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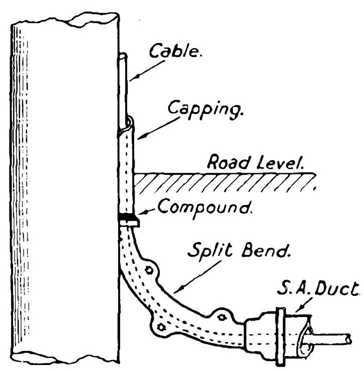
CITY AND GUILDS OF LONDON INSTITUTE EXAMINATIONS, 1933

V. TELEPHONY, PRELIMINARY, 1933: QUESTIONS AND ANSWERS

By W. S. Procter, A.M.I.E.E.

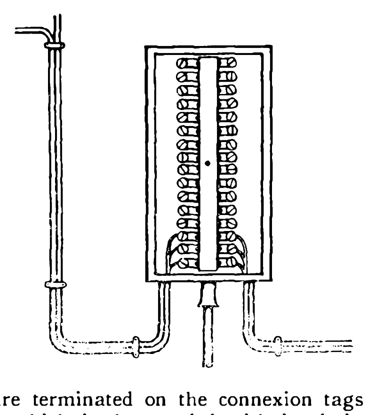
Q. 6. Describe, and illustrate with sketches, a method of terminating a small underground cable on a distribution pole, and connecting the circuits to the open wires leading-in to subscribers' premises. (35).

A. 6. As seen from the sketch, the single-way self-aligning earthenware duct is terminated in the bell-mouthed end of a



split bend, which accommodates the spigot end of the single-way duct; special double-spigot ducts are provided for use in this position. The cable is pulled through the bend, and, for protection, is enclosed for some ten feet above the ground line by a length of capping steel which is held in position by dog-eared spikes. Where the capping steel abuts against the bend, the space is filled with compound to prevent the ingress of water and soil.

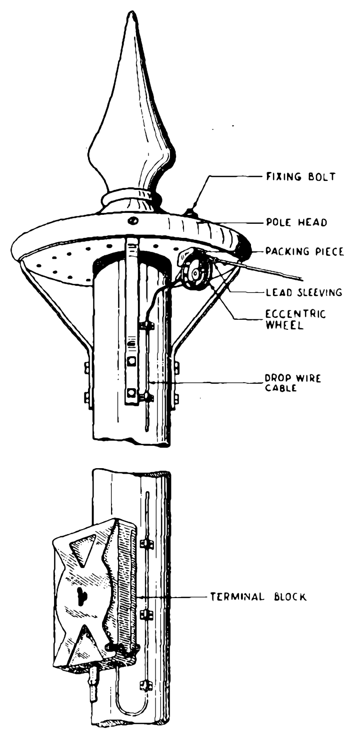
The cable is taken up the pole and is terminated on a connexion block fitted just below the lowest arm position on the pole; the terminal block is shown in the sketch. The



cable pairs are terminated on the connexion tags at the back of the block, which is then sealed with insulating compound. The 1-pair lead-covered cables to the terminal insulators are terminated on the screw tags at the front of the box, as shown, the centre plate being provided for labelling.

The connexions between the cable and the line wires are made in the cavity provided in the top of the terminal insulator; when the joints are completed, insulating compound is pressed into the cavity and the cover of the insulator is screwed home. In the second insulator, the third hole (leading from the cavity to the inner surface of the shed) is not required and it is plugged before the cavity is sealed.

The arrangements when drop wiring is used are shown in the sketch, the drop wire being connected directly to the screw tags in the terminal block.



Q. 7. Give reasons for the following features in the type of induction coil used with local battery telephones:—

(a) Open magnetic circuit;
(b) Use of iron wires for the core;
(c) Low resistance of the primary winding;
(d) Difference in the number of turns in the two windings.

(35).

A. 7. (*a*) A transformer, with a closed magnetic circuit, is more efficient in the transmission of speech currents; if it were used in place of the induction coil, however, the permanent flux due to the continuous current would tend to saturate the iron core, so rendering the coil useless for the transformation of speech currents. Further, the increased hysteresis and eddy current losses due to the greater volume of iron would cause a reduction in the power efficiency of the transformer, and practically treble the impedance of the primary and secondary windings. With local battery instruments, the secondary winding is an impedance in series with the receiver and it is necessary that this impedance should be as low as possible. For these reasons, the induction coil with an open magnetic circuit is used.

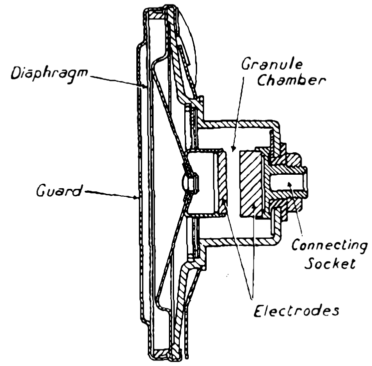
(*b*) Iron wires are used for the core first, because soft iron has a high permeability; and second, because the use of fine iron wires instead of a solid core is necessary to reduce the eddy current loss in the core to as low a value as possible. Were the core solid, the currents induced in it would be a maximum owing to the low resistance of the circulating path through the core; by breaking the core into a number of fine strips, offering a high resistance in the path of the eddy currents, the magnitude of the induced current is reduced. As a result, the eddy current loss, which represents a proportion of the total electrical energy, is reduced.

(*c*) The resistance of the primary circuit is kept as low as possible in order that variations in the resistance of the transmitter may produce the maximum possible variation in the resistance of the primary circuit as a whole, and so give rise to the maximum possible variation in the current flowing through the primary winding of the induction coil. In turn, this gives rise to the maximum variation in the resulting magnetic field and, hence, in the currents induced in the secondary winding.

(*d*) The difference in the number of turns in the primary and secondary windings arises from the need for matching the impedances of the primary and secondary circuits, as well as from the necessity for stepping up the voltage for transmission over the line. In the local battery instrument, the impedances connected to the induction coil are in the ratio of approximately 3 to 1, and hence this ratio is used for the relation between the number of turns of wire on the primary and secondary windings.

Q. 8. Give a sectional sketch and description of an "inset" type of transmitter such as is used in a hand microtelephone. (35).

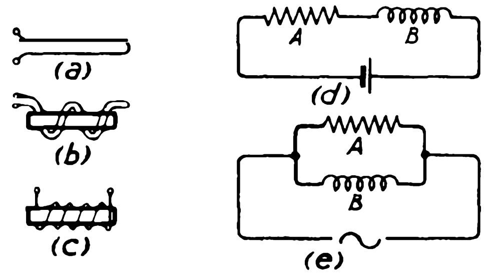
A. 8. The required sketch is given in the accompanying illustration. The transmitter consists of a single corrugated



aluminium cone diaphragm having a small aluminium cylinder fixed to its centre, the purpose of the corrugations being to give increased strength to the diaphragm. The cylinder projects into the granule chamber and carries the moving carbon electrode. The other carbon electrode is fixed to the base of the transmitter case, the faces of the two electrodes being 75-81 mils apart at about the centre of the granule chamber. Rings of silk, forming a sliding fit on the cylinder attached to the diaphragm, are clamped in the granule chamber to prevent leakage of the granules. The granule chamber is filled with a quantity of granules sufficient to ensure that in whatever position the transmitter may be placed, the electrodes are always completely immersed. A perforated ebonite cover fixed in front of the diaphragm protects it from damage. Contact is made by a plug and socket for one connexion, and by springs making contact with the transmitter case for the other.

Q. 9. Describe, briefly, the construction of (a) a resistance spool, and (b) a retardation coil. When a spool A and a coil B are connected in series with a battery the voltage drop is the same across each. If they are connected in parallel across an alternating current supply, however, the current in A is much greater than that in B. What is the reason for this? (40).

A. 9. (*a*) A resistance spool may be constructed by winding the required amount of wire on a former in bifilar fashion, as shown in sketches (*a*) and (*b*). Alternatively, the wire may be wound on the former in a series of widely spaced turns. In either case, the wire is brought out to suitable connecting tags.

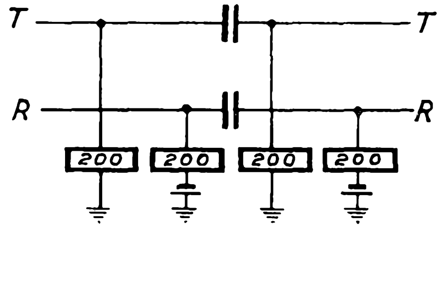


(*b*) A retardation coil is constructed by winding the required length of wire of requisite gauge on a core of soft iron wire, and terminating the winding on suitable connecting tags, as in sketch (*c*).

Since the voltage drop across the spool and across the coil is the same when they are connected in series with a source of direct current, it follows that their resistances must be equal. When they are connected in parallel and joined to a source of alternating current, the inductance of the coil makes its effect felt and the impedance of the coil becomes greater than that of the spool, which remains as its ohmic resistance only. Hence, since the impedances of the coil and the spool are no longer equal, the greater current will flow in that parallel circuit which has the least impedance, *i.e.*, the resistance spool.

Q. 10. Describe the electrical effects in a central battery cord circuit of the impedance coil and condenser type which enable a conversation to take place between two subscribers. Give a sketch, showing only that portion of the cord circuit necessary for the transmission of speech currents. (40).

A. 10. The diagram shows the elements of that portion of the cord circuit necessary for the transmission of speech currents. The battery connected through the impedance coils to the two condensers inserted in the T and R wires maintain a certain potential on the plates of the condensers and this



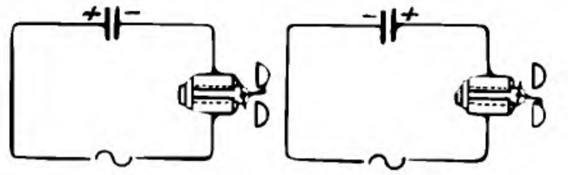
remains constant so long as there is no variation in the resistance of the circuit connected to the cord.

In the C.B. telephone, the effect of talking into the transmitter is to vary the current flowing in the line circuit by varying the potential across the terminals of the substation instrument. Consequently, the potential across one side of the two condensers also changes and a charging current or a discharge current, dependent upon whether the potential is increased or decreased, flows into or out of the plates of the condenser. This gives rise to a precisely similar flow of current either out of or into the plates connected to the other side of the cord circuit.

Since the variations in transmitter current at the telephone are occurring at speech frequency, it follows that the condenser charges and discharges are also occurring at this frequency. Hence, a current at this frequency is flowing round the loop provided by the telephone connected to the other side of the cord circuit, and this current is made up of those charge and discharge currents flowing into and out of the condenser plates due to the variations in the potential of the plates on the other side. The current is therefore alternating and the impedance coils feeding transmitter current to this side of the cord circuit offer high impedance to this current. Consequently, the greater portion of this current flows through the telephone instrument connected to the cord circuit. Hence, speech is received by pulses of current from the condensers, these pulses being superimposed upon the steady current flowing in the circuit from the central battery.

Q. 11. A magneto-generator, a condenser, and a magneto bell are connected in series. Describe the electrical and magnetic effects which occur in the condenser and bell when the generator is operated. (40).

A. 11. A magneto-generator supplies alternating current of low frequency and sketch (*a*) shows such a generator connected

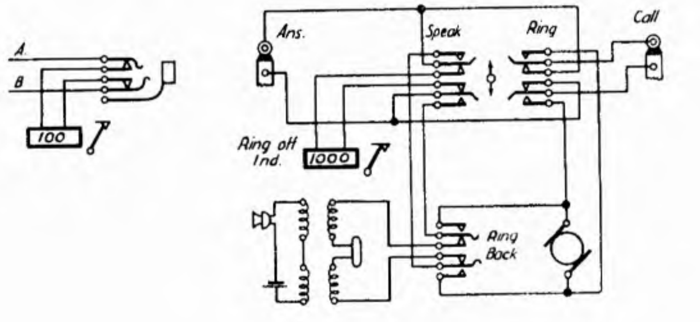


(a) (b)

in series with a condenser and magneto bell. When the generator is supplying a positive half-wave, electricity is driven into one of the plates of the condenser and a similar amount is driven out of the other plate. The electricity is in the form of a charging current and flows through the coils of the magneto bell which, being polarized, attracts its armature to one side and causes the hammer to strike the bell gong. When the generator is supplying a negative half-wave, the condition of things is everywhere reversed. Electricity is driven out of one of the plates of the condenser and a similar amount is driven into the other plate. This charging current flows through the coils of the magneto bell which now attracts its armature to the other side and causes the hammer to strike the other bell gong. The condition in these circumstances is shown in sketch (*b*).

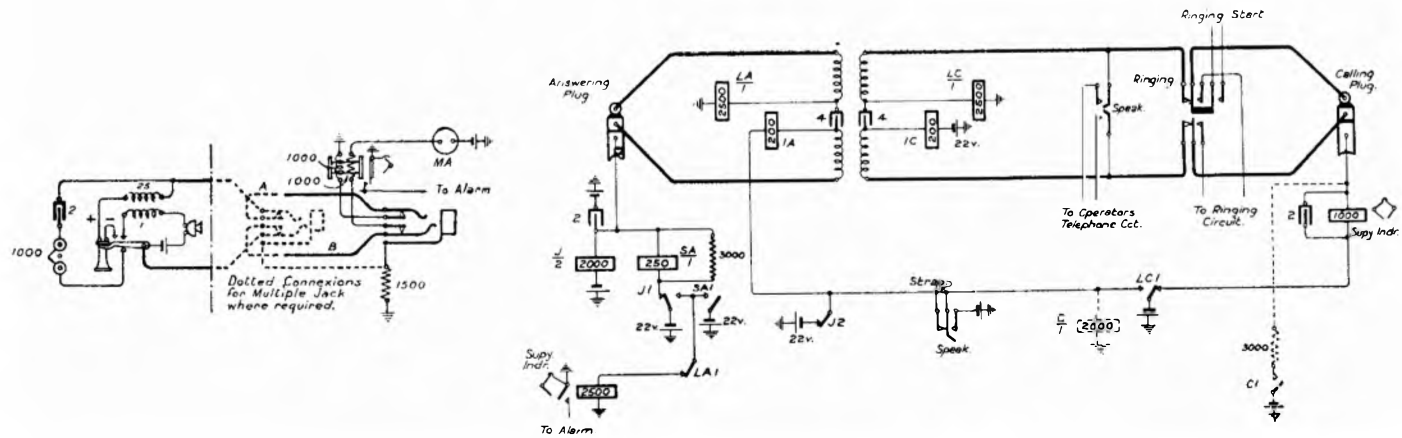
Q. 12. Answer either (a) or (b) only.
  (*a*) *Give diagrams of the line and cord circuit arrangements at a magneto exchange of the non-multiple type.*
  (*b*) *Give outline diagrams illustrating the general features of a modern central battery signalling system.* (40).

A. 12. The required diagrams are given in sketches (*a*) and (*b*) respectively.



LINE CIRCUIT. *CORD CIRCUIT.*

SKETCH (*a*).



C.B.S. No. 2 SYSTEM, LINE CIRCUIT. C.B.S. No. 2 SYSTEM, CORD CIRCUIT.

SKETCH (*b*).

CITY AND GUILDS OF LONDON INSTITUTE EXAMINATIONS.

INTERMEDIATE TELEPHONY EXAMINATION

The attention of readers is drawn to the statement on page 316 of the current issue of the Journal, wherein a concession for the year 1934 only is given to those students who obtained the Institute's Final Certificate in Section 1—Automatic Telephony—without having previously passed the Institute's Intermediate Grade Examination in Telephony.

EXAMINERS' REPORTS.

By courtesy of the City and Guilds of London Institute, we are able to publish the examiners' reports on the 1933 examinations in Telegraphy, Telephony, and Radio Communication; these, we feel sure, will be a useful guide to students.

37 B. TELEGRAPHY.

Grade I. The general standard was satisfactory, but it would be wise for candidates and teachers to concentrate more on fundamental principles. Candidates frequently gave correct diagrams and text-books answers, but failed where the question tested their understanding of the subject rather than their memory of facts.

Final Grade. The proportion of very good papers was higher than usual, and the general standard is good.

37 A. TELEPHONY.

Preliminary Examination. Many of the candidates were unable to apply the elementary principles of magnetism and electricity to their work in this examination. The majority of answers to the first question in the paper merely described a test for internal resistance, but omitted any explanation of the theory—a simple application of Ohm's Law. Mention of the magnetic circuit in Questions 5 and 7 seemed to cause difficulty with some candidates; they were apparently not aware of the meaning of the expression. A large number of the sketches of a telephone relay omitted the heel-piece, an essential part of the magnetic circuit. In answer to Question 7 (*b*) many stated that a core of iron wires had a greater permeability than a solid core, and equally incorrect answers were frequently given to the other parts of this question.

Generally, the descriptive work was satisfactory, but the foregoing examples point to a need for ensuring that candidates have a better understanding of the fundamental principles of the subject.

Intermediate Examination. The average number of answers submitted was seven, and they were fairly well distributed over the paper. The general quality of the work, however, was disappointing, particularly in regard to questions which presupposed some acquaintance with elementary mathematics. A large number of candidates attempted Question 9, but the majority were content to quote a formula which did not take into account the resistance of the voltmeter. Only 45% attempted the simple impedance calculation—Question 11—for which high marks were allotted, and many answers were incorrect.

The answers to Question 5 showed that many candidates did not understand the principles of central battery transmission.

Final Examination (Automatic). The main weakness here was in regard to subjects which fell under the heading "design of Magnets and Relays." Comparatively few candidates attempted the straightforward magnetic circuit problem (Question 1), or that relating to the operating lag of a relay (Question 12). Explanations of the effects of copper slugs on the action of relays (Question 6) were generally very indifferent, the average credit in this case being only 43%. The great majority of answers to the last part of this question were incorrect.

The best answers submitted to this section were those relating to circuit description (Questions 9 and 11). Good credit was also obtained in most cases for the trunking work included in the paper.

Final Examination (Transmission). There was a general improvement in the standard of the candidates' papers in this section. The average number of answers submitted was seven, Questions 4, 6, 8, and 10 receiving less attention than the others. The answers to the following questions, some of which refer to fundamental principles, were below standard:—Question 1, 5 (part 1), 6 (part 2), 7 (parts 1 and 3), and 12 (part 3). There was evidence of failure in the application of theory to practical problems.

37 C. RADIO COMMUNICATION.

Grade I. This paper was answered very well on the whole. Questions 1-4 were generally answered correctly. In Question 5, many candidates gave the wrong polarity for the D.C. output. In Question 6, common errors were—no provision for varying grid potential or adjusting anode potential—milliammeter in anode circuit, also measuring current through voltmeter across H.T. battery. In Question 7, many candidates showed a resonant type wavemeter with incandescent lamp across condenser instead of in series; or telephones across condenser without a rectifier. Question 8 was often incorrectly answered. In their answers to Question 9 many candidates assumed the inductance and resistance to be in series instead of in parallel, while others obtained the individual currents correctly but were unable to add them in quadrature. Question 10 was well answered.

Final Examination. This paper was not answered so well on the whole. Many candidates could not carry out the simplest computations, such as might be required for Grade I. Questions 1, 6, and 7, when attempted, were usually answered correctly. Question 2 was frequently incorrectly answered, many candidates omitting to plot added inductance against wavelength *squared*. Others plotted correctly but did not obtain the required intersection on the correct baseline. In Question 3, many candidates did not know the meaning of attenuation factor. Question 4 was well answered on the whole, but a number of candidates described a plain reacting detector circuit, while others described a super heterodyne circuit. Many candidates attempted Question 5 and failed, although it required only four lines of simple algebraical manipulation. Question 8 was correctly answered, although a number of candidates ignored the fact that the two overturning moments were at right angles and must be added vectorially. Many candidates failed with Question 9. Many suggested putting the telephones across the coil to indicate resonance in the presence of a variable oscillator. A number answered correctly, suggesting plotting added capacity against wavelength squared. A still fewer number suggested using the coil as an absorption circuit weakly coupled to a variable oscillator—which is the simplest and most practical method. The second portion was the subject of many foolish mistakes, although a knowledge of little more than Ohm's Law was required. The last part of the question relating to buzzer excited oscillations was rarely answered correctly. In Question 10, many answered the first part rightly except that they omitted to show the anodes at earth potenial, a very common arrangement where water-cooled valves are used. Very few were able to answer the latter part, many multiplying by the power factor instead of dividing, while others omitted to divide by $\sqrt{3}$.

VI. TELEPHONY, FINAL; SECTION 2, TRANSMISSION. QUESTIONS AND ANSWERS

By W. S. PROCTER, A.M.I.E.E.

Q. 1. *Show that a given number of népers is multiplied by 8.686 to obtain the equivalent number of decibels. Explain why units of transmission are based on ratios of voltages, currents or powers, and not on differences. State the condition under which the current ratio is the square root of the power ratio. (30 marks.)*

A. 1. The number of units of transmission, based upon the relation between powers P_1 and P_2, may be expressed in népers or decibels. For a given ratio of powers, let the number of népers be x and the number of decibels be y. Then

$$\frac{1}{2}\log_e\frac{P_1}{P_2} = \frac{2.3026}{2}\log_{10}\frac{P_1}{P_2} = x \text{ népers}$$

and $10\log_{10}\frac{P_1}{P_2} = y$ decibels.

Since the value of $\frac{P_1}{P_2}$ is the same in both expressions,

$$\log_{10}\frac{P_1}{P_2} = \frac{2x}{2.3026} = \frac{y}{10}$$

giving $\frac{20}{2.3026}x = y$

Hence, the numbers of népers, x, must be multiplied by 8.686 to give the equivalent number of decibels, y.

An equal proportion and not an equal amount of power is expended in transmission over each unit length of uniform line, *i.e.*, the decrease in amplitude of the propagated wave follows an exponential or logarithmic law and not a straight-line law. Voltage, or current, differences in successive lengths are not equal and also depend upon the amplitude at the sending end. As the ratios of currents (or voltages or powers) in successive unit lengths of uniform line are equal, the corresponding ratio for any length of the line is more conveniently found by adding exponents than by multiplying ratios; the units of transmission should therefore be exponential in character.

When the respective voltages act in equal impedances the ratio of the resultant currents is the square root of the power ratio, a condition which applies to a finite uniform line closed with its characteristic impedance.

Q. 2. *Explain how in carrier current telephony speech is transmitted in a higher range of frequencies and translated back to speech frequencies at the receiving end. Describe a method of modulation and demodulation. State the circumstances in which carrier current working is employed. (30 marks.)*

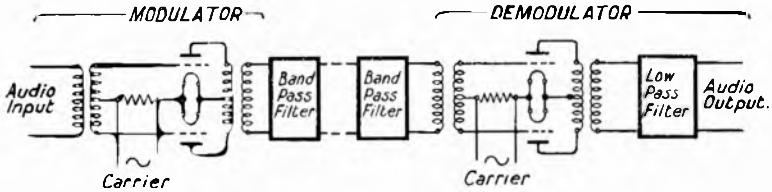
A. 2. The translation is usually effected by employing the non-linear characteristics of valves in the modulating and demodulating circuits. Frequencies in the audio range and the relatively high carrier frequency, when together impressed upon the modulator input, produce in the output a variation in the amplitude of the carrier current accompanied by variations in the frequencies of the output current. The effect is similar to the variation in the amplitude of the output current which would result if the audio frequencies were not present but the polarizing voltage on the grid were varied so that action takes place over different parts of the grid-voltage/output-current curve. The frequency and amplitude of the components of the modulated output are found by substitution in the valve equation of the sum of the input voltages. The output wave contains:—

(*a*) Components identical with the input frequencies,

(*b*) Components respectively equal in frequency to the sum and difference of the input frequencies, and (*c*) separate frequencies twice those of the input frequencies.

One of the components of the output wave under (*b*), which contain the audio frequencies stepped up to the carrier frequency, is essential for transmission to line. Filters are therefore used to limit transmission to one of the sum or difference components, *i.e.*, one side-band, or to the carrier plus one side-band. The process of demodulation is identical with that outlined for modulation, the side-band and carrier frequencies (or re-introduced carrier), when applied to the input of the demodulator, produce in the useful output a component having a frequency equal to the difference between the input side-band and carrier frequencies, viz., the audio frequency. Thus, in demodulation the frequency is stepped down to restore the conditions existing before modulation was introduced at the sending end.

The figure shows the well-known suppressed carrier system employing balanced modulators and demodulators operating on a "push-pull" basis. The carrier currents must be maintained at the same frequency and are introduced in such a manner that the instantaneous values of carrier voltage applied to the grids of each pair of valves is the same, so that the output currents are neutralized in the output transformer; the individual side-band currents, however, combine usefully. The band filter limits transmission in the case of multi-channel operation to one side-band, thereby increasing the channel capacity of the circuit. The operation of the demodulator is similar to that of the modulator.



Carrier current working has not been extensively used by the British Post Office, except to provide additional circuits in suitable existing submarine cables. The introduction of mains-operated carrier current equipment and other developments in the art have opened up the field for the use of carrier equipment on inland underground cables, which have a suitable frequency range, for the relief of congested open-wire routes and for the provision of additional circuits in any emergency.

Q. 3. *Sketch an alternating current bridge for the measurement of line impedance. Give the solution of the bridge for impedances having positive and negative angles. Assume values for the bridge elements when balanced at 800 periods per second, and calculate the components of* either *the admittance* or *the impedance of the unknown arm. (30.)*

A. 3. Sketch (*a*) shows the connexions of an alternating current bridge for the measurement of line impedance. Sketch (*b*) shows the connexions when the impedance has a negative angle, and sketch (*c*) when the angle is positive.

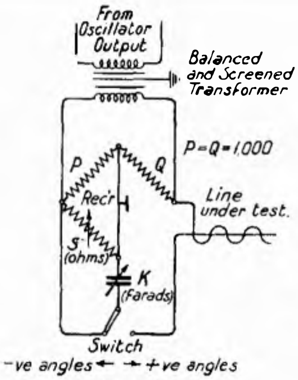
On balance, the products of the admittances of opposite arms equate—

$$\gamma_1\gamma_3 = \gamma_2\gamma_4$$

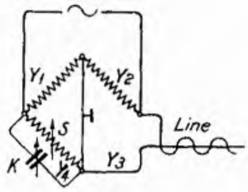
In practice, $\gamma_1 = \gamma_2$ and therefore $\gamma_3 = \gamma_4$

The components of the admittances must also be equal—

$$g_3 + jb_3 = g_4 + jb_4$$

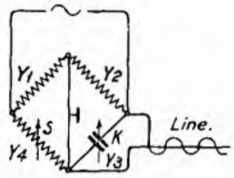


SKETCH (a).



Negative Impedances.

SKETCH (b).



Positive Impedances.

SKETCH (c).

When the line impedance is negative, its admittance is $\gamma_0 = g_0 + jb_0$

and $g_3 + jb_3 = \frac{1}{S} + j\omega K = g_4 + jb_4 = g_0 + jb_0$

$$\therefore\ g_0 + jb_0 = \frac{1}{S} + j\omega K \quad\text{.........(1)}$$

When the line impedance is positive, its admittance is

$$\gamma_0 = g_0 - jb_0$$

and $g_3 + jb_3 = \frac{1}{S} = g_4 + jb_4 = g_0 - jb_0 + j\omega K$

$$\therefore\ g_0 + jb_0 = \frac{1}{S} - j\omega K \quad\text{.........(2)}$$

If solutions of (1) and (2) are required in the form of resistance, r, and reactance, x, then from (1)

$$r_0 - jx_0 = \frac{g_0 - jb_0}{g_0^2 + b_0^2} = \frac{\frac{1}{S} - j\omega K}{\frac{1}{S^2} + \omega^2 K^2} = \frac{S - j\omega KS^2}{1 + S^2\omega^2K^2} \quad ..(3)$$

and from (2) $r_0 + jx_0 = \frac{S + j\omega KS^2}{1 + S^2\omega^2K^2}$ ....(4)

If solutions for impedance are required in the form of modulus and angle,

$$Z = r_0 \cos\phi$$
$$\phi = \pm \tan^{-1} \omega CR$$

$\omega = 800 \times 2\pi = 5000$ radians

Let $S = 1000\Omega$; $K = 0.1\ \mu F = 0.1 \times 10^{-6}$ F.

To calculate the value of the admittance components from (1),

$$g = \frac{1}{S} = \frac{1}{1000} = .001 \text{ mhos}$$

$$jb_0 = j\omega K = j\,5000 \times 0.1 \times 10^{-6} = .0005 \text{ mhos}$$

or, alternatively, to calculate the value of the impedance components from (3), using the same values for S and K,

$$r_0 - jx_0 = \frac{S - j\omega KS^2}{1 + S^2\omega^2K^2}$$
$$= \frac{1000 - j\,5 \times 10^3 \times 0.1 \times 10^{-6} \times 10^6}{25 \times 10^6 \times 25 \times 10^6 \times .01 \times 10^{-12}}$$
$$= \frac{1000 - j\,500}{6.25}$$

Q. 4. Show what is the effect of the length and composition of an exchange line on the transmitting and receiving efficiency. (30).

A. 4. The composition of a subscriber's line is normally $6\frac{1}{2}$, 10, or 20 lb. non-loaded cable or 40 lb. bronze or cadmium copper aerial wire. The composition of the line depends upon the economics of line plant provision and the maintenance of a satisfactory standard of sending and receiving efficiency. A maximum permissible resistance of local line is assigned to each exchange area, based on realizing this grade of transmission which is equal to that obtained by the use of a C.B. telephone with a No. 22 transmitter on a 300-ohm direct exchange line when the transmission bridge at the exchange is of the usual C.B. manual 22-volt repeating coil type.

In C.B. Manual and Automatic exchange areas, the resistance which permits the standard grade of transmission to be realized may, with lines of the normal composition stated above, range from 300 to 450 ohms. The factors determining the allowable line resistance are (i) the resistance and transmission equivalent of the line, (ii) the audio frequency loss and resistance of the transmission bridge, (iii) the transmission voltage, and (iv) the type of telephone transmitter.

In local battery areas, the resistance permitted for local lines is usually 450 ohms. The problem of feeding the transmitter current over the exchange line does not arise in such areas; the important factors are (i) the composition of the line, (ii) the type of telephone and bell-set, and (iii) the number of cells locally feeding the transmitter. The attenuation due to the exchange transmission bridge is, however, taken into account; it is approximately 1 db. for exchange bridges of the repeating coil type and 0.5 db. for those of the Stone type.

To obtain the standard grade of transmission on all exchange calls, allowance is made for the resistance of series apparatus at private branch exchanges.

Q. 5. Explain the terms propagation constant, attenuation constant, and wave-length constant. Calculate the attenuation constant of an open wire line having the following primary constants per mile:—R = 88 ohms, L = 3.6 millihenries, C = 0.009 microfarads, and G = 2 micro-mhos, when the angular velocity is 5,000 radians per second. (35).

A. 5. The ratio of the currents at the beginning and end of each unit length of uniform line is

$$\frac{I_1}{I_2} = e^{\gamma} = e^{\beta + j\alpha}$$

γ, the propagation constant, is a complex quantity because the current I_1 and I_2 differ in phase; it therefore expresses jointly the magnitude and phase relations of the currents I_1 and I_2.

β, the attenuation constant, represents the change in magnitude of the currents. $\beta = \log_e \left|\frac{I_1}{I_2}\right|$ is the natural logarithm of the ratio of maximum instantaneous values of the currents per unit length of line.

α, the phase (or wave length) constant, represents the phase shift in radians per unit length of line.

$R^2 = 8.8$ $\qquad G = 2 \times 10^{-6}$

$\omega L = 5 \times 10^3 \times 3.6 \times 10^{-3} = 18$ $\qquad \frac{\omega L}{R} = 2.045$

$\omega C = 5 \times 10^3 \times .009 \times 10^{-6} = 45 \times 10^{-6}$ $\qquad \frac{\omega C}{G} = 22.5$

$$\gamma^2 = (R + j\omega L)(G + j\omega C)$$

$$= \sqrt{(R^2 + \omega^2 L^2)(G^2 + \omega^2 C^2)} \,\Big/ \tan^{-1}\frac{\omega L}{R} + \tan^{-1}\frac{\omega C}{G}$$

$$= \sqrt{(8.8^2 + 18^2)(2^2 + 45^2)}\, 10^{-12} \,\Big/ \tan^{-1}\frac{18}{8.8} + \tan^{-1}\frac{45}{2}$$

$$= 10^{-6}\sqrt{401.44 \times 2029} \,/ 63.9^0 + 87.45^0$$

$$\gamma = 10^{-3}\sqrt[4]{401.44 \times 2029} \,\Big/ \frac{63.9^0 + 87.45^0}{2}$$

$$= 10^{-3} \times 30.04 \,/ 75.67^0$$

$$\beta = .03004 \cos 75.67^0$$

$$= .03004 \times .24748$$

$$= .00744 \text{ népers per mile.}$$

Q. 6. Derive an expression for the sending end impedance of a finite uniform line closed by any terminal impedance. Explain the practical application of the expression to a particular problem. (35.)

A. 6. The sending end impedance is expressed in terms of the characteristic impedance Z_0 and propagation constant γ. The change in sending end impedance, when the impedance of the receiving end termination is altered, is due to reflection of voltage and current. The reflected voltage and current are expressed in terms of the normal voltage, and current, which exists when the line is terminated with impedance Z_0. The sending end impedance is therefore given by the ratio of the respective sums of normal and reflected voltage, and current.

The voltage E_R and current I_R at the receiving end of a finite uniform line of length l, propagation constant γ, and characteristic impedance Z_0, when it is terminated with its characteristic impedance, are

$$E_R = E_S\, e^{-\gamma l} \text{ and } I_R = I_S\, e^{-\gamma l}$$

where E_S and I_S are the incident sending end voltage and current. By Thevenin's Theorem, the open circuit voltage E_0 at the receiving end is

$$E_0 = 2\, E_S\, e^{-\gamma l}$$

and the voltage E_r which is reflected when impedance Z_T is substituted for the terminating impedance Z_0 is

$$E_r = \frac{E_0}{2} - \frac{E_0 Z_0}{Z_0 + Z_T} = \frac{E_0}{2}\left(\frac{Z_T - Z_0}{Z_T + Z_0}\right)$$

$$= E_S\, e^{-\gamma l}\left(\frac{Z_T - Z_0}{Z_T + Z_0}\right)$$

The part within the brackets is the reflection factor. In transmission to the sending end of the line, the reflected voltage E_r' becomes

$$E_r' = E_S\, e^{-2\gamma l}\left(\frac{Z_T - Z_0}{Z_T + Z_0}\right)$$

The total voltage E at the sending end is therefore

$$E = E_S + E_r' = E_S\left[1 + e^{-2\gamma l}\left(\frac{Z_T - Z_0}{Z_T + Z_0}\right)\right]$$

Similarly, the total current I at the sending end is

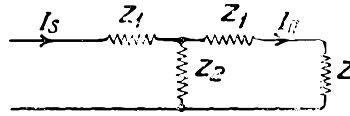
$$I = I_S + I'_r = I_S\left[1 + e^{-2\gamma l}\left(\frac{Z_0 - Z_T}{Z_0 + Z_T}\right)\right]$$

The sending end impedance Z when the receiving end is terminated with impedance Z_T is therefore

$$Z = \frac{E_S\left[1 + e^{-2\gamma l}\left(\frac{Z_T - Z_0}{Z_T + Z_0}\right)\right]}{I_S\left[1 + e^{-2\gamma l}\left(\frac{Z_0 + Z_T}{Z_0 - Z_T}\right)\right]} \text{ where } \frac{E_S}{I_S} = Z_0 \ldots\ldots(1)$$

This expression may easily be rearranged, if desired, in the form

$$Z = Z_0\left(\frac{Z_0 \sinh \gamma l + Z_T \cosh \gamma l}{Z_0 \cosh \gamma l + Z_T \sinh \gamma l}\right) \ldots\ldots\ldots\ldots(2)$$



The expression for the sending end impedance is employed to calculate the secondary constants and characteristic impedance of a line of length l from measured sending end impedances under conditions of known terminating impedance. The measured values are substituted for Z in equations (1) or (2), but the equation is simplified by making Z_T zero or infinite.

When the distant termination is open-circuited,

$$Z = Z_{OC} = Z_0 \coth \gamma l = \frac{Z_0}{\tanh \gamma l}$$

When short-circuited,

$$Z = Z_{SC} = Z_0 \tanh \gamma l.$$

Therefore $Z_0 = \sqrt{Z_{OC} Z_{SC}}$

Also $\tanh \gamma l = \sqrt{\frac{Z_{SC}}{Z_{OC}}}$

Q. 7. Explain the necessity for the filters associated with 2-wire repeaters. Give reasons for the use of balancing networks for 4-wire terminations of repeatered circuits. Explain what is meant by the singing point of a line and network. (35).

A. 7. The 2-wire repeater contains two amplifying elements, one for each direction of transmission. Each of the lines is connected to the input of one amplifier and to the output of the other by means of a three-winding transformer. The repeater and associated lines act as an oscillator when the sum of the gains given by the two amplifier elements exceeds the sum of the losses in the connexions between the outputs and inputs of the amplifier elements. The differential transformers act on the bridge principle and the losses are made to fully exceed the gains by maintaining a specified degree of balance between the impedance of the line and that of its network. For coil-loaded cable circuits, this balance is increasingly difficult to maintain at frequencies approaching the cut-off frequency, and filters of the low-pass type, having a critical frequency somewhat lower than the cut-off frequency of the line, are therefore provided in the output circuit of each amplifier element. These introduce sufficient loss at the higher frequencies to compensate for the unbalance between line and network, and to a practical extent prevent singing at higher frequencies within the transmission range.

A 4-wire circuit may be regarded as a 2-wire repeater with each of the amplifier elements replaced by a line with unidirectional amplifiers in tandem. At the circuit terminations, where the separate transmission channels unite, sufficient loss must be introduced in the return path to prevent howling or instability. As the 2-wire side of the terminations are connected to lines of different type and composition, the balancing impedance is usually a 600-ohm resistance. A compromise in regard to this balancing impedance is possible only because there is one primary echo path. If a 4-wire circuit has a long 2-wire end permanently connected, a full balancing network and filter are necessary.

The term " singing point " owes its origin to the 2-wire repeater having one amplifying element and one differential transformer. The effective operation of a circuit with such a repeater depends upon the equality of the impedance characteristics of the two lines associated with the repeater, *i.e*, one line is required to effectively balance the other. The degree of balance was conveniently expressed as the gain given by the repeater when a circuit is on the border-line of the singing condition. The singing point was therefore the loss across the differential transformer, from amplifier element output to input, less the energy losses in the transformer, which amount to about 6 db.; this practical definition holds in the case of the later two-element repeaters. Theoretically, the singing point at the repeater is the ratio, expressed in decibels, of the normal current transmitted to line when no reflection occurs to the current returned from the line due to reflection.

Q. 8. The impedance frequency curves for a line of x route miles normally show successive " humps " at a constant frequency interval of n periods per second, due to end reflection. As the result of a line fault the curves show large " humps " at a wider frequency spacing m periods per second. Express the distance to the fault in terms of x, n and m. How would the distance to the fault be found if the curves were normally very irregular? (35).

A. 8. At the two frequencies f_1 and f_2 such that $f_2 = f_1 + m$, the respective wave-lengths are λ_1 and λ_2. The distance to the fault and back, $2d$, expressed in wave-lengths is, at frequency f_1

$$2d = a\lambda_1$$

where a is the number of wave-lengths in distance $2d$ miles. If the sending end impedance passes from one maximum to the next maximum value as frequency f_1 is increased to f_2, the number of wave-lengths is increased by unity. Assuming that the phase change at the point of partial reflection is the same at frequencies f_1 and f_2

$$2d = a\lambda_1 = (a + 1)\ \lambda_2$$

and since $\lambda = \frac{V}{f}$,

$$2d = \frac{aV_1}{f_1} = \frac{(a+1)\,V_2}{f_2}$$

$$\text{or}\quad aV_1 f_2 = (a+1)\,V_2 f_1$$

In practice, the velocity of propagation over the range of frequencies m may be regarded as substantially constant, *i.e.*,

$$V_1 = V_2$$

$$\therefore\ aV_1(f_2 - f_1) = V_1 f_1$$

$$i.e.,\quad a = \frac{f_1}{f_2 - f_1}$$

$$\therefore\ d = \frac{a\lambda_1}{2} = \frac{aV_1}{2f_1} = \frac{2(f_2 - f_1)}{V_1} = \frac{V_1}{2m}\ \text{miles.}$$

To find V_1,

$$x = \frac{V_1}{2n}\quad\text{or}\quad V_1 = 2nx$$

$$\text{Then } d = \frac{2nl}{2m} = \frac{ln}{m}\ \text{miles}$$

The answer is obvious from inspection, except for a statement regarding the assumptions that (i) the phase changes at the points of reflection are constant, and (ii) that the velocity of propagation is constant.

If a curve showing the normal impedance/frequency characteristics of the circuit is available, the ordinates of the normal curve and a second curve showing the fault conditions would be subtracted to obtain a difference curve which shows the required frequency interval r for substitution, as before, in the equation $d = \frac{lr}{m}$ miles.

Q. 9. State briefly the considerations that determine the choice of loading coil inductance, the spacing of the coils, and the weight of the conductors for a modern cable. (40).

A. 9. The loaded cable must satisfy transmission requirements in regard to (i) the attenuation over the range of frequencies to be effectively transmitted, and (ii) the permissible attenuation over a substantial portion of that range. The permissible attenuation is governed by cross-talk considerations, as the gain which can be introduced by repeaters is unlimited. In main trunk cables, the maximum attenuation at 800 p.p.s. is limited by cross-talk to about 30 db. The range of frequencies necessary for satisfactory commercial intelligibility on long trunks is such that the cut-off frequency should be not less than 3,400 p.p.s., giving effective transmission up to about 0.8 of that frequency on condition that attenuation equalization is introduced on long lines. The cut-off frequency is governed by the capacitance of a loading section and the inductance load. The attenuation is governed by the primary line constants and the added inductance per loading section. The optimum spacing of loading coils and weight of conductor may be calculated, but where an existing duct line is available the spacing of existing manholes for the accommodation of loading pots reduces the problem to the selection of a conductor weight consistent with the added inductance per loading section. In present-day practice, the coil spacing is standardized, 1.136 miles, and the coil inductance for side circuits is 120 mH. The conductor weight is now usually 20-lb. per mile for trunk circuits and as low as 10-lb. per mile for short trunk circuits, which, of course, have shorter repeater or amplifier sections.

Q. 10. An equivalent T network has two series elements each equal to $Z_0 \tanh \frac{\gamma l}{2}$, and a shunt element $Z_0/\sinh \gamma l$, and will represent at one frequency a circuit of l miles, having a propagation constant of γ and an impedance Z_0. Explain briefly how the expressions for the elements may be derived. Calculate the resistance of the elements for a non-reactive network of 3 decibels and $Z_0 = 600$ ohms. (40).

A. 10. The expressions are derived from consideration of the requirement that the values assigned to the network elements are (i) the impedance at the input terminals must be Z_0 when the load connected to the output terminals is Z_0, and (ii) the ratio of input current I_S to output current I_R under the terminating conditions stated in (i) is given by $\frac{I_1}{I_2} = e^{-\gamma l}$ where γ is the propagation constant of the network.

Expressing these requirements in terms of the impedance of the network elements,

$$Z_0 = \frac{Z_1 + Z_2(Z_1 + Z_2)}{Z_1 + Z_2 + Z_0} \quad \text{......(1)}$$

$$\frac{I_R}{I_S} = \frac{Z_2}{Z_1 + Z_2 + Z_0} = e^{-\gamma l} \quad \text{......(2)}$$

$$\therefore\ Z_0 = Z_1 + (Z_1 + Z_0)\,e^{-\gamma}$$

$$\text{or}\quad Z_1 = \frac{Z_0(1 - e^{-\gamma})}{1 + e^{-\gamma}} = Z_0 \tanh \frac{\gamma l}{2} \quad \text{......(3)}$$

$$\text{Similarly } Z_2 = \frac{Z_0\,2e^{-\gamma}}{1 - e^{2\gamma}} = \frac{Z_0}{\sinh \gamma l}$$

$$Z_0 = 600\Omega \qquad 20 \log_{10} \frac{I_S}{I_R} = 3$$

$$\frac{I_S}{I_R} = e^{\gamma} = 10^{.15} = 1.4125$$

$$\tanh \frac{\gamma}{2} = \frac{e^{\gamma} - 1}{e^{\gamma} + 1} = \frac{0.4125}{2.4125} = 0.171$$

$$\therefore\ Z_1 = 600 \times 0.171 = 102.5\ \text{ohms.}$$

$$\text{Sinh } \gamma = \frac{e^{\gamma} - e^{-\gamma}}{2} = \frac{1.412 - 0.708}{2} = \frac{0.704}{2}$$

$$\therefore\ Z_2 = \frac{600 \times 2}{0.704} = 1705\ \text{ohms.}$$

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