatus is associated with the frequency generating equipment. It consists of a small cathode ray oscillograph with appropriate power supplies and single stage amplifiers which permit 60 kc/s and 1 860 kc/s obtained locally to be compared. A further single stage amplifier incorporating a 60 kc/s filter permits the line pilot frequency to be applied to the tube with sufficient amplitude.

Switching facilities are provided to enable the local 1 860 kc/s to be compared with:

(a) the incoming pilot;

(b) each of the two local oscillators separately;

(c) any other suitable frequency which may be connected to terminals on the panel allocated for this purpose.

ANNEX 45

METHODS USED BY THE DANISH TELEPHONE ADMINISTRATION TO MEASURE THE DIFFERENCE BETWEEN THE INPUT AND OUTPUT FREQUENCY OF A TEST SIGNAL SENT OVER A CARRIER CHANNEL

First Method

The outgoing station transmits a frequency of 800 c/s over a carrier channel. In parallel with the input of the channel is connected a rectifier and the second harmonic i.e. 1 600 c/s as well as the 800 c/s is transmitted from end to end of the channel.

If the virtual frequency at the receiving station is lower by Δ c/s from that at the sending station the frequencies $800 + \Delta$ and $1\,600 + \Delta$ are received at the incoming station. At the receiving station a rectifier is also connected to the channel in question and thus produces, amongst others, the frequency $2\,(800 + \Delta) = 1\,600 + 2\,\Delta$ which beats with the received frequency $1\,600 + \Delta$ giving the difference frequency Δ c/s which may be measured by counting.

Second Method

A channel with a relatively low virtual carrier frequency and another channel with a relatively high virtual carrier frequency are connected together and the frequency of 800 c/s for example is sent over the loop.

The two ends of the looped channels are connected to an oscilloscope where the two signals sent and received produce a Lissajous figure of which the form varies if there is a difference between the master oscillators of the two terminal stations.

The rate at which this figure changes corresponds to the difference between the virtual frequencies.

The second method has the advantage that slow variations on the screen may be observed and counted.

ANNEX 46

METHOD USED BY THE FRENCH TELEPHONE ADMINISTRATION TO MEASURE THE DEVIATION BETWEEN THE FREQUENCY OF A SIGNAL SENT OVER A CARRIER CIRCUIT ON ONE OR MORE CARRIER SYSTEMS AND THE FREQUENCY OF THIS SIGNAL AT THE END OF THE CIRCUIT

Three waves S_1, S_2 and S_3 of frequency respectively F_1, F_2 and $(F_1 + F_2)$ are sent simultaneously into the input of a telephone circuit. At the end of this circuit the frequencies of the waves S_1, S_2 and S_3 have the respective values $(F_1 + E)$, $(F_2 + E)$ and $(F_1 + F_2 + E)$, E being the deviation which is to be measured. Each of the received signals are filtered and the signals S_1 and S_3 are applied to a modulator where a signal of frequency $(F_1 + F_2 - E) - (F_1 + E) = F_2$ is extracted. The comparison of this frequency F_2 and the frequency $(F_2 + E)$ of the signal S_2 gives the value E of the deviation sought for.

The values for the frequencies S_1, S_2, S_3, are given below:

$$F_1 = 620 \text{ c/s}$$
$$F_2 = 2\,000 \text{ c/s}$$
$$F_3 = F_1 + F_2 = 2\,620 \text{ c/s.}$$

so that the harmonic and intermodulation products do not disturb the measurement.

ANNEX 47

APPARATUS USED BY THE AUSTRALIAN TELEPHONE ADMINISTRATION FOR THE LOCALISATION BY MEANS OF PULSES OF IMPEDANCE IRREGULARITIES ON LINES

The Australian Administration has employed, on an experimental basis, equipment intended for the localisation of impedance irregularities on open, overhead trunk-lines and on trunk cables, making use of a method of measurement by means of d.c. impulses. Particular attention has been given to long-distance, open overhead lines. Table 1 below summarises the type of construction and performance characteristic of 3 different equipments which are in the course of field trial. Equipment No. 2 (used at the trunk-circuit termination point in Sydney) has been briefly described in an article entitled " Fault location on transmission lines " published in *The Electrical Engineer and Merchandiser* (Melbourne), of 16th June, 1947. This equipment was devised by the Railways Department of New South Wales, principally for the purpose of measurements on open, high-voltage power lines. Equipments Nos. 1 and 3 were developed for measurements on the trunk lines of the Australian Telephone Administration. Experience gained in the field with Equipment No. 3 is decribed in an article entitled " The Application of Pulse Technique to the location of faults on Telephone circuits " by P. M. Hosken in *The Telecommunication Journal of Australia* for February 1949. The details given in the column marked " Equipment No. 4 " in the following table refer to a projected equipment, for which a number of manufacturers have been invited to tender. The clauses of the specification relating to this equipment are based on experience gained with the 3 equipments already tested.

The greater part of the long distance telephone lines in Australia are of open wire construction and with these lines it has been found that echo testing equipment has the following advantages:

1. The initial location of the fault may be made rapidly.
2. The relative position of the faultman and the fault can be quickly determined.
3. Intermittent faults which are otherwise slow and expensive to locate and rectify are located rapidly and accurately.
4. The normal condition of a line, including impedance irregularities due to line filters, may be determined and recorded, thus providing reference information for use in locating faults and verifying that line equipment is normal.

An additional type of line testing equipment using pulse echo methods has been brought into use recently for the testing of coaxial cables and balanced cables intended for television. The pulse has a peak amplitude of 15 volts and a width at half-height of 30 milli-micro-seconds. The reflection sensitivity is 70 db and the instrument has been found useful in testing the impedance uniformity of cable joints and the effects of bending and other operations in laying cables.

Table 1

COMPARISON OF VARIOUS TYPES OF EQUIPMENT FOR FAULT LOCATION ON LINES BY MEANS OF IMPULSES

Construction and performance details	Equipment No. 1	Equipment No. 2	Equipment No. 3	Equipment No. 4
Type of line on which measurements can be made.	Open, overhead lines: loaded and non-loaded audio-frequency cables (by using a similar line as a balancing network.	Open, overhead lines with earth return.	Open, overhead lines. Could perhaps be used on non-loaded cables but with reduced sensitivity.	Open, overhead lines, loaded and non-loaded audio-frequency cables, etc.
Maximum range (in miles)	Limited by amplifier gain; between 300 and 400 miles of open, overhead line.	Nominal range 180 miles, limited by the sweep amplitude of the oscilloscope. On telephone lines a limit lower than this value (about 100 miles) on account of the attenuation of the short impulse and the limited gain of the amplifier.	270 miles. Limited by the impulse repetition frequency.	500 miles on open overhead lines.
Maximum range (expressed in the form of line attenuation in decibels at the frequency of the impulses) for a deflection of 1 mm on the cathode-ray oscilloscope screen.	30 db	28 db	40 db	50 db

Table 1 (continued)

Construction and performance details	Equipment No. 1	Equipment No. 2	Equipment No. 3	Equipment No. 4
Accuracy of determination of the distance of the fault from the measuring point.	1% on an open overhead line. 3% on a loaded cable with a 3 kc/s transmission band.	1% on an open, overhead line.	1% on an open, overhead line.	1% on an open, overhead line. 3% on a loaded cable with a 3 kc/s transmission band.
Is the equipment satisfactory for use on trunk circuits which are symmetrical with respect to earth?	Satisfactory (using a hybrid transformer).	Not satisfactory (output impedance not symmetrical with respect to earth).	Not satisfactory (output impedance, at a.c., not symmetrical with respect to earth).	Satisfactory (hybrid transformer with an output impedance symmetrical to earth).
Method of determination of the fault distance.	The "pip" representing the reflected impulse on the screen of the oscilloscope is displaced to the end of the time-base, by varying the pulse repetition frequency. The pulse repetition frequency is then measured by comparison with a stable audio-frequency oscillator.	The distance is measured by interpolation between calibration "pips" corresponding to 10 mile intervals, on the oscilloscope screen.	*(a)* By means of a variable calibration pip on the oscilloscope screen and a graduated scale. *(b)* By interpolation between calibrating pips spaced 20 microseconds apart, which represents an interval of 1·7 miles on an open, overhead line.	By means of a variable calibrating pip and a graduated scale.

Table 1 (concluded)

Construction and performance details	Equipment No. 1	Equipment No. 2	Equipment No. 3	Equipment No. 4
Waveform of the impulse.	D.c. impulse corresponding approximately to one cycle of a sine wave at 7 kc/s.	Short impulse of about 1 microsecond duration. A smaller impulse of opposite polarity follows the main impulse.	D.c. impulse of variable overall length. Build-up time about 1 microsecond. Total duration 4 to 230 microseconds.	D.c. impulses: *(a)* approximately one cycle of a sine wave, total duration 5 microseconds. *(b)* approximately one cycle of a sine wave, total duration 150 microseconds.
Pulse repetition frequency.	Adjustable.	50 c/s	315 c/s	150 c/s
Sensitivity of receiving amplifier (sine-wave signal)	40 millivolts RMS for a deflection of 1 inch of the spot on the oscilloscope screen.	Approximately 1 volt RMS for a deflection of 1 inch.	10 millivolts RMS for a deflection of 1 inch.	10 millivolts RMS for a deflection of 1 inch.
Number of valves.	Cathode ray oscilloscope: 6 + the cathode ray tube. Oscillator: 4. Auxiliary amplifier: 2. Total: 12 + cathode ray tube.	12 + cathode ray tube.	Cathode ray oscilloscope: 13 + cathode ray tube. Fault locating equipment: 7. Total: 20 + cathode ray tube.	14 + cathode ray tube.

ANNEX 48

APPARATUS USED BY THE CUBAN TELEPHONE COMPANY FOR THE LOCALISATION BY MEANS OF PULSES OF IMPEDANCE IRREGULARITIES ON LINES

The Cuban Telephone Company uses two types of pulse measuring equipment in the field which are known under the following designations:

1. Portable pulse-echo equipment for fault location, type SR 1232.

This equipment provides a means for the rapid location of serious faults on open, overhead lines, coaxial pairs, non-loaded telephone cable pairs, as well as on overhead or underground power lines; it is described in the attached Appendix 1.

2. Pulse-echo measuring equipment type SR 1216.

This equipment provides a means for showing the presence of impedance irregularities on a coaxial cable and for the determination of their nature and location, by means of a short impulse appearing on the screen of a cathode-ray tube. In addition, accurate measurements may be made of the end impedances of a coaxial cable compared to a suitable reference cable. This equipment is described in Appendix 2 below.

Appendix 1 (to Annex 48)

Portable pulse-echo equipment for fault location type SR 1232

This equipment was developed to provide a rapid means of fault location on open, overhead lines, on coaxial cables and symmetrical non-loaded telephone pairs, as well as on overhead and underground power lines. It is capable of indicating the nature of the fault and its position to less than about 1 %, and its range varies from some hundreds of yards, up to 100 miles in the case of open, overhead lines. The impedance conditions along a cable or overhead line are shown on the screen of a cathode-ray tube in such a way that it is possible to see two or more faults on the line at the same time, provided that the faults nearest to the measuring equipment are not practically equivalent to a complete break or a short circuit. Since this information appears permanently on the screen of the cathode-ray tube, it is possible to watch for the appearance of an intermittent fault and to locate it approximately at the moment it occurs. Oscillograms of cables can be obtained at the time they are laid, by leaving only a small attenuation in the amplifier circuit, and these oscillograms indicate the position and nature of any appreciable impedance irregularities; for example, a variation in the cross-section of the conductors will give a " blip " (that is, an approximate replica of the initial pulse) in the positive direction if the variation corresponds to a transition from a larger to a smaller cross-section. Oscillograms taken subsequently during the life of the cable will indicate any changes which may have occurred and it may be possible to reveal incipient faults.

Such tests cannot be made on a cable beyond a point at which a circuit is connected in shunt, unless the circuit is first isolated.

Main characteristics

The principle of operation consists in applying a series of approximately rectangular impulses at the input of the cable or overhead line under test. Each impulse is propagated along the cable at a speed which depends on the dielectric constant of the insulation and, in the case of a perfect cable, it will reach the far end of the cable and will then be reflected and return to the measuring equipment. If there is a fault at some point on the cable, a proportion of the impulse will be reflected from this point towards the input end, and the time which elapses between the emission of the impulse and the return of the echo (or reflected impulse) gives a measure of the distance of the fault from the input.

The reflected impulse is amplified and applied to the vertical deflection plates of an oscilloscope having a linear time-base (for the horizontal deflection) synchronised with the impulse repetition frequency. The position of the fault may be determined by measuring the distance on the screen of the tube between the initial impulse and the reflected impulse and comparing it with the distance between the initial impulse and the impulse reflected from a point (such as the distant end of the cable) whose distance from the input is known. If it is not possible to see an impulse reflected from the end of the cable because the cable is too long or because the fault consists of a complete break, or a full short circuit, a similar cable in good condition may be used as a reference. Alternatively, the distance of the fault from the input may be determined from a knowledge of the speed of sweep of the oscilloscope time-base and the speed of propagation along the cable.

The general nature of a fault can usually be deduced from an examination of the trace appearing on the oscilloscope screen. Usually, any fault which produces a break or has the effect of inserting a series resistance at a point in the cable will appear as " blip " in the same direction as the initial impulse. Any fault which produces a short circuit or introduces a shunt resistance between the conductors, or between the conductors and earth in the case of a symmetrical cable, appears as a " blip " in the opposite direction. A fault which is equivalent to a reactive component of impedance (for example, a partially crushed coaxial pair) will produce a double " blip " consisting of one " blip " in each direction. The ratio between the emitted and reflected impulses may be measured by means of an attenuator having a range of 0 to 80 db in steps of 1 db. This is done by noting the difference between the attenuator settings giving the same vertical deflection on the cathode-ray screen for the emitted and reflected impulses. If this difference is A db, then

$$A = 20 \log_{10} \frac{Z_a + Z_b}{Z_a - Z_b}$$

where Z_a is the impedance of the cable above the fault,

Z_b is the impedance looking towards the fault.

This formula must be used with care. If there are two or more faults at the same time, the measured attenuations for the faults located beyond the first one must be corrected for the attenuations experienced (in both directions of transmission) in traversing the faults (or large irregularities) closer to the input. Account must also be taken of the normal attenuation of the cable when the length of the cable makes this attenuation appreciable. It may be measured by using the attenuator to compare the levels of the emitted and reflected impulses, for the case where the reflection coefficient is equal to 1 (that is, when there is a complete break or a short circuit) at a point located at a known distance along the line. If the characteristic impedance of a cable is not known, it can usually be determined with sufficient accuracy by adjusting, in such a way as to produce minimum reflection, a variable resistance terminating a suitable length of the cable under test, and then measuring the value in ohms of that resistance.

General arrangement

The block schematic diagram (fig. 1) indicates the functions of the various parts of the complete equipment. The 100 kc/s crystal oscillator controls a chain of multivibrators working on fundamental frequencies of 20 kc/s, 5 kc/s, 1 kc/s and 250 c/s. The oscillator and the first two multivibrators produce markers on the horizontal sweep of the oscilloscope, these markers being used for calibration of the equipment and for measurement. The other two multivibrators control the impulse repetition frequency and the time-base.

The repetition frequency must be selected in such a way as to make it possible to see all the reflections occurring on the cable before the beginning of the next impulse. In the type SR 1232 fault-location equipment two different repetition rates are used, depending on the setting on the time-base switch. When the 3 longest time-bases are used, namely 200 to 1 600 microseconds, the impulse repetition frequency is 200 c/s, whereas it is 1 kc/s for other values of time-base. The object of using a higher repetition frequency for the short time-bases is to maintain the brightness of the cathode-ray trace.

The impulse generator is controlled through a variable delay circuit in such a way that the impulses can be emitted after the beginning of the time-base sweep and may be displaced along the oscilloscope trace into a suitable position for measurement on the graticule. The normal impulse " width " is 0·75 microseconds, but much wider pulses are now necessary in the work of locating faults on cables having considerable attenuation to the high-frequency components in the impulse; for example, power cables or telephone cables containing audio-frequency pairs, several miles in length. The equipment permits a choice from along 5 impulse widths up to 20 microseconds.

The impulse is applied to the cable or overhead line through a balanced termination or hybrid transformer. In this way, the impulse is applied to the cable and all the resulting reflections are deviated towards the vertical deflection amplifier of the cathode-ray tube, while the initial pulse is prevented from being applied directly to the amplifier which would affect its operation and mask any reflections which might occur up to a considerable distance from the transmitting end. A balance control covering a range of cable impedance of 20 ohms to 1 000 ohms makes it possible to balance the hybrid transformer to give an attenuation of the initial pulse of about 30 db.

Summary of technical characteristics

Impulse width. — 0·75, 1·5, 4, 10 and 20 microseconds, value selected by a rotary switch.

Amplitude of impulse. — Peak voltage of about 100 volts into 600 ohms.

Impulse repetition frequency. — 1 kc/s with time-bases Nos. 1 to 4, 250 c/s with time-bases Nos. 5 to 6.

Time-bases. —
1. 25 to 50 microseconds.
2. 50 to 100 „
3. 100 to 200 „
4. 200 to 400 „
5. 400 to 800 „
6. 800 to 1 600 „

Time-base length controlled by a rotary switch and a variable potentiometer.

Calibration markers. — A 4-position switch makes it possible to apply to the vertical deflection amplifier of the oscilloscope a sinusoidal input producing markers on the oscilloscope screen corresponding to the following times:

10 microseconds (sinusoidal input at 100 kc/s),
50 microseconds,
200 microseconds.

Formation of images on the screen of the cathode-ray tube. — A cathode-ray tube type VCR 97 is used, having a diameter of 6 inches.

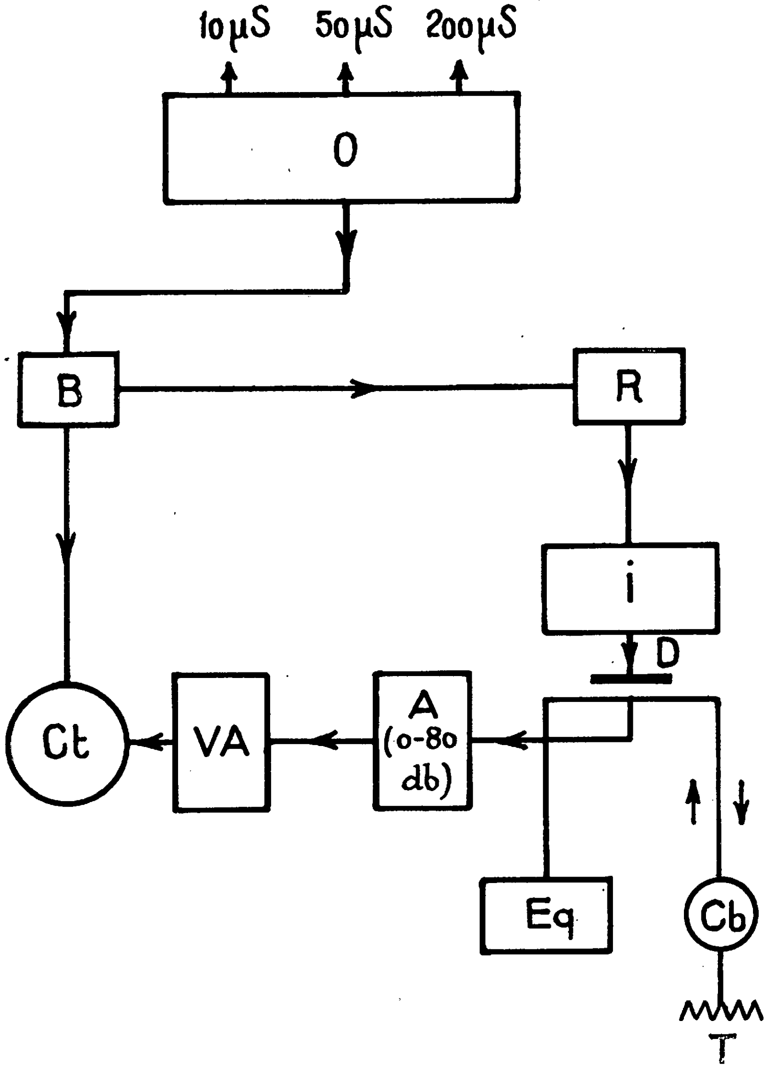


FIGURE 1. — *Block Schematic of Apparatus SR 1232*

O = Primary oscillator (100 kc/s) and impulse repetition circuits
B = Time base
I = Impulse generator
Ct = Cathode-ray tube
A = Attenuator (0 to 80 db)
Cb = Cable
R = Impulse delay network
D = Hybrid transformer
VA = Video amplifier
Eq = Balance circuit
T = Terminating impedance

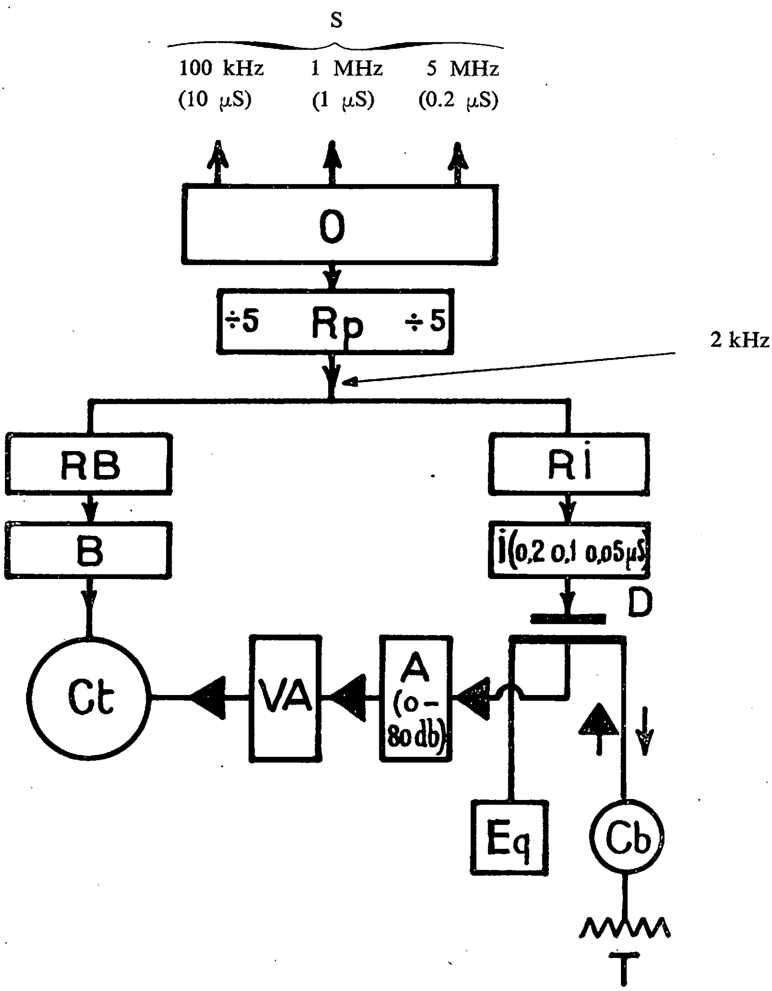


FIGURE 2. — *Block schemater of Pulse Echo Measuring Equipment*

S = Sinusoidal frequencies
O = Primary 50 kc/s oscillator
Rp = Impulse repetition circuits
RB = Delay networks for the time base
RI = Delay network for the impulse generator
B = Time base
I = Impulse generator

Ct = Cathode-ray tube
VA = Video amplifier
A = Attenuator
D = Hybrid transformer
Eq = Balance
Cb = Cable
T = Termination

Range. — The maximum distance up to which faults may be located depends on the attenuation characteristics of the cable under test and the magnitude of the fault. In the case of an open overhead line, a break or a short-circuit can be located up to 100 miles, and a fault corresponding to a shunt resistance of 20 000 ohms up to about 20 miles; in the case of a power cable, the upper limit may be only 10 miles. For the shortest impulse, a reflected impulse having a height of 1 cm measured on the screen of the cathode-ray tube, is equivalent to a voltage about 60 db lower than that of the emitted impulse. The minimum distance is about 350 yards.

Power supplies. — A.c. voltage 200 to 250 volts,
Frequency 40 to 100 c/s,
Required power 250 watts.

Layout. — The equipment is contained in 2 boxes, each with a carrying-handle, the dimensions of each box being: 30 inches × 9 inches × 13 inches high.

Weight. — Box containing the power supplies and impulse generator: 54 lb.
Box containing the amplifier and oscilloscope: 35 lb.

APPENDIX 2 (to Annex 48)

Pulse-echo measuring equipment type SR 1216

Introduction

The detection and measurement of impedance irregularities in coaxial cables, by means of echos of short pulses appearing on the screen of a cathode-ray tube, represents an important step forward in the technique of quality control during the manufacture and laying of these cables. Equipment type SR 1216 is intended not merely to give a complete picture of the impedance irregularities on any length of cable, from production sections which may be as short as 55 yards up to repeater sections with a length of 6 miles, but also to permit an accurate measurement of the position, magnitude and sign of each irregularity. In addition, the equipment includes provision for examining long lengths of cable, such as repeater sections, in segments of 400 yards at a time, in order to localise faults or large irregularities at great distances with greater precision, within the limits inherent in this method which are imposed by the attenuation of the impulse during its propagation over the cable. Furthermore it is possible to make an accurate measurement of the " end impedance " * of any coaxial cable having a nominal impedance of 75 ohms, by comparison with a standard reference coaxial cable which forms part of the equipment. All these measurements may be carried out very rapidly.

General arrangement

The block schematic diagram (fig. 2) shows the arrangement of the various parts of the complete measuring equipment. The primary oscillator, in conjunction with multivibrators, controls the impulse repetition frequency and also of the time-base, so that a stationary picture is obtained on the screen of the cathode-ray tube. The value of 2 kc/s for the repetition frequency is sufficiently high to allow the screen to be viewed in day light, and yet low enough to avoid overloading the impulse generator and to allow the use of the longest time-base.

* The " end impedance " is the real component of the characteristic impedance of a short length of a coaxial pair, measured from one end; a " short length " means a length of about 10 yards or more depending on the pulse width used.

The impulse generator and the time-base are both controlled through variable delay networks so that the initial pulse may be set at a convenient position on the cathode-ray trace and so that a short time-base may be used to examine in detail the reflections occurring at any instant up to the maximum delay time.

A calibrated control on the variable delay associated with the time-base provides a measurement of the distance of an irregularity from the transmitting point by displacing the picture, on the screen particularly backwards or forwards, as required. The difference in microseconds, between the setting of this control required to bring the initial impulse to a given reference point and the setting required to bring the reflected impulse to the same point represents the propagation time, and hence the distance, from the transmitting point to the irregularity. By operating a switch, the graduations on this control are made to give a direct reading of the distance in yards (or in metres). The variable linear time-base controls the horizontal deflection of the trace on the screen of the cathode-ray oscilloscope and determines the maximum length of cable that can be examined on the screen at one time.

There is a choice between 3 transmitted impulse widths in order to meet different conditions regarding the transmitted frequency bandwidth. The emitted impulse passes through the hybrid transformer and is then transmitted over the cable connected to the equipment. Cable irregularities produce impulses reflected back towards the transmitting end, and these return through the hybrid transformer into a variable attenuator and video amplifier controlling the vertical deflection of the cathode-ray trace.

The hybrid transformer and balance circuit reduce by 40 decibels or more the amplitude of the initial impulse in the receiving circuit so that no overloading arises from this pulse.

The equipment is connected to the cable under test through a flexible coaxial cord 40 yards long, a special coaxial feeder of 120 yards length and a measuring connector of short length (a yard and a half). A similar circuit, electrically indentical to the first, connects the balance winding of the hybrid transformer to a balance circuit forming part of the measuring equipment, so that the impedance mismatch at the input to the cable and the balance circuit neutralise one another. The balance circuit contains a variable resistance which is controlled by a knob with a pointer moving over a graduated scale which serves to measure the impedance to the emitted signal of the coaxial cable under test. Calibration is carried out immediately before a measurement by connecting to the equipment a reference coaxial cable always the same, and effecting the balance by means of an auxiliary control. This network of measuring the impedance of a coaxial cable is quick and very sensitive; differences of 0·01 ohms can be detected.

When the equipment is to be used only for measuring the position and magnitude of impedance irregularities in a production length or a repeater section of a cable, it is necessary to use the reference and feeder cables. In this case a single flexible coaxial cord, 40 yards long, is connected to the cable under test and another to the balance network. There is a certain residual mismatch at the point of connection to the cable under test, depending on the quality and previous history of the coaxial cords, and this mismatch may distort reflections occurring in the first 30 or 50 yards of the cable under test. In the case of production lengths, all difficulty may readily be avoided by making measurements from both ends.

The variable attenuator permits the determination of the logarithmic ratio in decibels between the voltages of the emitted and reflected pulses for any given irregularity. This is done by noting the difference between the two attenuator settings which give the same vertical deflection on the cathode-ray tube screen for the emitted and reflected pulses respectively. A correction can be applied to take account of the attenuation of the impulse in travelling to the reflection point and returning from this point.

This attenuation may be estimated by using the attenuator to compare the levels of the emitted and reflected impulses in the case of complete reflection (that is, a break or a short circuit) from a point located at a known distance along the line.

The magnitude in ohms of an irregularity or an impedance mismatch can be obtained from the expression

$$M = 20 \log_{10} \frac{Z_a + Z_b}{Z_a - Z_b}$$

where M is the logarithmic ratio in decibels between the heights of the emitted and reflected impulses.

Z_a and Z_b are the impedances before and beyond the point of mismatch.

Main features.

The apparatus consists of five easily-carried boxes and is intended for use either in the factory or in the field, for testing coaxial cables with a nominal impedance of 75 ohms. However, it may readily be used with other types of cable if that is required.

In the factory, oscillograms may be taken for each production length of cable, showing the position and magnitude of all important irregularities. At the same time, the end impedances may be measured to an accuracy of 0·05 ohms by comparison with a standard cable. The apparatus may therefore be used to give an accurate control of quality during the process of manufacture and also to provide the necessary information for impedance allocation (the distribution of production length according to their impedance) during the laying of the cable.

Permanent oscillogram records taken in the field on complete repeater sections may be kept for future use in the event of an interruption to service. The quality of each joint may be examined as soon as it is made. The position and nature of one or several faults may be determined with speed and accuracy. The reproduction of the reflected impulses on the oscilloscope screen, in an enlarged form and with a delay, allows short section of the cable throughout its length to be inspected in detail. During laying " end impedances " of lengths as short as 10 yards may be matched.

There is an operating desk size 5 feet 4 inches × 3 feet, with locating pins, for mounting the 5 units constituting the measuring equipment proper. This desk has been designed for maximum convenience to the operator and it may be placed on a bench, on a table, or trestles or it may be mounted in a van. The indicator unit is usually placed at a suitable angle for direct inspection of the screen of the cathode-ray tube, but it may be lowered to the horizontal to facilitate taking an oscillogram by means of a special device incorporating a semi-reflecting mirror. Ample space has been allowed for writing and recording results.

A special camera can be provided with the equipment and may be bolted to the front of the oscilloscope in place of the mask or of the special device used for taking oscillograms. This camera is intended for taking instantaneous shots of the oscilloscope trace on 35 mm film and the size of 25 mm × 25 mm allows about 36 exposures to be recorded on a 1·25 m length of film. The camera can be loaded in daylight and a guillotine allows the film to be withdrawn after any desired number of exposures. The camera includes a lens and mirror system by means of which the number indicated by an electric counter is photographed at the same time as the cathode-ray tube beam. This facilitates the later identification of oscillograms.

The two coaxial feeders of matched impedance are contained in steel boxes painted grey like the rest of the equipment. The overall dimensions of each box are 24 inches × 17½ inches × 22 inches high and one box is fitted with wheels so that it may easily be moved to the required measuring position. The wheels increase the length by 3½ inches. The reference coaxial cable, about 70 yards long is contained in the same box as the mobile power unit and is coiled in the top of this box. One of its ends is permanently terminated in a resistance of 75 ohms.

Calibration unit, type 1216/4, for delay measurement

The primary oscillator, incorporating a piezoelectric crystal oscillating at 50 kc/s, forms a part of this unit which determines the impulse repetition frequency (2 kc/s) and provides the calibrating frequencies of 100 kc/s, 1 Mc/s and 5 Mc/s. These calibration frequencies are of sinusoidal waveform and serve to calibrate the time bases, the length of each period being respectively 10 microseconds, 1 microsecond and 0·2 microseconds.

Impulses at 50 kc/s, in the form of the tips of the negative half-cycles of the sine-wave derived from the first buffer amplifier applied through a diode, control the first multivibrator, which divided the frequency by 5. The frequency is again divided by 5 in a second multivibrator, followed by two stages of differentiation which make the pulse more sharp. The negative-going impulses derived from these stages trigger a linear single-shot saw-tooth generator at the repetition frequency of 2 kc/s. The negative-going saw-tooth wave derived from this generator and limited to + 250 volts is applied to two circuits through cathode-follower stages providing signals with a peak-to-peak amplitude of about 200 volts. One of these circuits provides the gating signal for the time-base and the other the gating signal for the impulse generator; the two circuits are similar except that one is arranged to produce a negative signal and the other a positive signal.

A potentiometer, connected across a stabilised negative-voltage supply, serves to control the value of the voltage which the saw-tooth wave may reach before a diode allows it to be applied to the control grid of a pentode, normally maintained in the operated condition. When the sweep voltage exceeds this value by 4 volts in the negative direction, the pentode is completely blocked until the end of the cycle and a flat-topped wave appears in the anode circuit. The time position of the leading edge of that square wave, and its width, are determined by the setting of the potentiometer and by a range-switch. This wave is differentiated and applied to a pentode having a large bias resistance in the cathode lead. For the time-base a negative gating pulse is needed and consequently the output voltage to the coaxial plug located on the panel is taken from the anode circuit. The corresponding delay circuit for the impulse generator provides a positive gating pulse, the output voltage in this case being derived from the cathode of the output pentode.

The width of these pulses depends on the setting (controlled by a switch) of the delay of the saw-tooth generator. However, it is of the order of 5 microseconds, the amplitude of the impulses being about 100 volts.

A four-position switch changes the condenser in the circuit of the saw-tooth generator so as to provide maximum delays of 5, 10, 50 and 100 microseconds. In order to obtain an accurately calibrated control which can serve to delay the beginning of the wave produced by the time-base for the purpose of measuring the time an impulse has taken to travel to a fault, a spiral-wound potentiometer of 10 complete turns is used which permits a reading accuracy of 0·1 %. The use of this control in conjunction with the calibration frequencies gives an overall accuracy better than 1 % for measurements of the distance of an irregularity. Finally a separate 2-position switch, in conjunction with pre-set potentiometer, controls the saw-tooth generator so that the readings of the spiral-wound potentiometer indicate directly, either microseconds or yards (or meters) of 75 ohms coaxial cable, or yards (or metres) of some other previously-chosen type of coaxial cable. The potentiometer in the delay circuit of the impulse generator is not calibrated but it covers approximately the same range of variation as the spiral potentiometer.

A signal derived from the crystal oscillator is applied, through a buffer stage, to a frequency doubler one output of which, after amplification, provides the 100 kc/s calibrating frequency. The signal frequency of 100 kc/s is converted to 1 Mc/s in 2 stages, and to 5 Mc/s in a further stage, the amplified outputs from these stages providing, in each case, the other calibrating frequencies. The calibrating frequencies are applied, by operation of a push-button switch, to the oscilloscope through a video-amplifier. This unit incorporates monitoring circuits which make it possible to inspect, on the screen of the oscilloscope, the waveform produced by the 50 kc/s oscillator and the 10 kc/s and 2 kc/s multivibrators.

These frequencies may be selected by means of a push-button switch, two or more buttons on which may be operated at the same time so as to permit a check of the accuracy of frequency division.

This calibration unit for delay measurements is contained in a well ventilated steel box, finished in grey cellulose paint with chromium handles. The overall dimensions are 10 × 13 × 24 inches deep and it weighs 37 pounds.

Impulse generator unit, type SR 1216/5

The impulse forming, ampliying and transmitting stages, together with the attenuator, the power unit for giving an E.H.T. supply and the power unit for giving a stabilised voltage of 300 volts negative, are contained in this unit. The transmitting stage comprises the hybrid transformer and balance circuit.

The gating impulse for the transmitter, derived from the calibration unit for delay measurement, is applied to the grid of the thyratron, the anode circuit of which contains a delay line, normally charged through a high resistance from a source of high positive voltage. When this tube strikes, its resistance falls to a negligible value and the delay line discharges through the primary of a unity-ratio pulse transformer. This produces, across the secondary of the transformer, a rectangular impulse whose amplitude is about 150 volts and whose duration is equal to twice the delay time of the delay line. A push-button switch permits the selection of any of 3 delay times, giving impulses having a duration of 0.05 microseconds, 0·1 microseconds or 0·2 microseconds. The delay lines are open-circuited at the termination; they are screened and are double wound in order to obtain a high LC value (inductance × capacity) in a restricted space.

It is inevitable that the impulse-forming stage should produce reflections and ripples, although the level of these may be at least 20 decibels lower than that of the main impulse. They are suppressed by means of a heavily-biassed amplifying stage, which applies a positive impulse to the output stage through an impulse transformer connected between the two stages. The output valve operates in the emission-limited condition, so that the amplitude of the emitted impulse is practically the same whatever the impulse width. The three pairs of output terminals on the hybrid transformer are connected to plugs on the panel of this unit, for connection to the cable under test, the balance circuit and the attenuator. These last two components are also included in the unit and may be connected in circuit by coaxial cords connected to plugs on the panel. This arrangement allows some flexibility in operation. Thus an external balance circuit may be used, if required for measuring a non-standard type of cable. The attenuator may also be used for other purposes, for example to check the gain of the video-amplifier. The attenuator is provided with three rotary 6-position switches, covering a range of variation from 0 to 80 decibels in steps of 1 decibel.

A power pack contained in the same unit provides the heater voltages, the negative bias voltage and the E.H.T. voltage, the application of the latter being delayed by a thermal-delay switch of the vacuum type. The negative voltage of 300 volts is maintained constant by means of two gasfilled voltage stabilisers. The positive voltage of 2 000 volts, for supplying the anodes of the impulse amplifying values, is derived from a valve rectifier, while the negative voltage of 1 800 volts for the cathode-ray tube in the indicator unit is derived from the same winding of the mains transformer through a selenium rectifier. These voltages may be checked by plugging a voltmeter into the appropriate jacks on the panel of the unit. A small selenium rectifier provides the direct voltage of 6 volts required for the titling device in the unit containing the camera. The impulse transmitter unit is contained in a steel box with a rear detachable cover 3 inches deep for holding the connexion cords, the voltmeter and certain accessories. It is finished in grey cellulose paint and fitted with chromium handles. The overall dimensions are: 20 × 13¼ × 12¼ inches high. It weighs 56 pounds.

The impedance-measuring network is in the middle of the front panel. A large knob makes a pointed move over an illuminated graduated scale, visible through a circular " perspex " window. The input to this circuit, the phase adjustment control and the zero adjustment control are all placed close to this knob. Below this circuit are the push buttons which determine the pulse width, and the attenuator switches.

Indicator unit type SR 1216/3

The impulses appear on a cathode-ray tube of 6 inches diameter; the video-amplifier and the time-base are mounted on the same chassis.

The negative gating pulse derived from the calibration unit brings into action a linear saw-tooth generator providing only a single cycle of a saw-toothed wave.

A rotary switch in conjunction with a potentiometer allows the duration of the time-base sweep to be controlled to any value between 2·5 and 230 microseconds. The output valve of the time-base circuit is automatically balanced by a radio-frequency power pentode, which produces the positive cycle of the symmetrical saw-tooth voltage applied to the horizontal deflection plates of the cathode-ray tube. The time-base also provides the necessary wave for eliminating the fly-back trace of the cathode-ray tube beam. This wave is applied to the grid of the cathode-ray tube where a diode restores the d. c. component on the cathode.

The first three stages of the video-amplifier each have a single output value and have a common gain control, operated from the front panel of the unit to adjust the height of the impulse to a suitable value. The fourth stage is in push-pull and feeds a cathode-follower stage which in turn feeds the push-pull output stage. The signal output from this last stage is applied to the vertical-deflection plates of the cathode-ray tube. In order to obtain a flat " gain-frequency " characteristic over the entire band of frequencies desired, inductance-compensation is applied to the anode circuits of all stages, except the cathode-follower. In the output stage, the input capacity of the cathode-ray tube is used to form a resonant circuit with the inductance of the connecting leads to the vertical deflection plates. The response curve of the amplifier is flat from 60 kc/s to 10 Mc/s, it falls by 3 decibels at 15 Mc/s and by 10 decibels at 20 Mc/s; overall gain is about 55 decibels.

The cathode-ray tube operates with a voltage of 1 800 volts, the positive side being connected to earth. It is provided with the customary controls for brilliance, focus and for horizontal and vertical shift of the cathode-ray spot. A small pre-set condenser compensates for the parasitic coupling (" crosstalk ") between plates.

The indicator unit is mounted in a box similar to the delay measurement calibration unit, but it is provided with a detachable mask mounted over the screen of the cathode-ray tube to facilitate viewing the screen in daylight. This results in an increase of the overall dimensions to 10 × 13 × 26 inches deep. The weight of the unit is 38 pounds.

The cathode-ray tube with its permalloy screen is slightly offset from the middle of the chassis to allow for a convenient layout with the video-amplifier on one side and the time-base on the other. The perspex graticule which can be adjusted slightly for tilt and also up and down is marked in centimetre squares and the two axes are also graduated in millimetres.

Power supply unit type SR 1216/1

This unit contains the stabilised power supply of 350 volts, at a current of 250 milliamperes, the level being fixed by means of an internal pre-set potentiometer. A thermal delay switch, of the vacuum type, delays the application of the H.T. voltage until the filaments of the valves are warmed up, thus protecting the electrolytic condensers used for smoothing.

A voltmeter mounted on a small bracket and fitted with a cord and plug may be fixed to the front panel of this power unit by a clip, for checking the voltages and currents in the various parts of the pulse-echo measuring equipment. The voltmeter is a moving-coil instrument, 2 inches in diameter, for currents of 0 to 1 milliampere, and when not in use it is housed in the rear cover of the impulse-generating unit.

It is possible to measure the voltages derived both from the power packs contained in the impulse-generating equipment and from the two power-supply units by plugging the voltmeter into the appropriate jacks on the panels of these units. In the indicator unit and in the delay-measurement calibration unit, the valve currents are monitored by connecting the voltmeter across small resistors connected in the H.T. circuits, the values of these resistances being such that the readings corresponding to normal values are always within a green band marked on the graduated voltmeter scale. Each of these units is provided with a jack and a rotary switch numbered in accordance with the detailed schematic of the equipment. The current values are not monitored for valves which are biased to cut-off, that is to say which have a short transition period from the operating to the blocked condition, as is the case for the valves in the final stages of the impulse-generator. Similarly, monitoring of the current values is not carried out for currents whose waveform may be seen on the oscilloscope screen, namely in the 50 kc/s oscillator, the multivibrator, the calibration circuits and the impulse-forming stage.

The box of this supply unit is made of steel plate, it is provided with ventilation holes and finished in grey cellulose paint with chromium handles. The overall dimensions are 10 × 13 × 23½ inches deep and the weight is 51 pounds.

Power supply unit, type SR 1216/2.

This unit contains the stabilised supply of 250 volts, at 250 milliamperes the level being controlled by means of internal pre-set potentiometers. A thermal delay switch, of the vacuum type, delays the connection of the H.T. voltage until the valve filaments are warmed up, thus protecting the electrolytic condensers.

The unit is fitted in a box similar to that used for supply unit SR 1216/1 the dimensions being 10 × 13 × 23½ inches deep and the weight 51 pounds.

The complete measuring equipment is intended to operate from a mains supply of 200 to 250 volts A.c., a small panel with several tapping points, corresponding to the supply voltages, being located at the rear of both of the supply units. The consumption of the complete measuring equipment is about 800 watts.

Summary of technical characteristics

Impulse width: 0·05, 0·1 or 0·2 microseconds, controlled by a push-button switch.

Impulse amplitude: peak voltage of about 150 volts into a 75-ohm impedance.

Impulse repetition frequency: 2 kc/s.

Time-base. — The duration of the linear sweep may be adjusted at will to any value between 2·5 and 230 microseconds.

Calibration markers. — Sinusoidal waves for the calibration of the time base are available on the following standard frequencies: 100 kc/s (10 microseconds), 1 Mc/s (1 microsecond), 5 Mc/s (0·2 microseconds).

Time-base delay. — The beginning of the time-base sweep may be delayed over the range 0 to 100 microseconds by means of a spiral potentiometer and a multi-position switch.

By operating a switch, the potentiometer graduations can be made to read directly in yards (or in metres) of 75-ohm coaxial cable.

Attenuation of the impulse. — An attenuator makes it possible to measure the attenuation of the initial impulse up to 80 decibels in steps of 1 decibel.

Impedance measurement. — A circuit inside the equipment provides for measurement of the end impedance of a cable to an accuracy of 0·05 ohms and with a sensitivity of 0·01 ohms.

Testing facilities. — The valve currents and supply voltages can be measured. In the stages where it is possible, provision is made for viewing the waveform on the screen of the cathode-ray tube.

Power-supply. — 200 to 250 volts A.C.; frequency 40 to 100 c/s; the power consumption is about 800 watts.

Camera type SR 1216/7 for taking instantaneous pictures of the traces

This camera, with its light-proof hood and an arrangement for fixing it over the screen of the cathode-ray tube was specially designed for use with pulse echo measuring equipment type SR 1216 and with portable fault-locating equipment type SR 1232, for providing instantaneous oscillograph records.

The camera takes 35 mm film or high-sensitive paper, with a length of approximately 11 feet. A spool previously loaded with film or paper may be inserted in the camera in daylight.

The size 25 × 25 mm allows about 36 exposures to be taken on a film 4 feet long. The number of exposures is recorded on a counter which may be re-set to zero at any time.

The film moves forward by an amount corresponding to one exposure by operating the film advance lever and a special click mechanism prevents excessive unwinding of the film. When any desired number of exposures has been taken, operation of a push-button at the rear of the camera actuates a vertical guillotine, located inside the camera itself which cuts the exposed part of the film and allows it to be withdrawn from the camera.

A roller on the shutter mechanism is connected through gear wheels with the mechanism for rotating the spool on which the exposed film is wound and with the lever which causes the film to advance. This roller carries points for perforating the edge of the paper in order to pull it without play; the other roller is free.

To take an exposure a small lever opens or closes a simple shutter; the lens has an aperture of *f*/4.3, and a focal length of 1¼ inches. Focussing is by means of a rack and pinion on the lens mounting, used in conjunction with a small ground-glass screen which is revealed by pulling back an inspection cover.

One end of the protecting hood is fixed to the camera by 4 screws, while the other end is hinged on to a small frame which may be bolted directly over the screen of the cathode-ray tube, of 6 inches diameter forming part either of the indicator unit of the pulse-echo measuring equipment or of the fault-locating equipment. The camera is hinged in this way in order to facilitate detailed inspection and alignment of the cathode-ray trace before taking exposures. In order to allow a final inspection, there is also a small light-tight flap in the upper part of the protecting hood.

To the protecting hood is fixed an electrical device for numbering which operates each time the film-advance lever is depressed. The necessary power for the relay in this device and for the lamp which illuminates the figures to be inscribed is derived from a 6-volt source of supply. In the case of the indicator unit forming part of the pulse-echo measuring equipment, a suitable supply voltage is available at the front panel of this equipment. A system of mirrors is arranged in such a way that the figures appearing in the titling device are photographed at the same time as the cathode-ray trace. In this way any particular exposure may be identified afterwards.

The weight of the camera with its accessories is about 10 pounds and the overall dimensions (excluding the protecting hood and the mounting device in front of the cathode-ray screen) are: axial length 4½ inches, width 8 inches, height 4½ inches. The length of the protecting hood with its mounting device is 6¾ inches. A leather case is provided for carrying the camera and all its accessories.

ANNEX 49

APPARATUS FOR MEASURING AND LOCALISING IMPEDANCE IRREGULARITIES ON LINES BY MEANS OF PULSES USED BY THE FRENCH TELEPHONE ADMINISTRATION

1. Measurement of characteristic impedance and impedance regularity of coaxial pairs by means of pulses

Impedance and regularity of impedance is measured on all factory lengths by means of pulses.

The measurements are made using an echometer or a transimeter with raised cosines with a half amplitude width of 0·1 μs, 0·2 μs or 0·05 μs.

The pulses are applied to the cable by means of a differential transformer or by a bridge.

An adjustable balance network consisting of resistances and capacitors reproducing the input impedance of the cable over the whole frequency range covered by the test signals, balances the differential transformer or bridge and avoids reflections from the input to the line.

A second balance network of the same type is connected to the remote end of the cable to suppress echos from this point. These two balances serve to indicate the impedances at the cable input and the remote end.

The echos reflected from impedance irregularities along the cable are observed on a cathode ray tube. The amplitude of this response curve as a function of time is, at each point, about proportional to the reflection coefficient of the coaxial pair at the corresponding point $\frac{(\Delta Z)}{(2 Z)}$, in so far as the attenuation suffered by the echo signals can be neglected.

Z represents the mean impedance and ΔZ the difference between the impedance at the point of reflection and this mean impedance.

Furthermore, on the trace, the distance between the original pulse and the echo is proportional to the time between the application of the pulse and the return of the echo and therefore to the distance between the end of the cable and the point of reflection. Thus the apparatus indicates directly, the size and location along the cable of the impedance irregularities therein.

An integrator adds the energies reflected from the various irregularities along the pair and enables the " equivalent deviation " to be calculated; this represents a single irregularity which, located at the sending end of the cable length, would reflect the same energy as the whole of the factory length.

A measure of the " tailing " at the *remote end* of a line of length L may be obtained by measurements of echo at the *sending end.* If two pulses, separated in time by θ μs, are sent to line, and the complex echo is received on a square law integrator, the reading on this instrument, after deducting twice the echo energy, gives the relative amplitude of the signal tail arriving θ μs after the main pulse. To obtain the complete tail curve it is necessary to be able to vary θ from 0 to $\frac{2\,L}{v}$, v representing the velocity of propagation of the impulse along the line.

2. Testing of repeater sections of coaxial pairs by means of pulses

Measurements of impedance and impedance regularity are made on repeater sections of coaxial cable pairs by means of pulses.

In principle the measurements are the same as those made on factory lengths using an echometer.

The pulses in the form of raised cosines have a half amplitude width of 0·10 — 0·17 or 0·20 μs and the repetition rate is 5 kc/s.

The echos caused by reflection from irregularities in the line under test are received by the differential transformer and pass through a correcting network before reaching the received echo amplifier.

The correcting network corrects for the amplitude and phase distortion experienced by the various components of the echo according to the frequency of the components and the distance along the line of the irregularities which give rise to the echos.

The correcting network is effective for echos arising from 0·1 μs (or longer) pulses and irregularities not more than 5 km from the sending end of the line.

The impedance of the sending end of the line is read directly from the balance network.

To determine the " equivalent deviation ", an echo curve with " energy " correction is traced. This correction is applied to the amplitude of the signal so as to compensate for the loss of energy due to the attenuation of the circuit.

Tailing is measured as on factory lengths by using two pulses separated in time and receiving the complex echo in a square law integrator. The method is somewhat more complicated than in the preceding case because of the correction to be applied to the echo. The echo which is retarded most can be corrected for amplitude and, from the readings of the integrator, the relative amplitude of the " tail " produced θ μs after the main signal can be deduced, θ being the difference in time between the two pulses.

ANNEX 50

APPARATUS USED BY THE BRITISH TELEPHONE ADMINISTRATION FOR PULSES TESTS ON COAXIAL PAIR CABLES

Three pulse testing equipments for use on coaxial cables have been developed and are in use by the British Administration.

1. Cable fault locator designed for localising faults within a normal 6-mile repeater section of cable.

2. A pulse testing equipment for investigating impedance irregularities in short length of cable and irregularities occurring at joints.

3. An equipment for determinating of the amplitude and location of echos as well as for measurement of the impedance of one end of coaxial pairs at 2·5 Mc/s.

1. Cable Fault Locator

This consists of a portable, mains operated tester which transmits 1 volt DC pulses of 3 microseconds duration at intervals of about 90 microseconds. Observation of reflections due to irregularities in the cable is made on a cathode ray tube. Two types of display are provided, a normal linear time base with " Y " deflections, and a circular time base with brightness modulation which gives the advantage of increased scale length. Satisfactory fault localisations have been made of high resistance joints in the centre conductor of 0·375 inch coaxial pairs up to distances of about 6·5 miles.

2. The 20 Mc/s Pulse Testing Equipment

This equipment employs pulses of 20 Mc/s of 0·3 microseconds duration, at 500 microseconds intervals. Echoes received 1 microsecond or more, after the transmitted pulse, and of amplitudes down to about 90 decibels below it, can be measured to within 2 decibels. An adjustable cable-terminating impedance unit is used to terminate the cable at the far end, so that cable irregularities near the far end may be detected without interference by reflection from the cable end.

This equipment has been used to make tests on factory lengths of cable, and also to measure the return loss coefficient of joints in coaxial cables in connection with design work for the improvement of joints.

3. Apparatus for measuring the amplitude of echoes and their location and also for measuring the end impedance of coaxial pairs at 2·5 Mc/s

This is a transportable apparatus contained in five cases which can be used to test a repeater section or a length of cable. For testing repeater sections raised cosine pulses with a peak voltage of approximately 150 V duration 0·1 micro-seconds, and intervals of 500 micro-seconds are normally used. The amplitude and location of the echoes are given by variation of the trace on a cathode ray oscilloscope. It is usual to adjust the time base so that 1 cm of horizontal trace represents 1 micro-second i.e. 158 yards of Polythene spacer 0·375 inch coaxial pair, but the trace is extended and/or shifted by potentiometers when this is necessary to investigate fault conditions. The vertical trace is adjusted so that a deflection of 1 cm represents a reflection of 70 decibels at the end of the test leads.

When a permanent record is required (i.e. for new cables), the trace is recorded on 35 mm photographic film, 10 cm at a time, and prints with a full-sized trace are filed for reference. For tests on repeater sections of 0·975 inch coaxial pair and on lengths of 0·375 inch coaxial pair, a pulse duration of 0·05 micro-seconds is used. The resistive component of the end impedance of a coaxial pair at approximately 2·5 Mc/s is measured by pulsing simultaneously into the coaxial pair and a network and adjusting a calibrated potentiometer and an uncalibrated variable capacitor (contained in the network) until the combined reflections for the pair and the network exhibit a " W " or " M " pattern of minimum and balanced dimensions.

ANNEX 51

APPARATUS FOR THE LOCALISATION OF IMPEDANCE IRREGULARITIES ON COAXIAL CABLES, BY MEANS OF PULSES, USED BY THE SWEDISH TELEPHONE ADMINISTRATION

For testing cables as well as for the location of faults on coaxial cables, the Swedish Administration has successfully employed an impulse-type echo-meter, consisting of an impulse generator, a sweep generator and a receive-amplifier. The receiver has the feature that its gain varies periodically with time in such a way that the part of the gain exceeding a constant part corresponds, at any instant, to approximately twice the attenuation of the section of circuit up to the point of reflection under study. This variation is achieved by controlling the receiver gain by means of a saw-tooth wave synchronously with the sweep amplification.

The duration of the emitted impulse may be at the most 1 microsecond for measuring a complete repeater section (of 10 km), in which case the receive-amplifier must pass a band of frequencies up to at least 1 Mc/s with good uniformity.

With the aid of this device, impedance variations as small as 0·1 ohms may be examined with the same accuracy throughout the length of the repeater section.

The normal variations of impedance for frequencies up to 1 Mc/s do not, in general, exceed 0·5 ohms, but it is possible to locate additional lumped resistances (for example, at bad joints) of an order of magnitude down to 0·1 ohms. To perform the location photographs are taken, from each end of the cable, of the curves recorded by the impulse echo-meter. If there are no additional lumped resistances, the curves are identical when one of them is turned through 180°. On the other hand, for each lumped resistance the curves show deviations of the same magnitude but of opposite sense, which enables the fault to be readily located. Using this method, it is possible to locate additional lumped resistances having a value considerably less than the other impedance variation encountered on the circuit.

ANNEX 52*

DESCRIPTION OF THE TELEVISION WAVEFORM GENERATOR CONSTRUCTED BY THE CUBAN TELEPHONE COMPANY

The Television Waveform Generator consists of nine panel units as follows:

1. Master Frequency Generator.
2. Line Frequency Generator.
3. Counter Panel.
4. Line and Frame Sync. Mixing panel.
5. Vision Mixing Panel.
6. Power Unit for Counter Panel.
7. Monitor tube unit.
8. Monitor time base unit.
9. Power unit for monitor.

The connections between the various panels of this waveform generator as shown in figure 1.

Master Frequency Generator. — This unit produces the master frequency pulses from which all other pulses throughout the generator are derived. The recurrence frequency is variable from 10 kc/s to 50 kc/s, and the pulse width is variable from 5 microseconds to half the period of the pulse recurrence frequency which can be locked to a multiple of the mains frequency automatically.

Line Frequency Generator. — The Line Frequency Pulses are derived from the back edge of the Master Frequency Pulses. For normal double interlace a gate circuit is used to pass alternate pulses. The pulse width is adjustable from 5 to 25 microseconds.

Counter Panel. — The Master Frequency Pulses are counted down to give Frame Frequency Pulses by means of three step counters in this unit. Each step counter is capable of counting from two to twelve over the required range of input frequency, e.g., for the British Standard system the dials are set to 9·9-5.

*) Annexes 52 to 56 are retained pending the editing of the maintenance instructions for television circuits.

There are two monitor tubes provided which indicate directly the number of count of each of the three step counters and synchronism of the Frame Frequency with the mains frequency.

Line and Frame Sync. Mixing Panel. — This panel produces the Frame Sync. Pulses and mixes them with the Line Sync. Pulses to give the complete synchronising waveform. The first Frame Sync. Pulse can be delayed in half-line steps from the start of each Frame Frequency Pulse by adjustment of the *Frame Sync. Delay* control, they delay being variable from one half-line to ten lines. The number of Frame Sync. Pulses can be varied from one to twelve by adjustment of the *Frame Sync. Length* control.

Vision Mixing Panel. — Vision signals from an external source may be added to the Frame and Line Sync. Pulses, together with the necessary Blanking Pulses, to produce the complete video Television Waveform. Three controls are provided to adjust the *Line Blackout Delay, Line Blackout Length* and *Frame Blackout Length.* The amplitude of the Vision Signals and the Sync. Pulses in the complete waveform can be independently adjusted.

Power Unit for Counter Panel. — This unit provides stabilised positive and negative supplies for the Counter Panel together with extra high tension for the cathode ray tubes.

Monitor tube Panel. — This unit contains a six-inch diameter cathode ray tube on which can be displayed any of the waveforms provided by the generator. An amplifier is incorporated with a gain control providing a continuous range of gain from 1·5 to 10 times.

An electronic " double beam " feature is provided for use with interlaced television systems enabling the " odd " and " even " frame waveforms to be displayed as separate traces.

Monitor Time-Base Panel. — The range of time-base speeds is such that any length of time-base between 250 microseconds (i.e. approx. 2½ line periods on 405 line system) and 33 milliseconds (i.e., approx. 1½ frame periods) can be obtained. The monitor is normally synchronised to the Frame Frequency pulses and a delay

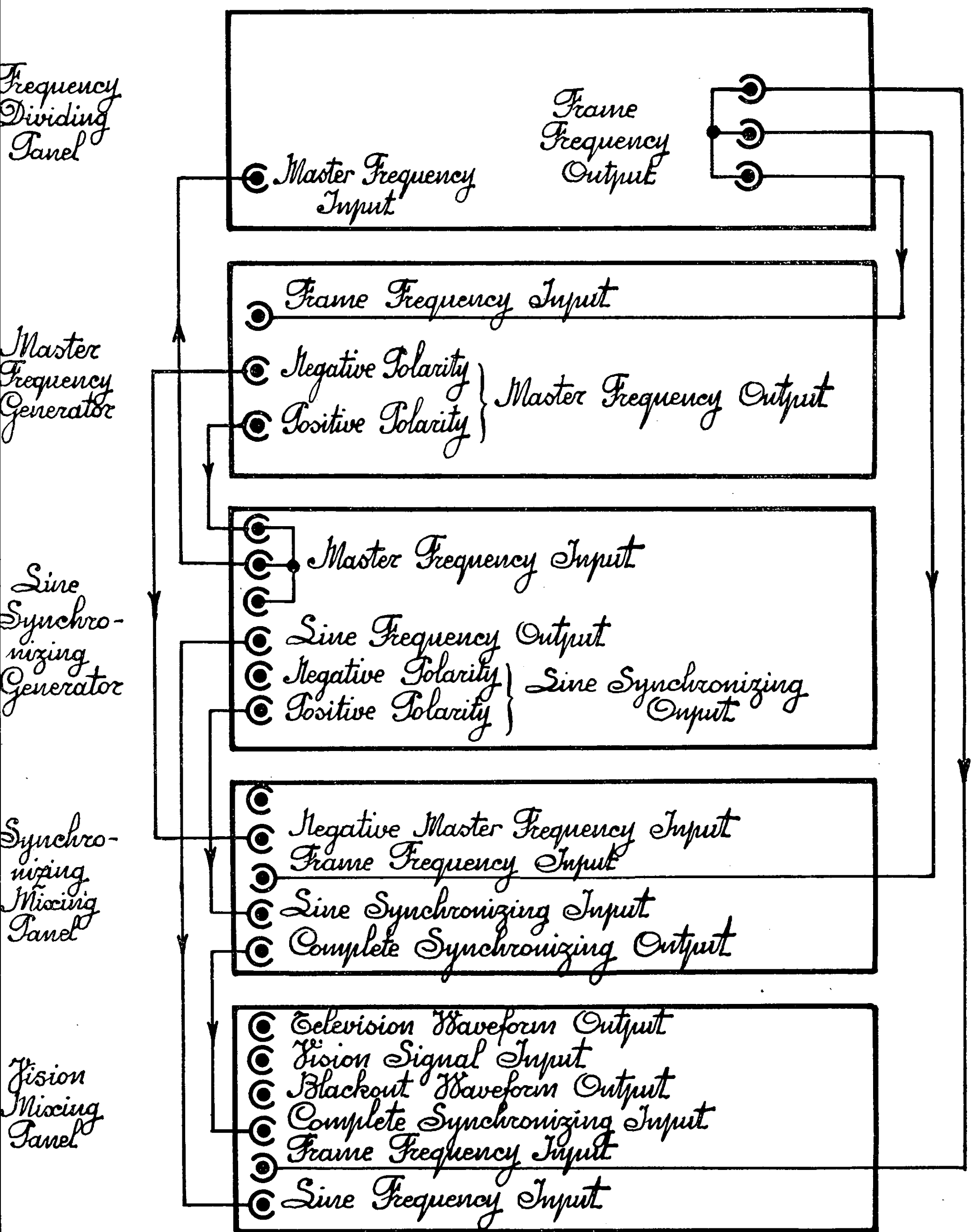


FIGURE 1. — *Inter panel connections of the television waveform generator*

circuit is provided so that any portion of a frame scan may be monitored using any time base speed.

Power Unit for Monitor. — This provides power supplies for the monitor cathode ray tube, amplifiers and time-bases.

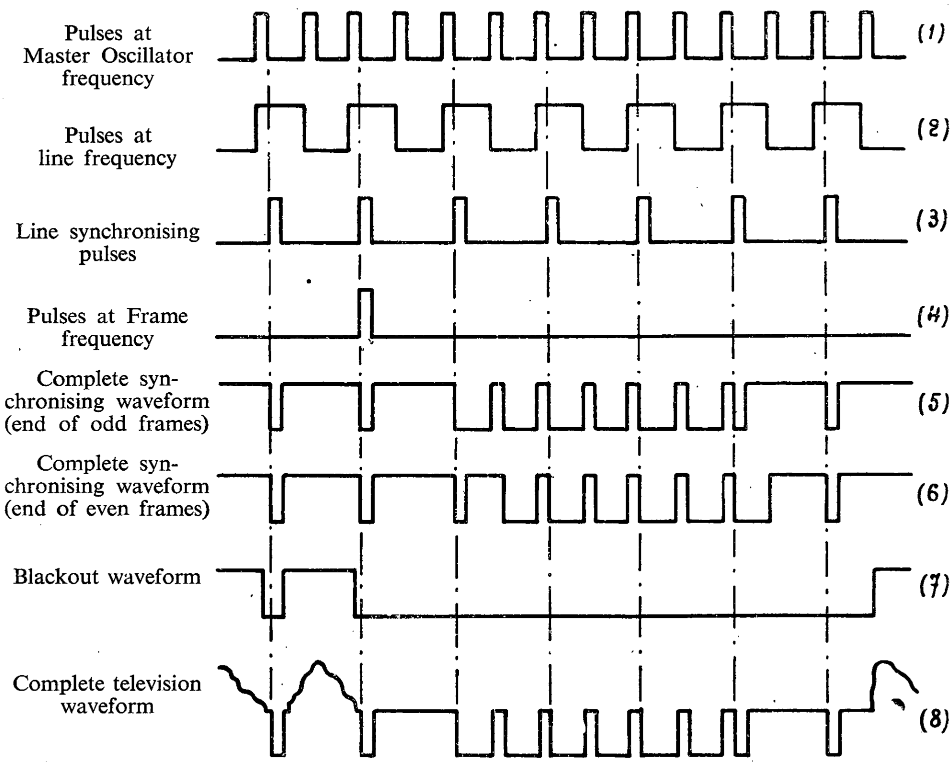


FIGURE 2. — *Output waves fram the various television waveform generators units*

Output Waveforms. — The output waveforms from each panel, of approximately 10 volts amplitude, are available for monitoring and test purposes, and may be used for the electronic generation of transmission test signals. The complete television waveform is also provided at a standard switching level of one volt (peak to peak) into two external loads of 75 ohms each which may be simulataneously connected.

Figure 2 shows typical waves which may be produced.

Drawings attached: H-TL 477 Output Waveforms.
P-TL 656 Inter Panel Connections.

ANNEX 53

TELEVISION TEST SIGNAL GENERATOR USED IN GREAT BRITAIN

The British Telephones Administration and the British Broadcasting Corporation employs an arrangement of electronic valves to generate a test signal which is found very useful in practice for testing of circuits where the attenuation and phase distortion have been corrected. This test signal consists of a 2 microseconds pulse with a rise time of 0·1 microseconds measured between the points of 10% and 90% of its final value. The overshoot on this signal is not measured. This pulse is combined with the ordinary line synchronising pulses so as to obtain a fine vertical white line on the screen of a cathode ray oscilloscope used for observing the image. It has been found that this signal will give particularly high sensitivity in the determination of the frequency band transmitted by a circuit and the distortion caused by this circuit.

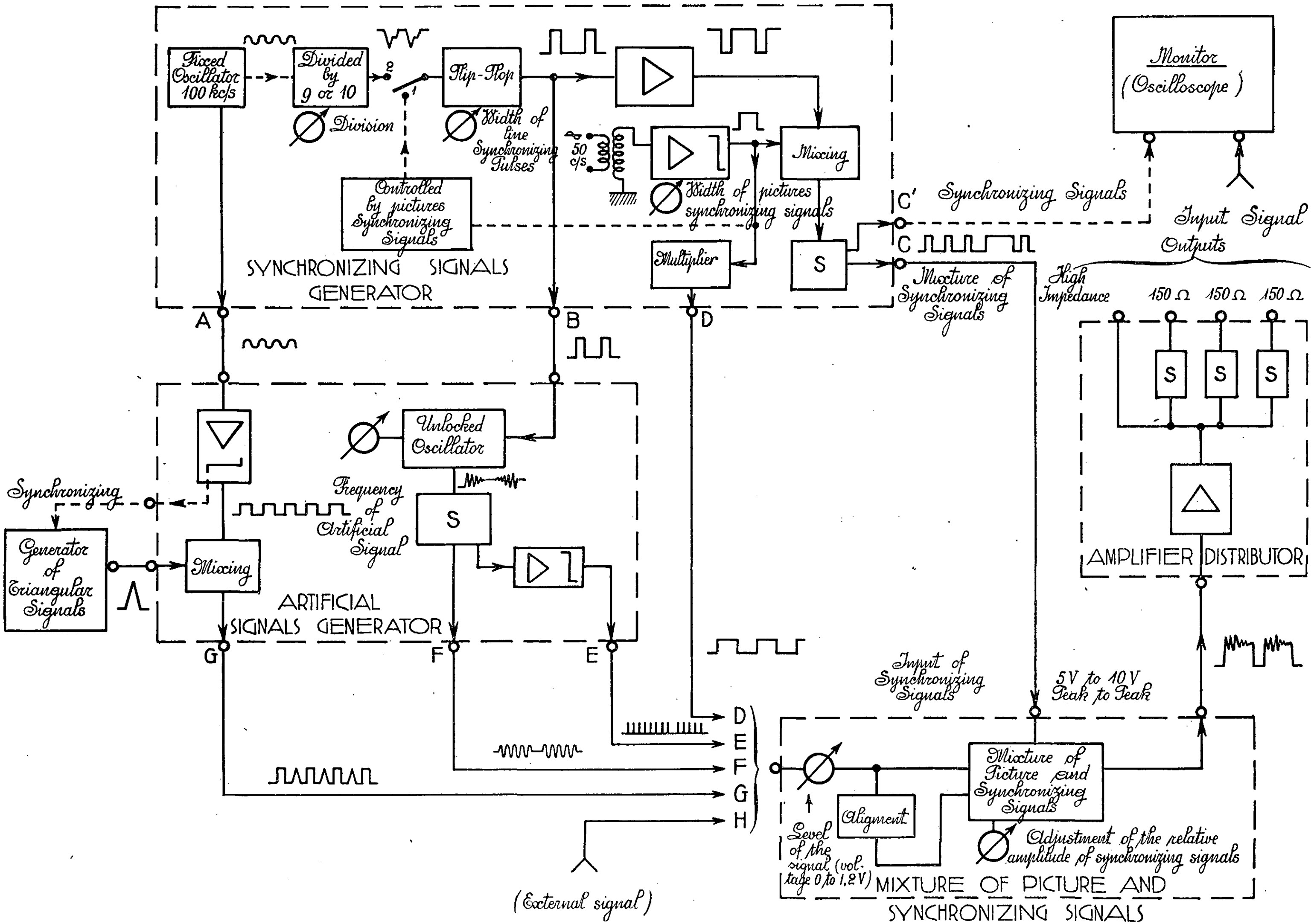
ANNEX 54

TELEVISION TEST SIGNAL GENERATOR USED BY RADIODIFFUSION FRANÇAISE

Principle. — The tests of television equipment made up to the present has shown that clasical methods are insufficient:

1. The tests based on observation are much more qualitative that quantative. They only give an idea of the global functioning of the chain and display equipment and do not enable the partitioning of the distortion caused by these.

2. The measurements made by the simple injection of a sinusoidal signal or pulses into the equipment do not in general correspond to the normal method of functioning of the equipment and these signals can only be observed with difficulty on the screen of the receivers.


Fixed Oscillator 100 kc/s
Divided by 9 or 10
Division
Flip-Flop
Width of line Synchronizing Pulses
Controlled by pictures Synchronizing Signals
50 c/s
Width of pictures synchronizing signals
Mixing
Multiplier
S
SYNCHRONIZING SIGNALS GENERATOR
A
B
D
C'
C
Synchronizing Signals
Mixture of Synchronizing Signals
Monitor (Oscilloscope)
Input Signal
Outputs
High Impedance
150 Ω
150 Ω
150 Ω
S
S
S
AMPLIFIER DISTRIBUTOR
Unlocked Oscillator
Frequency of Artificial Signal
S
Synchronizing
Generator of Triangular Signals
Mixing
ARTIFICIAL SIGNALS GENERATOR
G
F
E
D
E
F
G
H
(External signal)
Input of Synchronizing Signals
5V to 10V Peak to Peak
Mixture of Picture and Synchronizing Signals
Aligment
Level of the signal (voltage 0 to 1,2V)
Adjustment of the relative amplitude of synchronizing signals
MIXTURE OF PICTURE AND SYNCHRONIZING SIGNALS

Consequently, it is considered essential to produce an apparatus generating correct artificial television signals composed of known and measurable elements and furnishing test pictures on the screen of the receiver. Such an apparatus should be reliable and of small size. The following is an example of the apparatus made in the laboratories of the *Télévision-Radiodiffusion française*.

1. *Synchronizing signal generator.* — A simplified synchronizing signal generator producing:

(1) By direct limiting of the sinusoidal mains supply, firstly filtered, rectangular synchronizing signals with steep fronts and adjustable width between 4 and 10 times the duration of a line. Starting with these the output D of the generator gives rectangular, recurrent signals at a frequency which is a multiple of that of the mains supply.

(2) *From a multivibrator* of the " flip-flop " type, rectangular signals for line synchronizing of variable width between 5 % and 20 % of the duration of a line and with practically straight fronts; either from the picture signals (they then preserve fixed phase relation to them and produce fixed pictures on the screen).

or from a crystal oscillator (100 kc/s). They are then at a fixed frequency (10 kc/s or 22·15 kc/s). The line synchronising signals and pictures are then mixed and distributed at C and C′.

2. *Artificial signal generator.* — This produces:

(1) Rectangular signals obtained by limiting a 100 kc/s sine wave obtained from a crystal oscillator.

These signals may synchronize a generator delivering triangular pulses, of 25 microseconds duration and be mixed with these pulses to give the signal applied at G.

(2) Sinusoidal signals of variable frequency between 80 kc/s and 15 Mc/s approximately and of fixed phase relative to the line synchronizing signals.

They are obtained from a variable frequency oscillator not locked by the line synchronizing pulses.

These signals appear at the output F of this generator:

(3) Rectangular signals of variable repetition rate between 80 kc/s and 1·5 Mc/s with a rise time less than 0·04 microseconds and with a fixed phase relative to the line synchronizing pulses.

They are obtained by limiting the above sinusoidal signals and are distributed at E.

3. *Mixing and distribution.* — Each signal as well as one other signal coming from an external equipment may be mixed with the synchronizing signal to form a complete test signal. The proportion of signal to synchronization may be adjusted at will.

The mixing and distributing apparatus will satisfy particularly severe conditions of operation and cause practically no non-linearity distortion and no attenuation distortion in the video frequency band.

Summary: The apparatus described delivers different complete signals which are all fixed relative to the synchronizing signals. It enables:

1. *The measurement of the geometrical distortion of the receivers.* — These signals delivered at D give fixed horizontal bands equally spaced on the screen of the receiver (see fig. 1).

The signals delivered at E give fixed vertical bands equally spaced (fig. 2).

The comparison of the pictures of the bands on the screen of the receiver gives a measure of the geometrical distortion.

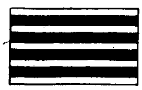


FIGURE 1

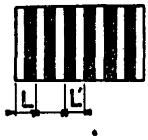
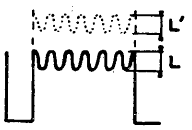


FIGURE 2

2. *The measurement of the non-linearity distortion.* — The sinusoidal signal delivered at F and the mixture of the synchronizing signal may be displaced relative to the base of the synchronizing signal so as to be situated successively over all the parts of the characteristic " amplitude at the input — amplitude at the output " of the equipment to be tested (fig. 3).

The difference in amplitude at the output is a measure of the non-linearity distortion.



Line synchronizing signal

FIGURE 3

3. *The measurement of the variation of attenuation as a function of frequency.* — The frequency of the sinusoidal signal delivered at F is variable from around 8 times the line frequency up to at least 1·4 times the maximum frequency transmitted.

The observation of this signal either on the oscilloscope or on the screen of the receiver after passing through the equipment to be tested enables the attenuation at all frequencies to be determined.

4. *The measurement of the transient operation.* — *(a)* The rectangular signals distributed at G with fixed phase relative to the synchronizing signals (fig. 4) may be observed either on the oscilloscope or on the screen of the receiver.

These signals consist practically of a Heaviside unit function and the distortion of front and top is a characteristic of the operation to transient signals of the equipment being tested.

(b) The signals distributed at G consist of a triangular pulse of which the transmission may be compared to that of a Dirac pulse (fig. 5).

The rectangular signals around these pulses form a reference base enabling the determination of:

on the one hand, the pulse attenuation;
on the other, the increase in width of this pulse.

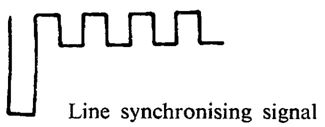


FIGURE 4

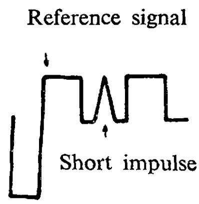


FIGURE 5

ANNEX 55

MONITORING APPARATUS FOR TELEVISION TRANSMISSIONS USED BY " RADIODIFFUSION FRANÇAISE "

A practical method to check a video signal at a point in a television circuit, for example at the output of an amplifier, consists of the use of a special oscilloscope enabling the examination of the complete slope of the signal at the point studied.

An ordinary portable oscilloscope might be used: nevertheless, it is preferable to use a special equipment capable of giving a more stable and precise oscillograph trace.

The figure opposite represents a satisfactory arrangement in this respect.

At the output of the amplifier (R) connected to a low-frequency cable a high impedance tap is taken connected to an amplifier (1).

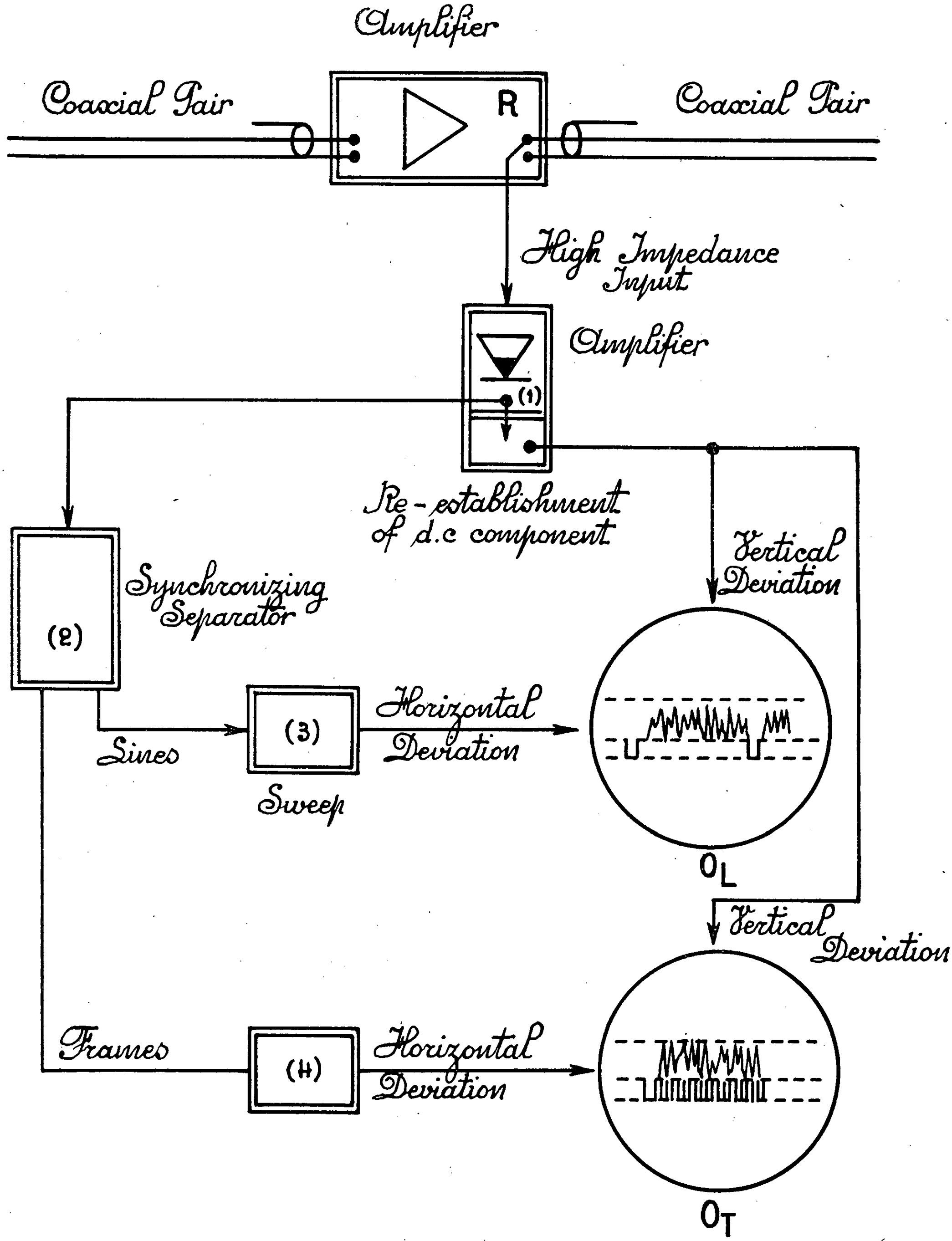
The signal amplified by the repeater (R) being a modulated video signal at carrier frequency, it is necessary to include a demodulator in the amplifier (1).

If at the point considered the direct current component exists the amplifier (1) transmits this component; if not the last stage of (1) includes an arrangement to re-establish this component, for example by aligning the bases of the synchronizing pulses to a reference potential.

Two oscillographs O_L and O_T are used for this check; one with the horizontal sweep at line frequency, the other at frame frequency. The vertical trace of these two oscilloscopes is controlled by the output signal of the amplifier (1). Meanwhile the synchronizing repeater (2) separates the frame and line synchronizing pulses for the sweep generators.

By means of the application of a calibration signal to the input of amplifier (1) it is possible to calibrate the oscilloscopes so as to align the signal on the screen.

The accuracy of measurements made with this apparatus on a 9 cm cathode ray tube may be 5%. This accuracy may be noticeably improved with fine spot and large diametre tubes.



Apparatus for monitoring television transmissions by the Radiodiffusion française

ANNEX 56

ESSENTIAL CHARACTERISTICS OF MONITORING EQUIPMENT (TO BE LOCATED AT THE POINT OF JUNCTION OF INTERNATIONAL TELEVISION CIRCUITS AND NATIONAL EXTENSION CIRCUITS) SUGGESTED BY THE BRITISH BROADCASTING CORPORATION

At this stage it is only possible to make a general recommendation regarding supervisory equipment at the national terminals of international television circuits, in the light of present experience, and it is realised that the proposals may have to be modified considerably as the technique of the long-distance transmission of television signals progresses.

It is assumed that the signal passing over an international television circuit will be transmitted in modulated form between the sending and receiving television programme authorities. It may be necessary to make certain measurements, at international boundaries on this modulated form of signal, but for the present we are unable to make any recommendations regarding equipment which would be useful in this respect. The recommendations are therefore restricted to tests made on the demodulated signal. This means that a bridging amplifier, with high input impedance, together with a demodulator must be provided at these stations. As both a waveform monitor and a picture monitor are recommended some form of distribution amplifier is proposed, although a probe might be admissible. The distribution amplifier has the advantage of being a permanent installation. The waveform monitor is intended to check the propagation characteristics of the television circuit whereas the main function of the picture monitor is to measure noise.

The following tests will therefore be made with the waveform monitor:

1. The overall shape of a picture signal together with its synchronising pulse at line and frame frequency can be displayed and from this an assessment of the phase and attenuation characteristics from 50 c/s to, say, 300 000 c/s can be made. This is a sensitive test and quite small deviations from normal operating conditions should be immediately obvious.

2. With special test signals, the time of rise and amount of overshoot of a sharp edge can be measured. From these measurements the operation of the

circuit from about 0·3 Mc/s to the highest transmitted frequency may be assessed in respect of attenuation and phase.

3. With special test signals the performance in respect of linearity may be assessed.

4. " Synch. " to signal ratio can be checked during transmission as a rough test of linearity.

5. The amplitude of steady type of interference such as hum, other television signals, steady high frequency tones etc. can be measured.

The picture monitor will be used for making the following observations:

(1) Observation of noise, particularly of intermittent or impulsive nature.

(2) As a general check on the picture quality during transmission, whereby any serious distortion could be observed and located.

Specifications for Waveform and Picture Monitor

Although no waveform or picture monitor is in being which is entirely suitable for the purpose proposed, experience with this type of apparatus has led the B.B.C. to draft the following specifications which we feel will constitute a useful guide concerning these two items of test equipment.

Waveform Monitor

1. The display shall be on a tube of a screen diameter of at least 3½ inches. The trace shall be bright and of sharp focus.

2. In the X direction repetitive linear sweeps at frame and line frequencies shall be fitted. It shall be possible to observe a short portion of a television signal repeating at line, and possibly frame frequency. It is felt that the desirable expansion should be such that 5% of the line (or possibly frame) period should occupy the whole screen, although it is agreed that this 5% need only be of the first 15% of the line period. The linearity of the sweep over the tube face shall be ± 5%.

3. The sweep circuits shall be capable of being synchronised to the incoming Y axis signal or to a signal injected separately. The synchronising signal may be of either polarity between 1v and 500 v. Adequate mains smoothing shall be provided to prevent irregularities in the synchronization due to residual mains hum.

4. The oscillograph shall be capable of displaying signals between 1 v (peak) to 2 v (peak).

5. Means shall be provided for measuring the amplitude of the signal with an accuracy of ± 2%. This limit may have to be relaxed somewhat for small amplitude signals.

6. Means shall be provided for measuring the time durations of pulses up to a maximum of 100 microseconds with an accuracy of 5% or 0·25 microseconds whichever is the greater. It is intended that this pulse width measurement should thereafter be used as the standard for time measurement of build-up time so that an accuracy of greater than 0·25 of a microsecond can be obtained when measuring these features of pulses.

7. *Electrical performance of Y Axis Amplifier.*

It is felt that the frequency characteristic should be as nearly uniform as possible and we have laid down ± 0·1 of a db limits from 50 c/s to 5 Mc/s per second, but we appreciate that some easement may be necessary here but we do not feel that the limits should exceed ± 0·25 db. The departure from the linear relationship β and ω shall be not more than ± 1^0 from 50 c/s to 200 kc/s. The group delay shall be constant within ± 0·01 μ secs. from 200 kc/s to 3 Mc/s. The performance of the amplifier with regard to phase and gain frequency characteristics outside the band specified shall be such as to cause no overshoot on a pulse having a time of rise of 0·15 μ secs.

Noise. — The content of the amplifier noise contributed by power supply hum shall be 50 db below the output which gives a deflection of 1 inch peak to peak with the minimum specified input level.

Linearity. — On the application of a repetitive square pulse or television signal comprising synchronizing signal, the display on the face of the cathode ray tube shall be such that variations of amplitude proportionately follow within ± 1% variations of input amplitude or pulse height of overall television signal up to a maximum height of display of 1 inch. At a maximum display of 2 inches the allowable distortion shall be ± 8%.

8. All controls shall be independent of one another in operation. The following controls shall be provided: Brightness, focus, speed of time base, synchronizing, X and Y shifts, X gain, Y gain.

9. It is expected that an amplifier will be required to drive the X axis plates. Access to the input of this amplifier shall be provided.

10. Access to the control grid of the tube shall be provided. If a beam intensifier amplifier is included it will be sufficient that the input of this amplifier shall be available.

11. The fly-back should be suppressed in order to give maximum clarity in deciphering the display.

Electrical Performance of Picture Monitor

1. The Monitor shall be capable of operation on A.C. or D.C. television signals of standard waveform (see Note 1) of 0·5-2 v. peak to peak unbalanced. The Monitor shall operate on signals of 50: 50 or 70: 30 picture signal ratio. A switch shall be provided so that positive or negative polarity signals may be accepted.

2. A gain control shall be provided for the proper adjustment of the Monitor to cover the range of input signals quoted in Clause 1. The input impedance shall be not less than 3 000 ohms. It is desirable that a contrast control varying the gain of the picture signal should also be included. A 75 ohm termination on the input shall be switchable in or out of circuit. The video amplifier shall be capable of passing signals up to 3·5 Mc/s with an overall deviation of ± 0·5 db up to 3 Mc/s and — 3 db at 3·5 Mc/s. Phase distortion, due to circuits in the Monitor, on pictures or test patterns, shall not be visible at a viewing distance of 2 feet. At the low frequency end of the band the response must be considered in conjunction with the D.C. restoration circuit employed. The distortion on components of the waveform at frame frequency (for example, frame synchronizing pulses) shall be negligible.

3. If necessary a pre-set control may be provided to enable satisfactory separation of vision and synchronizing signals. The time base generators shall give linear scanning signals. The departure from linearity at any one point shall not be more than 5% of the total scan, as measured on the trace on the tube face. The scanning generators must be capable of amplitude adjustment over a range of 50%-120% of normal scan for covering the screen without alteration of the synchronization controls. Separate line and frame shift controls must be provided. The circuit must be arranged so that the beam is not applied unless the scanning voltages are present.

4. A 12-inch tube with a white screen giving good brightness and contrast range shall be provided. Electrostatic or electromagnetic scanning may be used. Any form of focussing is acceptable. The focus shall as far as possible be uniform over the scanned area. As near as possible the tube end should be flat. The tube shape should be such that the glass walls reflect the minimum amount of light from the rear of the screen back on to the screen.

5. The monitor shall operate satisfactorily without visible distortion of line synchronization or perceptible hum bars on the picture when the local A.C. mains supply is not synchronized with the incoming signals.

NOTE

The Standard Television Signal shall be considered as an A.C. signal and shall have the following amplitude characteristics:

Characteristic	Value
Overall amplitude	1 volt double amplitude peak (see below)
Picture signal to synchronizing signal ratio	70-30
Synchronizing signal polarity	Negative with respect to black level
Picture signal polarity	Positive with respect to black level
Impedance of circuit	75 ohms

The signal may be superimposed on a steady unidirectional voltage not exceeding 5 v.

ALPHABETICAL INDEX

to the Book of Annexes to Volume III of the CCIF Green Book, 1954