Supplement

to

The Post Office Electrical Engineers' Journal

Vol XXVI April 1933 No 1

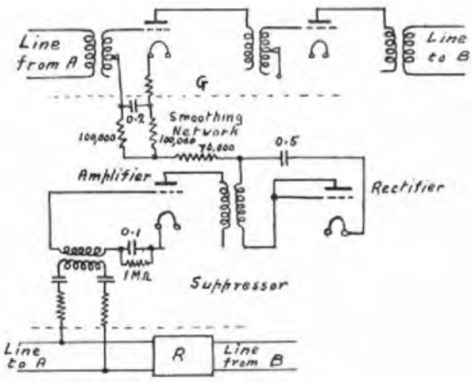
The answers to the examination papers which are given in this Supplement are not claimed to be thoroughly exhaustive and complete. They are, however, accurate so far as they go and are such as might be given within the time allowed by any student capable of securing high marks in the examinations.

XI.—TELEPHONY, FINAL; SECTION 2, TELEPHONE TRANSMISSION. QUESTIONS AND ANSWERS

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

Q. 6. Give an explanatory diagram of an echo-suppressor associated with a 4-wire repeater. Describe the operation of the suppressor. What bearing have the velocity of propagation and the overall transmission equivalent of the circuit upon echo effect? Compare echo effects on 4-wire and 2-wire repeatered circuits. (35).

A. 6. A diagram of an echo-suppressor associated with a 4-wire repeater is shown in the sketch. Speech currents from B are amplified by the repeater R and transmitted to A



where part of the energy is returned due to unbalance between the 2-wire line and network at A. This return current would be amplified by the repeater G and return to the talker, and if there were time lag or appreciable return current the effect would be disturbing. The current would make further return trips if the line and network at B were not balanced, causing echo trouble to both talker and listener.

With suppressor operation, the output from the repeater R is connected to the suppressor input circuit, two resistances of 8,000Ω usually being connected in series with the suppressor input to prevent the suppressor from unduly shunting the speech currents from B to A.

The input voltage to the suppressor is amplified by the suppressor amplifier and its output is rectified by a diode to produce a negative potential on the grid of the first stage valve of the amplifier G. The rectified current is smoothed and built up at the desired rate by a resistance-capacity combination. The magnitude of the alternating current component is reduced by this arrangement to prevent its input to the line from A to B.

The negative potential applied to the grid of the first valve of amplifier G changes the potential from its normal value of -1.5 volts to a more negative value depending upon the magnitude, wave form, and duration of the voltage at the suppressor input. As the grid voltage approaches -3 volts, the gain of amplifier G falls rapidly and is reduced by about 15 db. when the negative potential has reached 5 volts.

With suitable timing of suppressor operation, amplifier G becomes substantially inoperative before the echo current returns from A.

The sensitivity and timing of echo suppressors are important factors, care being taken to prevent false operation due to room noise, or cross-talk in the suppressor equipment and also to prevent undue hang over.

In general, the smaller the overall loss in the circuit the greater the return current. If the circuit is of light loading and the time of propagation is not appreciable, the echo currents tend to merge with the transmitted currents and are not troublesome. With longer circuits or heavier loading the propagation time increases and the echo effects become serious, particularly as the overall transmission equivalent is improved as in the case of zero circuits between zone centres for which echo suppressors are employed.

Echo troubles are not noticeable with 2-wire repeater circuits because the echo current paths are so numerous and the magnitude of the return currents so serious that it is not possible to work a 2-wire repeater circuit at as low an overall equivalent as a 4-wire repeater circuit nor to work with many 2-wire repeaters in tandem. Thus, although the loading is usually heavier for 2-wire circuits, the length of circuit obtainable is insufficient to give rise to echo effects.

Q. 7. State the approximate characteristic impedance (modulus and angle) and transmission equivalent per mile (decibels) of a typical (a) coil loaded cable circuit and (b) open wire circuit. A line is composed of 30 route miles of (a) and 20 route miles of (b).

What improvement in overall transmission equivalent would be given by the introduction of a suitable transformer at the junction of the cable and open wires, neglecting transmission losses in the transformer itself? (35).

A. 7. The approximate characteristic impedance of a 40-lb. cable circuit loaded with 89 mH coils spaced at 1.136 miles is $1110\,\overline{\backslash 5^\circ}$, whilst the transmission equivalent per mile is 0.2 db. A 150-lb. copper aerial circuit has a characteristic impedance of approximately $725\,\overline{\backslash 15^\circ}$, whilst its transmission equivalent per mile is 0.082 db.

Let it be assumed that the ends of the composite circuit are closed with the respective characteristic impedances above. Then an ideal transformer would match the impedance moduli at the junction of the cable and open wires, but would not affect the angles. The impedance looking into the transformer on the cable side would be $1110\,\overline{\backslash 15^\circ}$ and on the open wire side it would be $725\,\overline{\backslash 5^\circ}$. The improvement in transmission would be determined from the ratio of the power transmitted from a $1110\,\overline{\backslash 5^\circ}$ to a $1110\,\overline{\backslash 15^\circ}$ line to the power transmitted from a $1110\,\overline{\backslash 5^\circ}$ to a $725\,\overline{\backslash 15^\circ}$ line.

Let r be the ratio of the moduli of the cable and aerial circuit impedances, and β be the difference between their angles. Then the improvement in transmission due to the ideal transformer is given by the expression.

[1]Improvement (db) $= 10 \log_{10} \dfrac{1 + 2r \cos \beta + r^2}{2r(1 + \cos \beta)}$

$$r = \frac{1110}{725} = 1.53 \quad . \quad r^2 = 2.34$$

$$\beta = 15^\circ - 5^\circ = 10^\circ \qquad \text{Cos } \beta = 0.985$$

Improvement due to transformer

$$= 10 \log_{10} \frac{1 + 3.06 \times 0.985 + 2.34}{3.06\,(1.985)}$$

$$= 10 \log_{10} \frac{1 + 3.02 + 2.34}{6.07}$$

$$= 10 \log_{10} 1.046 = 0.195 \text{ db.}$$

As β, the angular difference, is small the result would have been given with sufficient accuracy by the alternative form of the first equation, neglecting angles:—

Improvement (db) due to transformer

$$= 10 \log_{10} \frac{(Z_T + Z_R)^2}{4 Z_T Z_R}$$

where $Z_T = 1110$ and $Z_R = 725$.

$$\text{Improvement} = 10 \log_{10} \frac{1835^2}{4 \times 1110 \times 725}$$

$$= 10 \log_{10} 1.048 = 0.204 \text{ db.}$$

The loss introduced by an actual transformer would exceed this theoretical gain. The loss in line transformers at audio frequencies ranges from 0.4 to 1.0 db., depending upon the resistance of the transformer windings and the impedances of the lines with which the transformer is used.

Q. 8. State the characteristic features of two valves of the type used for repeater or carrier current working. What governs the power in watts delivered to the line by a typical valve when the maximum permissible sinusoidal voltage is applied to the grid? Describe the effects of raising and lowering (a) the plate voltage, (b) the filament current, from the normal working value. What determines the selection of the value of a fixed grid voltage in the case of repeater valves? (35).

A. 8. The characteristic features of two valves used for repeater working are shown in the table.

	1st stage valve.	2nd stage (output) valve.
Filament current	0.9A	0.9A
Grid priming	−1.5V	−9V
Plate impedance	60,000Ω	6,000Ω
Amplification factor	32	5.9

The maximum instantaneous value of the voltage applied to the grid should not exceed the grid priming voltage E_g. As the output power is to be determined, the R.M.S. value must be taken, *i.e.*, $0.707\ E_g = \dfrac{E_g}{\sqrt{2}}$. The alternating current voltage acting in the plate circuit is $\dfrac{\mu E_g}{\sqrt{2}}$ where μ is the amplification factor of the valve. The voltage across the load impedance is $\dfrac{Z_L + Z_P}{Z_L}$ of the total voltage, where Z_L is the load impedance and Z_P the plate impedance:—

$$\frac{\mu E_g Z_L}{\sqrt{2}\,(Z_L + Z_P)}$$

and the power delivered to the load is

$$\left(\frac{\mu E_g Z_L}{\sqrt{2}\,(Z_L + Z_P)}\right)^2 \frac{1}{Z_L} = \frac{\mu^2 E_g{}^2 Z_L}{2\,(Z_L + Z_P)^2}$$

[1] See "Transmission Circuits for Telephone Communications," by K. S. Johnson, Chap. VII.

The maximum output power is obtained when $Z_L = Z_P$. Then

$$\text{Max. output power} = \frac{\mu^2 E_g{}^2}{8\, Z_P}$$

Taking the valve given above,

$$\text{Max. output power} = \frac{(5.9 \times 9)^2}{8 \times 6000} \text{ watts}$$

$$= 0.059 \text{ W} = 59 \text{ mW.}$$

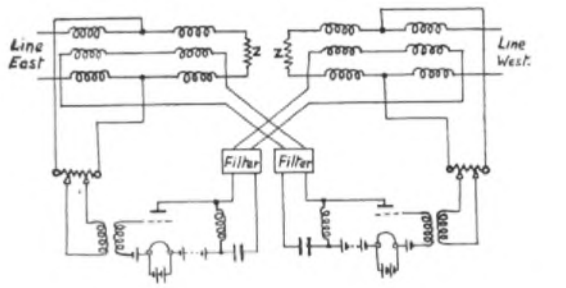
Raising the plate voltage lowers the plate impedance and vice versa. If the plate and load impedances are matched by a suitable transformer, the change of plate impedance will, in either case, reduce the output power.

The working filament current is such that normal variations above and below this value do not affect the filament emission. If, however, the valve is aged, the lowering of the filament current would be sufficient to affect the filament emission seriously and reduce the gain of the amplifier.

For amplification, the fixed grid voltage is set at the middle of the straight portion of the grid-volts/plate-current characteristic.

Q. 9. Give, without description, an explanatory sketch of a 2-wire telephone repeater. Explain why the resistance of the potentiometer is 300 ohms, when the nominal impedance of the repeater is 600 ohms. What reduction in gain would result from turning the potentiometer switch so as to connect the input transformer across 150 ohms instead of 300 ohms? (40).

A. 9. An explanatory diagram of a 2-wire telephone repeater is shown in the sketch. The nominal impedance of a 2-wire



repeater is made up of the impedance of the differential transformer with its plate circuit load, and the resistance of the potentiometer. These are usually made equal, the potentiometer being 300Ω and the impedance of the plate circuit (6,000Ω) being stepped down to 300Ω by the differential transformer.

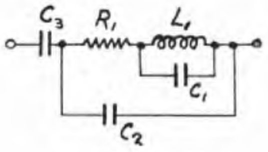
The potential applied to the input terminals of the input transformer is reduced to half when the potentiometer is changed from 300Ω to 150Ω. The change in repeater gain will be 20 $\log_{10}$ of the voltage ratio under the two conditions:—

$$20 \log_{10} \frac{E_1}{E_2} = 20 \log_{10} 2 = 6.02 \text{ db.}$$

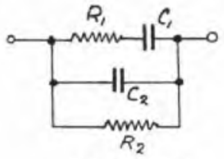
Q. 10. Give a diagram of the balancing network used for repeater working to simulate the impedance frequency characteristic of (a) a coil loaded, (b) an unloaded cable circuit. Outline either the practical or the theoretical method of determining the values of the components of one of the networks. (40).

A. 10. The balancing network usually employed in connexion with a coil-loaded cable circuit is shown in sketch (i) whilst that used for an unloaded cable circuit is shown in sketch (ii).

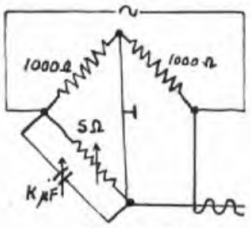
The line to be balanced is measured on a resistance-capacity bridge at suitable frequency intervals for plotting the bridge readings SΩ and K μF from 250 p.p.s. to 0.8 of the cut-off frequency or to the highest frequency to be effectively transmitted by the telephone repeater. For measuring lines with



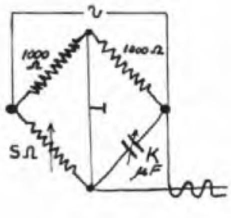
Sketch (i)



Sketch (ii).



Sketch (iii)



Sketch (iv).

a negative angle the bridge is connected as shown in sketch (iii), whilst for lines with positive angles the bridge connexions are shown in sketch (iv).

The values of the components of either network are determined from the plotted curves of bridge readings under both the theoretical and practical methods outlined below.

Coil-loaded Line: Practical Method. The value of L appropriate to each type of loaded line is scheduled; the value of this component is therefore predetermined. The part of the network (sketch (i)) comprising R_1, L_1, and C_1 is assembled by making R_1 equal to the lowest bridge reading given by a mean curve through the plot of bridge readings S, and using for C_1 an adjustable condenser set to a schedule value. The part of the network so formed is measured on the bridge, described above, at a frequency about 0.7 of the cut-off frequency of the line and C_1 is adjusted to give a value corresponding to the mean S curve at that frequency. Apart from slight re-adjustments that may be necessary, this fixes the value of C_1.

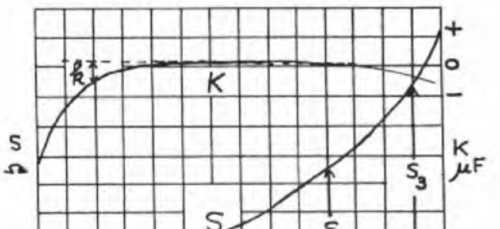
An adjustable condenser is then added in the position of C_2 (sketch (i)) and is adjusted until the bridge reading K μF, at the same single frequency, agrees with the mean K curve for the line. This fixes the value of C_2.

Condenser C_3 is then added and its value adjusted, usually in steps of 1 μF, until the K values for network and line agree at a low frequency of about 300 p.p.s.

The complete network is then tested at a few frequencies to check its S (ohms) and K (μF) bridge readings over the necessary range of frequencies.

After assembly in the repeater circuit, the wiring connexions are checked by means of a singing point test.

Loaded Line: Theoretical Method. Taking the common case of coil-loaded lines with half-section termination, the values of the network components are found by reference to mean curves of bridge readings, shown in sketch (v).



Sketch (v)

The lowest reading on the S curve is the resistance required for R_1. As the effect, at higher frequencies, of the series condenser C_3 may be neglected, components L_1 and C_1 are found from the rise of the S curve in respect of its lowest value S_1, which is usually at 0.2 of the cut-off frequency of the line f_0. Let S_2 and S_3 be readings on the mean curve at 0.6 f_0 and 0.75 f_0 respectively. Then

$$\frac{\omega_2 L_1}{1 - \omega_2^2 L_1 C_1} = \sqrt{S_1(S_2 - S_1)} = \text{(say) } A_2$$

$$\frac{\omega_3 L_1}{1 - \omega_3^2 L_1 C_1} = \sqrt{S_1(S_3 - S_1)} = \text{(say) } A_3$$

Rearranging—

$$C_1 = \frac{A_2 - \omega_2 L_1}{A_2 \omega_2^2 L_1} = \frac{A_3 - \omega_3^2 L_1}{A_3 \omega_3^2 L_1} \text{ farads......................(1)}$$

Solving (1):—

$$L_1 = \frac{A_2 A_3(\omega_3^2 - \omega_2^2)}{\omega_2 \omega_3 (A_3 \omega_3 - A_2 \omega_2)} \text{ henrys.................................(2)}$$

C_1 is then found by substituting this value of L_1 in equation (1).

Having first found R_1, L_1, and C_1, the value of C_2 is derived by equating the susceptance components respectively of the admittance of the line (from the mean curve K) and the network comprising C_1, C_2, R_1, and L_1, using a higher frqeuency.

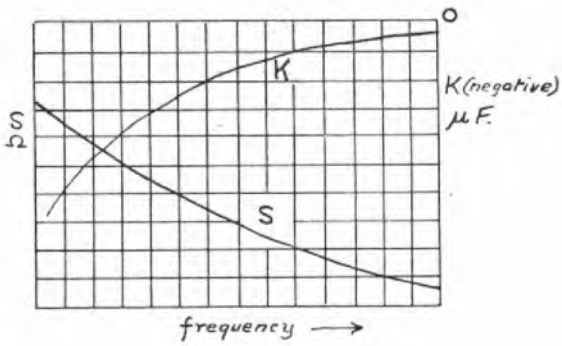
The series condenser C_3, which has been neglected up to this stage, is usually found by trial, but its value is given approximately by the equation

$$C_3 = \frac{1}{S_1 \omega_1^2 k} \text{ farads.}$$

where k is the difference between the K readings on the mean curve at ω_1 and ω_2, see sketch (v).

In all equations, L is expressed in henrys and K in farads.

Unloaded Lines. The theoretical method, in any case, is applied for finding the values of R_1 and C_1, after which R_2 and C_2 may be found by trial since changing R_1 will not affect the K curve and vice versa. Hence, the R_1C_1 combination decides the shape of the network curves whilst R_2 and C_2 shift the network curves bodily up or down to correct position in relation to the mean curves for the line. The mean S and K curves are usually as shown in sketch (vi).



Sketch (vi)

A method of calculating the values of the network components is to equate the admittance components of the line (from mean S and K curves) and network.

$$\text{Conductance of line} = \frac{1}{S} \text{ ohms.}$$

$$\text{Susceptance of line} = \omega K \text{ ohms.}$$

$$\text{Conductance of network} = \frac{1}{R_2} + \frac{R_1 \omega^2 C_1^2}{1 + R_1^2 \omega^2 C_1^2} \text{ ohms.}$$

$$\text{Susceptance of network} = \omega C_2 + \frac{\omega C_1}{1 + R_1^2 \omega^2 C_1^2} \text{ ohms.}$$

Then—

$$\frac{1}{S} \equiv \frac{1}{R_2} + \frac{R_1\omega^2C_1^2}{1 + R_1^2\omega^2C_1^2} \quad \ldots\ldots(1)$$

$$\omega K \equiv \omega C_2 + \frac{\omega C_1}{1 + R_1^2\omega^2C_1^2} \quad \ldots\ldots(2)$$

R_2 and C_2, respectively, may be eliminated by substituting two values for ω and corresponding values of S and K. Then $\frac{1}{S_1} - \frac{1}{S_2}$ gives an expression independent of R_2 and $K_1 - K_2$ is independent of C_2, from which may be calculated first, the value of the R_1C_1 product, and then, of R_1 and C_1 independently. Having found R_1 and C_1, the values are substituted in equations (1) and (2) to find R_2 and C_2.

Q. 11. Give the formula for the impedance of a line of characteristic impedance Z_0 and having uniformly distributed primary constants, when closed at the other end with an impedance Z_T. What is the impedance of a 1,200 ohm uniform line, having a transmission equivalent of 10 decibels, when (a) disconnected, (b) short circuited, and (c) closed with a 600 ohm resistance at the other end? What is the relation of the characteristic impedance to the impedances under conditions (a) and (b)? (40).

A. 11.

Z_S, the sending end impedance

$$= Z_O \times \frac{1 + e^{-2\gamma l}\left(\frac{Z_T - Z_O}{Z_T + Z_O}\right)}{1 + e^{-2\gamma l}\left(\frac{Z_O - Z_T}{Z_O + Z_T}\right)}$$

$$= Z_O \times \frac{Z_T \cosh \gamma l + Z_O \sinh \gamma l}{Z_O \cosh \gamma l + Z_T \sinh \gamma l} \quad \ldots\ldots(1)$$

where $\cosh \gamma l = \frac{e^{\gamma l} + e^{-\gamma l}}{2}$; $\sinh \gamma l = \frac{e^{\gamma l} - e^{-\gamma l}}{2}$;

γ = natural logarithm of current ratio per unit length of line when closed with Z_O; and l = particular number of unit lengths in question.

Given $Z_O = 1200\Omega$ (assume zero angle)

$Z_T = (a)\ \infty$, (b) zero, and (c) 600Ω.

$$20 \log_{10} \frac{I_S}{I_R} \equiv 10 \text{ db.}$$

Then $\log_{10} \frac{I_S}{I_R} = 0.5$ and $\frac{I_S}{I_R} = \text{antilog}_{10}\ 0.5 = 3.162 = e^{\gamma l}$

$\therefore\ e^{\gamma l} = 3.162$ and $e^{-\gamma l} = 0.3162$

$$\cosh \gamma l = \frac{3.162 + 0.3162}{2} = \frac{3.478}{2} = 1.739$$

$$\sinh \gamma l = \frac{3.162 - 0.3162}{2} = \frac{2.846}{2} = 1.423.$$

(a) From equation (1), when $Z_T = \infty$

$$Z_S = \frac{Z_O \cosh \gamma l}{\sinh \gamma l} \quad \ldots\ldots(2)$$

$$= \frac{1200 \times 1.739}{1.423} = 1466\Omega \text{ (slide rule).}$$

(b) From equation (1), when $Z_T = O$

$$Z_S = \frac{Z_O \sinh \gamma l}{\cosh \gamma l} \quad \ldots\ldots(3)$$

$$= \frac{1200 \times 1.423}{1.739} = 982.2\Omega.$$

(c) When $Z_T = 600\Omega$,

$$Z_S = 1200 \left\{\frac{(600 \times 1.739) + (1200 \times 1.423)}{(1200 \times 1.739) + (600 \times 1.423)}\right\}$$

$$= 1200 \left(\frac{1.739 + 2.846}{3.478 + 1.423}\right)$$

$$= \frac{1200 \times 4.585}{4.901} = 1123\Omega.$$

Let $Z_{OC} = Z_S$ when $Z_T = \infty$

and $Z_{SC} = Z_S$ when Z_T = zero

Then

$$Z_O = \sqrt{Z_{OC}Z_{SC}} = \sqrt{982.2 \times 1466} = \sqrt{360{,}000} = 600\Omega$$

illustrating that the characteristic impedance of a uniform line is given by the geometric mean of the open and closed impedances.

Q. 12. The side circuits of a 68 (route) mile coil-loaded cable are required to have a cut-off frequency of 3,400 cycles per second with loading pots spaced at 1.136 miles. Calculate the loading coil inductance (assuming a mutual electro-static capacity 0.065 microfarad per mile). What would be the conductor resistance per mile loop required to give an overall transmission equivalent of 22 decibels? Neglect the effective resistance of the loading coils and the leakance constant. (40.)

A. 12. As the loading coil spacing is fixed, the inductance per loading section (including the natural inductance of 1.136 miles of cable) to give a cut-off frequency of 3,400 p.p.s. is found from—

$$\omega_0 = \frac{2}{\sqrt{LC}}$$

$$f_0 = \frac{1}{\pi\sqrt{LC}}$$

$$L = \frac{1}{f_0^2\pi^2C}$$

where C = capacity in farads per loading section

L = inductance in henrys per loading section.

$$\therefore\ \frac{1}{L} = 3.4^2 \times 10^6 \times 3.1416^2 \times 0.065 \times 10^{-6} \times 1.136$$

whence L = 0.1186 henry.

$\therefore$ Inductance of loading coils = 118.6 mH (less the natural line inductance per loading section).

Assuming negligible leakance, the attenuation constant of a loaded line is given approximately by

$$\beta \doteq \frac{R}{2}\sqrt{\frac{C}{L}}$$

where R and C are the resistance and capacity, respectively, per mile and L is the inductance per mile (including added inductance).

Then, as a rough approximation—

$$R \doteq 2\beta\sqrt{\frac{L}{C}} \quad \ldots\ldots(1)$$

To find β. Given an overall transmission equivalent of 22 db.,

$$20 \log_{10} \frac{I_S}{I_R} = 22$$

$$\log_{10} \frac{I_S}{I_R} = 1.1$$

$$\frac{I_S}{I_R} = 10^{1.1} = e^{\beta l} = 10^{0.4343\beta l}$$

$$\therefore\ \beta l = \frac{1.1}{0.4343}$$

l = 68 miles

$$\therefore\ \beta = \frac{1.1}{0.4343 \times 68} = 0.0373 \text{ népers per mile.}$$

C per mile = 0.065×10^{-6} farad.

L per mile = $\frac{0.1186}{1.136}$ henry (from value calculated above)

Substituting these values in (1), the loop resistance per mile, R, is

$$R = 2 \times 0.0373\sqrt{\frac{0.1186}{1.136 \times 0.065 \times 10^{-6}}}$$

$$= 2 \times 0.0373 \times 10^3\sqrt{\frac{0.1186}{1.136 \times 0.065}}$$

$= 88.1\Omega$ per mile.

Printed by Birch and Whittington, Epsom, and Published by The Electrical Review, 4, Ludgate Hill, London E.C. 4.