SUPPLEMENT

TO THE POST OFFICE ELECTRICAL ENGINEERS' JOURNAL

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QUESTIONS AND ANSWERS

To conserve paper the answers to a few questions from each examination are omitted, the selection being made to cover as wide a field as possible.

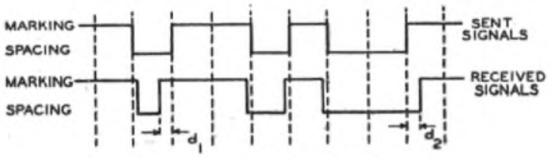
TELEGRAPHY I, 1951

Q. 1. *How is signal distortion defined in telegraphy? Illustrate your answer by means of a time chart of a distorted signal. What are the causes of signal distortion in a telegraph circuit?*

A. 1. In telegraphy, signal distortion is defined in relation to the instants of operation of the receiving relay (or of the armature of the electromagnet of the receiving instrument) compared with the corresponding operations of the tongue or moving contact of the transmitter.

This method enables the distortion to be quoted in terms directly related to the performance of the circuit, and for this reason it has been chosen as the method of defining telegraph signal distortion rather than by reference to the amplitude and shape of the received current; it has the further advantage that it is equally applicable to any form of transmission, e.g., single current, double current or voice-frequency.

The sketch shows time charts for the sent and received signals of a typical signal train. In any given transition the distortion is the time displacement of the signal change-over (from mark to space, or vice versa) from its true position. The total distortion is given by the maximum relative displacement of any pair of transitions, i.e. by the sum of the displacement of that transition which is most advanced and the displacement of that transition which is most retarded.



The percentage distortion is obtained from the ratio of this sum to the duration (t) of the shortest signal element. In the sketch the displacements are marked d_1 and d_2 and the percentage distortion is given by

$$\frac{d_1 + d_2}{t} \times 100 \text{ per cent.}$$

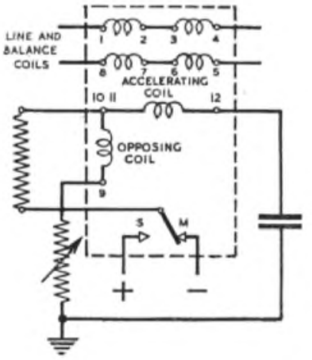
Signal distortion in a telegraph circuit is largely due to the primary coefficients of the transmission system. Line capacitance delays the increase of the received current to its final steady value, to an extent depending upon the distributed line resistance. The effect of leakance is to reduce the amplitude of the received signals, and on single current systems changes in leakance will produce bias distortion. The line inductance is too small to have an appreciable affect upon distortion. Interference currents will either augment or diminish the received current, producing variable degrees of advance or retardation to the transitions and resulting in fortuitous distortion.

Asymmetry in the transmitting or receiving apparatus will cause either the marking or spacing elements of the signals to be consistently lengthened and thus produce bias distortion.

Q. 2. *Why are the receiving relays used on telegraph lines normally polarised? Give a circuit diagram for a vibrating relay and explain its operation when used on a telegraph circuit.*

A. 2. In the non-polarised relay the armature requires a mechanical bias and the whole of the tractive force must be provided by the flux due to the line current; since this force is proportional to the square of the current the relay operation is independent of the current direction.

With the polarised relay the magnetic flux from the line current has only to overcome the flux produced in the armature by the permanent magnet; the tractive force is approximately proportional to the product of the permanent magnet flux and the line current flux. Accordingly, the polarised relay has a superior sensitivity and it responds rapidly to weak currents too small to produce serious interference problems. The operation of the polarised relay is also controlled by the direction of the line current. This means that double-current transmission may be realised, with its attendant advantages.



The sketch shows the circuit diagram for the auxiliary windings of a vibrating relay: the line and balance windings are connected in the conventional manner. When the tongue rests against either contact the current in the opposing coil is always in the direction tending to move the armature to the other position; this tendency is overcome by the steady line current until it commences to fall to zero. In this way the opposing coil anticipates the transitions as soon as its electromagnetic effect exceeds that of the line coils. During the transit time the auxiliary windings are disconnected from the power supply and the capacitor discharges through both windings, the direction of the discharge assisting the acceleration of the armature. On the tongue reaching the opposite contact the capacitor recharges, the charging current assisting the effect of the line current to produce a firm contact pressure. The accelerating coil carries currents only during the charging and discharging intervals. The tongue also repeats the signals into the local circuit.

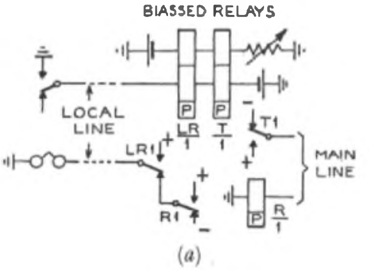
With no current in the line windings the relay armature would vibrate under the influence of the auxiliary windings at a frequency dependent upon the values of L, C and R. The use of vibrating relays produces a reduction in distortion and permits circuits to be worked at a speed higher than would otherwise be possible.

Q. 3. *Explain the purpose of the locking arrangements provided on the keyboard of a teleprinter, and describe their action with the help of simple sketches.*

Q. 4. *Explain, with the aid of simple schematic diagrams, the meaning of the following expressions used in telegraphy.*
(i) *Single current.*
(ii) *Double-current*
(iii) *Telegraph repeater.*

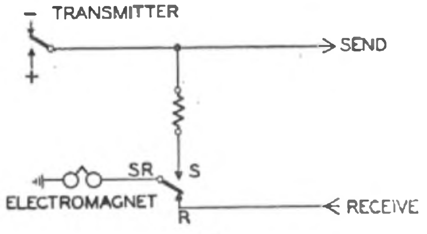
Q. 5. *Give circuit diagrams illustrating two methods of obtaining a local record of the transmitted signals in teleprinter working. Explain the operation in each case and state the circumstances in which each method is used.*

A. 5. *First method.* This arrangement is depicted in sketch (*a*). Single-current teleprinter signals are transmitted from the out-station over the local line into two polarised relays LR and T at the central station. Signals from T1 are repeated into the main line: at the same time the signals are repeated in double-current form from LR1 back over the local line to the transmitting teleprinter. The relay R responds to signals received over the main line and the series arrangement of LR1 and R1 enables the distant operator to interrupt the local record of the sending machine for such purposes as offering an urgent message, or asking for a repetition. This system has the advantage that no signalling current supply is required at the out-station.



(*a*)

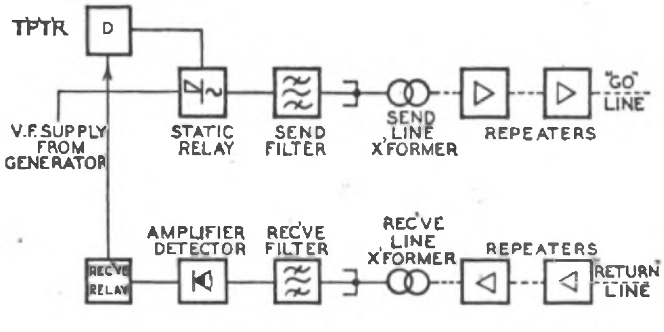
Second method. When double-current transmission is employed, necessitating provision of a source of signalling current at the teleprinter office, it is convenient to use the send/receive switch of the teleprinter to provide the local record. This switch is operated by a cam of the transmitter camsleeve and is in the send position for virtually the whole duration of a transmitted character, remaining in the receive position while the transmitter is at rest. By use of this switch (see sketch (*b*)) the transmitted signals are fed into the line with the local electromagnet in parallel through a suitable impedance.



(*b*)

Q. 6. *Draw a block schematic diagram of an 18-channel voice frequency telegraph system and explain the function of the various items shown in the diagram.*

A. 6. The sketch shows the essential equipment, in block schematic form, of an 18-channel voice-frequency telegraph system.



Static relay. The function of this item is to impress the modulations from the teleprinter transmitter upon the carrier current of the particular channel. Using a metal rectifier bridge in the secondary circuit of a transformer, the load on the primary is controlled by double-current signals from the teleprinter applied to the rectifiers. The primary winding is shunted across the carrier supply feed to the send filter and in this way the carrier current is modulated by the teleprinter signals.

Send filter. This is a band-pass filter whose mid-frequency corresponds with that of the channel carrier supply. Its functions are threefold. (i) to attenuate harmonic components from the teleprinter signals whose presence would otherwise cause interference with the signals in other channels; (ii) to suppress harmonic frequencies which may be present in the carrier supply; and (iii), since the 18 channels are paralleled on to the send line transformer at the output terminals of the send filter, the presence of the filters prevents the operation of the static relay from interfering with other channels.

Line transformers. These are required to match the equipment impedance to that of the line: they also isolate the unbalanced equipment from the balanced conditions in the line.

Repeaters are inserted at appropriate intervals in the line to restore the attenuated power to the correct transmission levels.

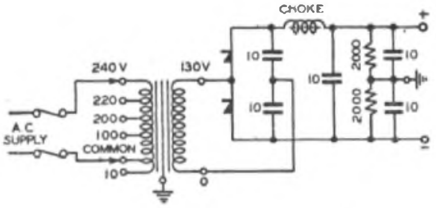
Receive filter. The input terminals of the 18 band-pass filters are connected in parallel. each receive filter is tuned to select the frequency range proper to its channel: compared with the send filter the conditions are more onerous and double-section filters are used.

Amplifier detector. The amplifier supplies the gain to apply the correct signal voltage to the detector. The detector or demodulator restores the D.C. envelope from the modulated signal so that the signals can be applied to the receive relay in the form of rise and fall of direct current corresponding to the instants of modulation. It is usual to incorporate an automatic gain control in this stage in order that moderate changes in line attenuation shall not result in signal bias distortion.

Receive relay. This is a polarised relay receiving single-current signals from the amplifier-detector. By appropriate adjustment of the bias control, double-current signals are transmitted from the relay tongue to the teleprinter.

Q. 7. *Describe the construction of a rectifier unit suitable for providing the line current for a double-current telegraph circuit. Give a circuit diagram of the rectifier unit: explain what arrangements are adopted for ensuring that the positive and negative supplies are closely balanced, and why this is necessary.*

A. 7. The circuit diagram of a rectifier unit suitable for providing the line current for a double-current telegraph circuit is given in the sketch. It consists essentially of a mains transformer, metal rectifiers arranged on the voltage-doubler principle, smoothing equipment and a centre-tapped potentiometer which, in association with capacitors, provides positive and negative potentials of equal magnitude.



The mains transformer is tapped on the input side to accommodate the normal input voltage range in steps of 10 V. The output winding is connected to the junction of two rectifiers in series, each rectifier shunted by a capacitor. During alternate half cycles, each rectifier passes a charge into its associated capacitor, the sum of the potentials being available at the smoothing circuit. One stage of the conventional choke-capacitance smoothing is provided.

It is important to maintain a close balance between the positive and negative potentials or bias distortion to signals will result.

The two 2,000-ohm sections of the potentiometer would give equal positive and negative potentials under no-load conditions. Under signalling conditions, one half or the other of the potentiometer is always loaded, and the potential across the loaded portion is always the lower. The two 10 μF capacitors gain or lose some charge with the reversals of load by the telegraph transmitter, and provide a low impedance source to the transient conditions.

The use of a voltage-doubler type of rectifier unit in association with the potential divider ensures that a well-balanced supply is maintained independently of any inequalities or ageing effects in the rectifier elements.

Q. 8. *Define the term "margin" as applied to a teleprinter. What are the arrangements adopted in the design of a teleprinter to secure the necessary margin, and why must this margin be provided?*

A. 8. The term "margin" applied to a teleprinter indicates the maximum signal distortion which it will accept while still correctly printing the signals. It is usual to measure margin by shortening and lengthening the start signal and so displacing the code elements with respect to the commencement of the start signal, the displacement being either early or late with respect to the true position.

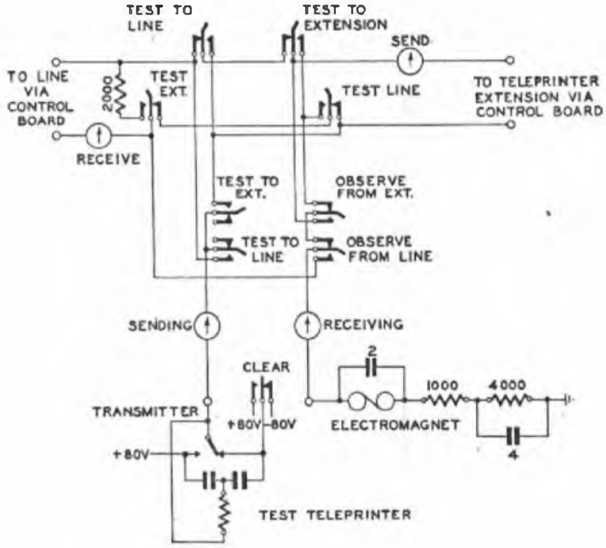
In the design, and under normal maintenance conditions of the equipment, a certain amount of distortion must inevitably occur due to minor inaccuracies in the transmitter and due to the line and terminal equipment forming the transmission medium. Furthermore, although the speed of the teleprinter is closely controlled by a governor, some inaccuracy in speed will occur and cause transmitter distortion and loss of margin. It is necessary to allow for the maximum speed difference which may occur between the sending and receiving teleprinters: for example, a speed difference equal to 2 per cent. would result in an equivalent distortion of 10 per cent. at the commencement of the fifth code element. The margin of the teleprinter must exceed the permissible maximum overall distortion to give correct printing: a good margin is essential to enable teleprinters to work successfully on long circuits and in switching systems where teleprinters may be interconnected over several tandem circuits.

In the teleprinter this margin is obtained principally by the design feature wherein the finger-setting blade need be in contact with the finger-setting pin for only a fraction of the duration of a signal element in order to set a selecting finger and produce correct registration. The receiving cam is constructed so that this period occurs at the centre of each code element and so long as the electromagnet armature is in the correct position during this central short period the element will be correctly recorded. The electromagnet is adjustable so that it can be maintained in a neutral adjustment.

The other important design feature which is closely concerned with margin is that the receiving cam is arranged to complete its cycle in the duration of 6·5 signal elements. This ensures that the receiving cam will be stopped before each start signal even when one character, having a late start signal, is followed immediately by a character whose start signal is early.

Q. **9.** *Give a circuit diagram of the Test and Observation Set provided in telegraph instrument rooms and explain how, and for what purposes, it is used.*

A. 9. A circuit diagram of the Test and Observation Set used in telegraph instrument rooms is given in the sketch. The set, which may be mounted with the teleprinter, either on a fixed table or upon a trolley, is essentially an apparatus unit comprising keys and milliammeters. Access to any teleprinter circuit is obtained via the Control Board either by permanent cabling to jacks on the control board if a fixed position, or by plugs and jacks for the transportable set; battery supplies are connected in a similar manner.



The test set provides facilities for (i) observing signals passing in either direction over a teleprinter circuit, and (ii) making teleprinter tests with the home or distant teleprinter. When testing to the home teleprinter the incoming line is looped through the 2,000-ohm resistor, and when testing to line the local teleprinter send and receive wires are looped; in this way the teleprinter, which is in effect cut off, receives its own signals and is made aware of the testing condition. Centre-zero milliammeters in the line and test circuits enable currents to be checked in the line under either observation or testing conditions. In this way the test set can be used for localising faulty working by determining whether the fault lies in the line equipment or in either teleprinter terminal.

The CLEAR key shown is used for sending a 5-second clearing signal on circuits which terminate on switchboards.

The set can also be used for originating or answering calls on "speaker" circuits to control boards at other telegraph offices. For this purpose a signalling set—not shown on the diagram—is associated with the test set. This signalling set provides the facilities for calling and clearing to the distant speaker set over a voice-frequency channel.

Q. **10.** *Outline the arrangements adopted so that teleprinter signals can be transmitted over the ordinary telephone exchange system. Detail the items of equipment required at the subscriber's premises*

LINE TRANSMISSION I, 1951

Q. **1.** *Describe the construction of a typical modern lead-covered cable containing both coaxial pairs and star quads.*

Q. **2.** *What are the sources of crosstalk in a repeater station accommodating carrier telephone system terminal equipment?*

What steps are taken to keep the crosstalk to an acceptably low value?

A. 2. Crosstalk within a repeater station accommodating carrier telephone system terminal equipment may arise from:—

1. Inadequate decoupling between carrier- or audio-frequency amplifiers.
2. Magnetic or electric coupling between pairs interconnecting apparatus (including distribution frames carrying signals at carrier- or audio-frequency).
3. Inadequate decoupling between carrier-frequency supply circuits.
4. Inadequate screening between panels or components serving different channels.

Crosstalk is kept to an acceptably low value—

1. By ensuring that the contribution of each crosstalk path is so small that the sum of many such paths is still within acceptable limits.
2. By segregating points of widely differing signal level.
3. By ensuring very small mutual coupling between circuits; this is effected either by keeping circuits very closely balanced or by screening. If the coupling is via a common supply source, i.e. the power supply or a source of carrier frequency, then adequate decoupling circuits are necessary.

A typical example of the segregation of pairs carrying signal levels of widely differing magnitude is seen in the Group Distribution Frame; test signal level differences may be of the order of 30 db. and to reduce the risk of crosstalk the frame is divided into two sections.

Wiring between balanced elements is effected by twisted pairs which often (except for audio-frequency circuits) are individually screened. Unbalanced circuits use coaxial leads which transmit frequencies at which the cable is self screening. Components very subject to mutual interference, e.g. transformers and inductors, may be provided with individual magnetic and electric screens. Complete panels and sub-assemblies are usually provided with magnetic and electric screens.

Decoupling between circuits using a common supply is effected by (*a*) maintaining the supply at a low impedance, and (*b*) ensuring that each load presents a comparatively high impedance to the common bus-bar.

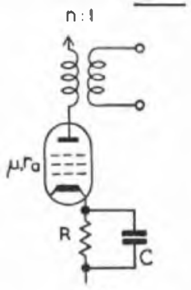
Q. **3.** *Outline the principles underlying the location of impedance irregularities in lines by the measurement of impedance/frequency characteristics.*

Q. **4.** *An indirectly-heated output tetrode, having an internal impedance r_a and amplification factor μ, is employed in a circuit comprising an output transformer, having a step-down voltage ratio n, together with a cathode-bias resistor R in parallel with a capacitor C. Assuming that the output transformer is perfect, determine the output impedance of the amplifier:—*

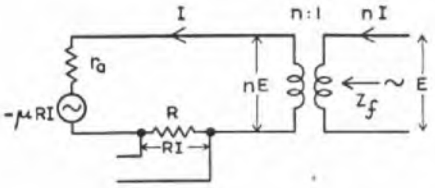
(*a*) *if the impedance of C is much smaller than that of R.*
(*b*) *if the impedance of C is much greater than that of R.*

A. 4. The circuit is shown in sketch (*a*).

If the impedance of *C* is much smaller than that of *R* then there will be only negligible negative-feedback, and the impedance of *C* will be negligible in comparison with r_a. Therefore, the impedance presented to the primary of the output transformer is r_a and the output impedance as measured at the secondary of the transformer is r_a/n^2.



(*a*)



(*b*)

If the impedance of *C* is much greater than that of *R* then there will be series negative-feedback. The circuit is re-drawn as sketch (*b*) in which r_a and the associated generator represent the valve.

If an alternating E.M.F. *E* volts is applied to the output windings of the transformer there will result a current of *nI* amperes; then the output impedance $Z_f = E/nI$.

$$\text{But } I = \frac{nE - \mu IR}{r_a + R}$$

$$Ir_a + RI = nE - \mu IR$$

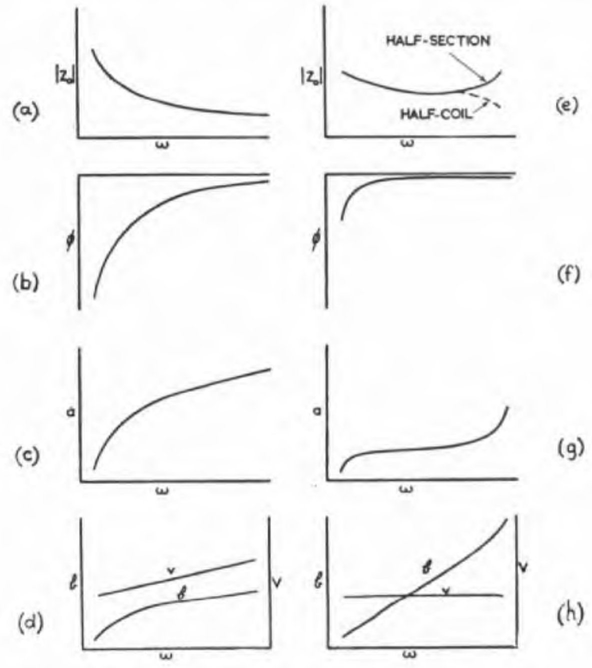
$$E = \frac{Ir_a + RI\,(1 + \mu)}{n}$$

$$\therefore Z_f = \frac{r_a + R\,(1 + \mu)}{n^2}$$

Q. 5. *Illustrate, by means of sketch curves, how the characteristic impedance, attenuation coefficient, phase-change coefficient and phase velocity of a uniform transmission line vary with frequency.*

How are these characteristics modified if the line is coil-loaded at regular intervals?

A. 5. Sketches (*a*) to (*d*) show how the secondary coefficients and the phase velocity vary with frequency when the transmission line is uniform.



Sketches (*e*) to (*h*) show how these quantities are modified if the line is coil-loaded at regular intervals.

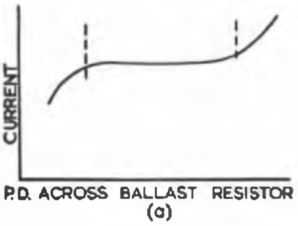
Q. 6. *Describe briefly a master telephone transmission reference system suitable for the comparison of subscribers' instruments, local lines and exchange transmission bridges.*

Q. 7. *Describe with the aid of sketches how (a) a ballast resistor is used as a current stabilizing device and (b) a neon tube may be used as a D.C. voltage stabilizer.*

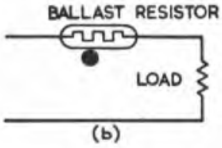
A. 7. (*a*) A ballast resistor is a device the resistance of which increases with the current passed by it. If, therefore, it is placed in series with a load impedance it tends to stabilise the load current.

In its practical form a ballast resistor (or "barretter") is a fine wire which is usually of pure iron. It is mounted in a bulb filled with hydrogen, the purpose of the gas being to permit the rapid removal of heat while inhibiting oxidation.

The form of the voltage/current characteristic of a ballast resistor is shown in sketch (*a*), the operative portion being indicated. Sketch (*b*) shows a barretter in series with the load, the current through which it stabilises.



(a)



(b)

(*b*) A neon tube is a device the impedance of which decreases with the voltage across it; it may therefore be used in parallel with a load to give voltage stabilisation. The voltage/current characteristic of a neon tube (after "striking") is of the form shown in sketch (*c*).

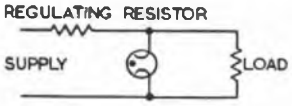
In construction, it consists of two plates in an atmosphere of neon. At low voltages its resistance is very high; when the voltage across the plates is increased to a particular value the tube "strikes" and becomes conductive, its resistance then becoming progressively less with further increase of applied potential.

The direct application of the "striking" voltage would produce a current of such magnitude as to destroy the tube; it is therefore used in series with a regulating resistor designed to limit the current to a safe value.

(c)

Sketch (*d*) shows the complete circuit of load, neon tube and regulating resistor.

Any increase of the supply voltage from its normal voltage will result in a fall in the resistance of the stabiliser and hence in an adjustment of the P.D. across the load.



(d)

Q. 8. *Channel filters used in multi-channel carrier telephone systems usually employ either inductors and capacitors only or, alternatively, a combination of inductors, capacitors and piezoelectric crystals. Discuss the relative merits and limitations of each type of filter.*

A. 8. Ideally, the components of filters should be purely reactive, i.e. they should have infinite *Q* (effective reactance divided by effective resistance) over the whole of the relevant pass and stop ranges. Capacitors and piezo-electric crystal resonators can have very high *Q* values but inductor coils are of much lower *Q* even at frequencies at which that quantity is a maximum.

Inductor/capacitor filters. These may be used for channel-forming within frequency bands up to about 60 kc/s; towards the upper end of this band the requirements for the inductors become very severe unless the frequency interval between adjacent channels is much greater than permitted by the existing C.C.I.F. standards. If we consider that the upper frequency limit for inductor/capacitor filters is about 30 kc/s it may be said that this form of construction has the merits of being cheap, robust, easy to manufacture and adjust, and requiring relatively easily obtainable raw material.

Piezo-electric crystal filters. These employ not only crystals but also, in general, capacitors and inductor coils; however, it is usually possible to allow in design for the comparatively low *Q* of the inductors. Quartz crystal channel filters are not often constructed for use much outside the frequency range 60 to 120 kc/s; resonators for use below 60 kc/s become progressively larger and very costly while those for frequencies in excess of about 120 kc/s become so small as to be excessively fragile and expensive to manufacture.

The merits of the crystal filter are that, in general, the transition ranges are steep, low attenuation distortion in the pass-band is easily achieved, and the crystal filter is usually somewhat smaller than its inductor/capacitor counterpart. It has, however, the disadvantages of being a little less robust, somewhat more difficult to manufacture and requiring a comparatively scarce raw material.

Q. 9. *What would be the effect upon music of the following forms of distortion in a transmission path ?*

(a) attenuation distortion.
(b) phase distortion.
(c) delay distortion.
(d) amplitude distortion.
(e) harmonic distortion.
(f) intermodulation distortion.

A. 9. (*a*) *Attenuation Distortion.* A transmission path having attenuation distortion introduces attenuation or gain which is not independent of frequency over the range involved. The relative amplitudes of the components of a complex waveform are therefore upset and objectionable reproduction may result. In its most common form the distortion is such that frequencies in the upper range are attenuated relative to those in the middle register resulting in the well-known "mellowness" or "woofyness" so common to radio receivers.

(*b*) *Phase Distortion.* This results in the relative displacement of frequencies comprising a complex waveform. As the ear is insensitive to relative phase this is generally unimportant though there is some evidence that, if modern atonal music is being transmitted, the trained musician may be able to detect this form of distortion.

(*c*) *Delay Distortion.* This causes a relative change in the transmission time of the components of a complex waveform. The beginning and ending of a discontinuous complex wave will therefore sound unnatural to an extent which may be unacceptable.

(*d*) *Amplitude Distortion.* This results when the gain or loss of a channel is amplitude-dependent. If unaccompanied by non-linear distortion it can be relatively severe before being noticeable. However, as it results in compression or expansion which may be frequency-dependent it should be avoided as resulting in an upset to the balance of the music.

(*e*) *Harmonic Distortion.* This produces frequencies which are multiples of those present in the original waveform. As musical instruments playing a common fundamental note are recognisable by their harmonic content, any change of harmonic relationships is disturbing and, in general, not more than about 5 per cent. is acceptable.

(*f*) *Intermodulation Distortion.* This occurs when a complex signal suffers distortion resulting in the production of not only harmonics of the components but also of their sum and difference frequencies and inharmonic sum and difference terms. It is most objectionable in music if inharmonic components are present in the original signal.

Harmonic distortion and intermodulation distortion are inseparable, being due to a common cause. If a single pure tone is applied to a transmission path which introduces non-linear distortion then both the fundamental and harmonics will be present at the output ; if two pure tones are applied simultaneously to the same transmission path then, at the output there will be not only the fundamental and harmonics of each input signal but also sum and difference products.

Q. 10. *A network composed of pure reactors has the configuration shown below.*

Determine the iterative impedance of the network and show :—

(a) that this quantity must be either wholly real or wholly imaginary.
(b) that the network, if terminated by its iterative impedance, offers no attenuation if that impedance is real.

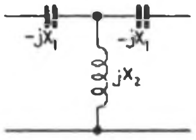


Fig. 1.

A. 10. (*a*) Let the iterative impedance of the network be Z ohms. Then as the network is symmetrical, Z will also be equal to the image impedance, i.e.

$$Z = \sqrt{Z_{oc} Z_{sc}}$$

where Z_{oc} and Z_{sc} are the open- and short-circuit impedances respectively.

$$Z_{oc} = -jX_1 + jX_2 = j(X_2 - X_1)$$

$$Z_{sc} = -jX_1 + \frac{(jX_2)(-jX_1)}{-jX_1 + jX_2}$$

$$= \frac{-jX_1 j(X_2 - X_1) + X_1X_2}{j(X_2 - X_1)}$$

$$= \frac{X_1(X_2 - X_1) + X_1X_2}{j(X_2 - X_1)}$$

$$\therefore Z^2 = 2X_1X_2 - X_1^2$$

$$Z = \sqrt{2X_1X_2 - X_1^2}$$

If $X_1^2 < 2X_1X_2$ the quantity under the radical is positive and hence Z is real.

If $X_1^2 > 2X_1X_2$ the quantity under the radical is negative and Z is imaginary.

(*b*) It is clear from inspection that, when the iterative impedance of the network is real and it is terminated by that impedance, power can be delivered to the network. As the elements of the network are non-dissipative all of the input power is delivered to the load. In view of the fact that the input and terminating impedances are the same there is no attenuation.

This fact can be demonstrated mathematically as follows :—

Let a generator of impedance Z produce a P.D. of E volts at the input of the network. Then the input current is E/Z.

The P.D. produced across the shunt arm of the network is

$$E - (-jX_1)\frac{E}{Z} = \frac{E}{Z}(Z + jX_1)$$

and hence the P.D. across the terminating impedance is

$$\frac{E}{Z}(Z + jX_1)\frac{Z}{(Z - jX_1)} = \frac{E(Z + jX_1)}{(Z - jX_1)}$$

As, if Z is real, $|Z + jX_1| = |Z - jX_1|$ the amplitude of the P.D. across the terminating impedance is E. Hence the network introduces no attenuation though it does produce a phase shift.

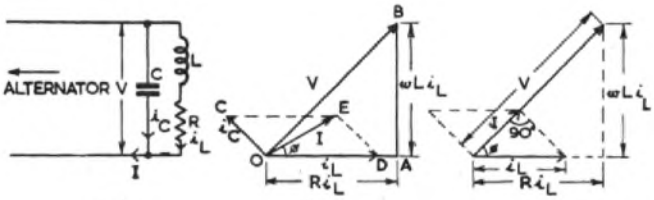
TELECOMMUNICATIONS (PRINCIPLES) III, 1951

Q. 1. *A capacitance, C farads, and an inductive resistance, L henrys R ohms, are connected in parallel across an alternator of variable frequency. Draw a vector diagram which indicates the currents and voltages in the various branches of the circuit, and from this, or otherwise, derive an expression for the frequency at which the current supplied by the alternator is in phase with the voltage across its terminals.*

Draw the vector diagram for this condition, and use this to obtain an expression for the impedance of the parallel resonant circuit at this frequency.

A. 1. The circuit is shown in sketch (*a*). Assume that the current flowing in the inductive resistance is i_L at an angular frequency ω radn./sec. The voltage across R is Ri_L in phase with i_L and the voltage across L is ωLi_L leading i_L by 90°.

The voltage, V, across the inductive resistance, which is also the voltage across the capacitance and across the alternator terminals, is the vector sum of Ri_L and ωLi_L, as indicated in the vector diagram, sketch (*b*).



(*a*) (*b*) (*c*)

The current through the capacitance, C, is $i_C = \omega CV$ leading the voltage V by 90° and the total current, I, supplied by the alternator is the vector sum of i_L and i_C.

The voltage V and current I will be in phase when $\phi = \underline{/AOB}$.

The vector diagram of sketch (*c*) represents the various currents and voltages for this condition. From this it will be observed that

$$\frac{i_L}{\sin 90^\circ} = \frac{i_c}{\sin\left(\tan^{-1}\dfrac{\omega L}{R}\right)} = \frac{\omega C V}{\dfrac{\omega L}{\sqrt{R^2+\omega^2L^2}}}$$

$$\text{but, } V = i_L\sqrt{R^2+\omega^2L^2}$$

$$\therefore i_L = i_L\frac{C}{L}(R^2+\omega^2L^2)$$

$$1 = \frac{C R^2}{L} + \omega^2 LC$$

$$\omega = \sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$$

Also,

$$I = i_L \cos\left(\tan^{-1}\frac{\omega L}{R}\right)$$

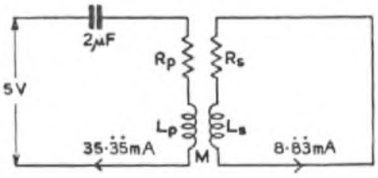
$$= \frac{R}{\sqrt{R^2+\omega^2L^2}}\cdot i_L$$

$$\therefore \frac{V}{I} = \frac{i_L\sqrt{R^2+\omega^2L^2}}{\dfrac{R}{\sqrt{R^2+\omega^2L^2}}\times i_L} = R + \omega^2\frac{L^2}{R}$$

$$= R + \frac{L^2}{R}\left(\frac{1}{LC} - \frac{R^2}{L^2}\right) = \underline{\frac{L}{CR}}$$

Q. 2. *The primary winding of an air-cored transformer is connected in series with a capacitance of 2μF across an alternator which has a constant output of 5 volts r.m.s. When the secondary winding is open-circuited, the primary current has a maximum value of 100 mA when the alternator frequency is 796 c/s. When the secondary winding is short-circuited under these conditions, the magnitude of the primary current is reduced to* $35{\cdot}\dot{3}\dot{5}$ *mA and the current in the short-circuited secondary winding is* $8{\cdot}\dot{8}\dot{3}$ *mA.*

Assuming that neither winding has leakage inductance or self-capacitance, calculate the resistance and self-inductance of each and the mutual inductance between them.



A. 2. Since the primary current has a maximum value under the conditions stated, it is apparent that the capacitance of 2μF resonates with the self-inductance of the primary winding, L_p, at the frequency of 796 c/s.

The reactance of the capacitance at this frequency is:—

$$\frac{10^6}{2\times 2\pi\times 796} = 100 \text{ ohms.}$$

$$\therefore 2\pi\times 796\times L_p = 100$$

$$\text{or } L_p = 100/5{,}000 = \underline{0{\cdot}02\text{H.}}$$

Also, the resistance of the primary winding, R_p, is $5/100 \times 10^3$, i.e. 50 ohms.

As there is no leakage inductance, all the primary flux must be linked with the secondary and vice versa. Moreover, as the transformer is air-cored, there are no core losses and, hence, when the secondary is short-circuited, the primary ampere turns must equal the secondary ampere turns, i.e. $I_p N_p = I_s N_s$.

Substituting, $\dfrac{N_s}{N_p} = \dfrac{I_p}{I_s} = \dfrac{35{\cdot}\dot{3}\dot{5}}{8{\cdot}\dot{8}\dot{3}} = 4$

But the self-inductance of a winding is proportional to the square of its number of turns. Also, in this case, the magnetic circuit of the primary winding must be that of the secondary winding. Since the primary inductance is 0·02 H, the secondary inductance must be

$$L_s = L_p\,(N_s/N_p)^2 = 0{\cdot}32 \text{ H.}$$

$$\text{and } M = \sqrt{L_sL_p} = \sqrt{0{\cdot}02\times 0{\cdot}32} = \underline{0{\cdot}08 \text{ H.}}$$

$$\text{Now, } V = (R_p + j\omega L_p + 1/j\omega C)\,I_p + j\omega M I_s$$

$$\text{and } 0 = (R_s + j\omega L_s)\,I_s + j\omega M I_p$$

$$\text{i.e., } I_s = -\frac{j\omega M}{R_s + j\omega L_s}\times I_p$$

$$\therefore \frac{V}{I_p} = R_p + j\omega L_p + \frac{1}{j\omega C} + \frac{\omega^2M^2}{R_s + j\omega L_s}$$

$$\text{But } \quad j\omega L_p + 1/j\omega C = 0$$

$$\therefore \frac{V}{I_p} = \frac{(R_p R_s + \omega^2 M^2) + j\omega L_s R_p}{R_s + j\omega L_s}$$

From which

$$|Z| = \left|\frac{V}{I_p}\right| = \sqrt{\frac{(R_pR_s + \omega^2M^2)^2 + \omega^2L_s^2R_p^2}{R_s^2 + \omega^2L_s^2}}$$

$$\therefore \frac{5{,}000}{35{\cdot}\dot{3}\dot{5}} = 10\sqrt{\frac{25R_s^2 + 16\times 10^4R_s + 3{\cdot}2\times 10^8}{R_s^2 + 2{\cdot}56\times 10^6}}$$

$$\text{and, } R_s = \underline{\frac{16\times 10^4 \pm \sqrt{256\times 10^8 - 4\times 175\times 1{\cdot}92\times 10^8}}{2\times 175}}$$

which is imaginary.

Q. 3. *Determine from the circuit shown in Fig. 1, assuming that the battery has negligible internal resistance:—*

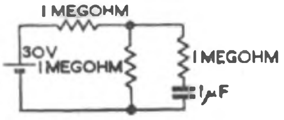


Fig. 1

(*a*) *the current supplied to the circuit when the battery is first connected across it,*

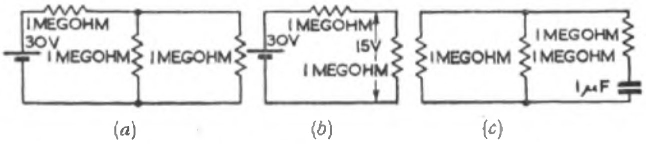
(*b*) *the final value of the battery current,*

(*c*) *the final value of the energy stored in the capacitor,*

(*d*) *the time constant of the circuit.*

Draw a graph to scale showing the variation of battery current with time.

A. 3. When the battery is first connected across the circuit, the capacitor is uncharged and at that instant can be regarded as a short-circuit. The circuit reduces to that shown in sketch (*a*) and the battery current, for this condition, is:—



(*a*) (*b*) (*c*)

$$I_0 = \frac{30}{1{\cdot}5\times 10^6} = \underline{20\mu\text{A.}}$$

When the capacitor is fully charged, the circuit across the battery can be regarded as two 1-megohm resistances connected in series, see sketch (*b*). Hence,

$$I_F = \frac{30}{2\times 10^6} = \underline{15\mu\text{A.}}$$

The voltage across the capacitor is $30/2 = 15$V.

∴ the energy stored in it is:—

$$\frac{1}{2}CV^2 = \frac{1}{2}\times 1\times 10^{-8}\times (15)^2$$

$$= \underline{112{\cdot}5 \text{ microjoules}}.$$

The time-constant of the circuit is the same during charge or discharge. For the latter, the battery must be replaced by a short-circuit so that the complete circuit will then be as shown in sketch (*c*). From this it will be realised that the time-constant of the circuit is:— $T = CR = 1\times 10^{-6}\times 1{\cdot}5\times 10^6$

$$= \underline{1{\cdot}5 \text{ seconds.}}$$

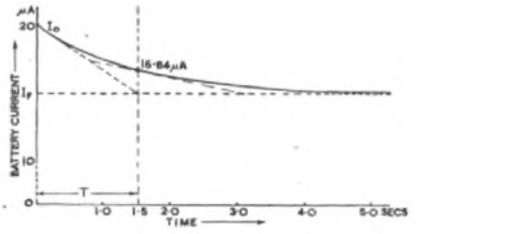
Thus, the initial fall of battery current will be

$$\frac{20-15}{1{\cdot}5} = \frac{5}{1{\cdot}5} \text{ or } 3\tfrac{1}{3}\mu\text{A/sec.,}$$

and the battery current 1·5 seconds after initial connection will be

$$20 - \frac{63{\cdot}2}{100}\times 5 = 20 - 3{\cdot}16 = 16{\cdot}84\mu\text{A.}$$

(see the graph of sketch (*d*)).



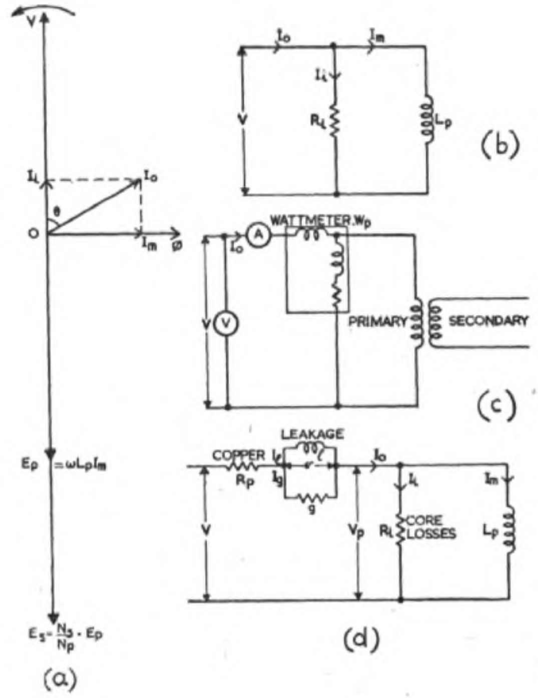
(*d*)

Q. 4. *Draw a vector diagram to show the current flowing in the primary winding of an iron-cored transformer, the voltage applied across it, and the e.m.f. induced in the secondary winding, when no load is connected across the latter. Explain what is meant by the component of this "no load" current known as the magnetising current, and indicate how its magnitude could be determined.*

Upon what factors does the magnitude of the "in phase" component of the "no load" current depend? Describe the steps taken to reduce this component in the design of transformers for telecommunications purposes.

What assumptions were made when the vector diagram was drawn?

A. 4. The required vector diagram is shown as sketch (*a*). The comparatively small "no load" current, I_o, lags behind the applied voltage, V, by an angle θ, and can be regarded as the resultant of two components, one, I_t, in phase with the applied voltage, and the other, I_m, lagging by 90°. The latter is termed the magnetising current of the transformer. Thus, it is assumed that, when the secondary winding of a transformer is open-circuited, the primary circuit consists of a non-reactive resistance, R_t, in parallel with a pure inductance, L_p, see sketch (*b*). The magnetising current flowing through this inductance generates a back E.M.F.,



$$e_p = -L_p \cdot di_m/dt = -N_p \cdot d\phi/dt$$

or, taking effective values, $E_p = -j\omega L_p I_m = -j\omega N_p \phi$, which is equal in magnitude and opposite in phase to the applied voltage, i.e. $V + E_p = 0$, as shown in sketch (*a*). The E.M.F., e_s, induced in the open-circuited secondary winding, will be in phase with e_p and its magnitude will be

$$e_s = -N_s \cdot d\phi/dt = e_p \cdot N_s/N_p$$

or, taking effective values,

$$E_s = E_p \cdot N_s/N_p = V \cdot N_s/N_p$$

In the above:—

N_p is the effective number of turns on the primary winding,
N_s is the effective number of turns on the secondary winding, and ϕ is effective value of the core flux linked with N_p and N_s, which is in phase with I_m. The magnitude of I_m,

$$|I_m| = |V|/\omega L_p$$

could be determined if the applied voltage, its frequency, and the effective inductance of the primary winding were known. It will be appreciated that the larger the primary inductance, L_p, the smaller will be the magnetising current, I_m, and, therefore, the smaller the no load current, I_o.

In practice, I_m is determined by measuring the power absorbed by the primary circuit, W_p, when the secondary is open-circuited, and the volt-amperes supplied to the primary, see sketch (*c*).

Then
$$W_p = VI_o \cos\theta$$
$$\cos\theta = \frac{W_p}{VI_o}$$
and
$$I_m = I_o \sin\theta.$$

The power absorbed by the primary circuit under these conditions is equal to the power dissipated in the shunt resistance, R_t, i.e. $W_p = I_t^2 R_t$. Since this resistance is regarded as being in parallel with the actual self-inductance of the primary winding, it must be due to any property of the core which may cause a power loss. The core loss or iron loss has two main components, namely, hysteresis loss, W_H, and eddy current loss, W_e. It can be shown that W_H is proportional to the area of the hysteresis loop for the working cycle of magnetisation and depends on the max. variation in flux density, B_{MAX}.

$$W_H = \eta B^{\gamma}_{MAX} f \times 10^{-8} \text{ Watts/cc.}$$

The eddy current loss is proportional to B^2_{MAX} and the square of the frequency, f.

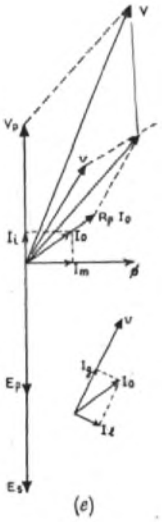
$$W_e = \frac{k}{\rho} B^2_{MAX} f^2 \times 10^{-8} \text{ Watts/cc.}$$

Thus, $W_p = \eta B_{\gamma MAX} f \times 10^{-8} + \frac{k}{\rho} B^2_{MAX} f^2 \times 10^{-8}$ Watts/cc,

and its magnitude can be reduced by making η (the hysteresis coefficient), as small as possible and ρ, the resistivity of the core, as large as possible.

Hence, in an efficient transformer the core should be made of a material which has a hysteresis loop of the smallest possible area and which has a high resistivity. The resistance of the core to circulating (eddy) currents can also be increased by laminating or by using finely powdered magnetic material, each grain of which is separately insulated.

In the foregoing, the winding resistance of the primary and any leakage inductance, with its associated power losses, have been neglected. These have been represented on the diagram of sketch (*d*). The vector diagram of the currents and voltages in this circuit is given in sketch (*e*). It will be observed that the E.M.F. induced in the secondary winding is no longer opposite in phase to the applied voltage and the true magnetising current of the primary winding is actually less than 90° out of phase with the applied voltage.



(*e*)

Q. 5. *Describe the principle and method of operation of an alternating current bridge suitable for measuring the inductance and resistance of small value inductors at audio frequencies. By means of a vector diagram of the balanced bridge, or otherwise, determine the values of the inductance and its resistance in terms of the remaining components of the bridge.*

Point out any possible sources of inaccuracy with the bridge described.

Q. 6. *The network shown in Fig. 2 is to be connected between a source which has an internal impedance of 200 ohms and a load which has an impedance of 800 ohms so that overall loss is a minimum. Find the ratio of a transformer such that the overall loss is a minimum, if the loss in the transformer alone is 0·5 db. What is the value of the overall loss? Give a diagram of the circuit used.*

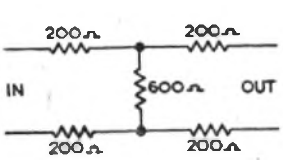


Fig. 2

A. 6. When an 800-ohm resistance is connected across the input terminals of the network, the impedance measured across the output terminals is:—

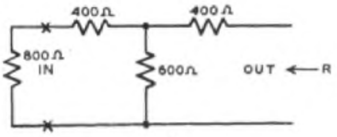
$$400 + \frac{600 \times 1{,}200}{600 + 1{,}200}$$

$$= 400 + \frac{7{,}200}{18} = 800 \text{ ohms (see sketch } (a)).$$

Thus, the characteristic impedance of the network is 800 ohms and the insertion loss of the network will be minimum when it is connected between 800-ohm resistances. The internal impedance of the source can be made to appear as 800 ohms, by a transformer which has a turns ratio of

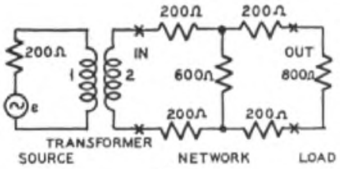
$$\frac{N_s}{N_p} = \sqrt{\frac{800}{200}} = 2$$

The arrangement is given in sketch (*b*).



(a)

The loss caused by the network, when connected between 800-ohm impedances, is found as follows:—When a source having an E.M.F., *e*, and internal impedances 800 ohms is connected to an 800-ohm load, the current in the load is:—

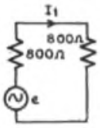


(b)

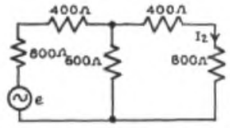
$$I_1 = \frac{e}{2 \times 800} = \frac{e}{1{,}600} \text{ amps.}$$

(see sketch (*c*)).

From sketch (*d*), the current in the 800-ohm load after the insertion of the network is reduced to I_2.



(c)



(d)

$$I_2 = \frac{e}{4} \cdot \frac{1}{1{,}200}$$

$$\text{Insertion loss} = 20 \log_{10} \frac{I_1}{I_2} = 20 \log_{10} \frac{4{,}800}{1{,}600}$$

$$= 20\,(0{\cdot}4771) = 9{\cdot}542 \text{ db.}$$

Since the transformer introduces a loss of 0·5 db., the minimum overall loss is 9·542 + 0·5 = $\underline{10{\cdot}042 \text{ db.}}$

Q. 7. *A carrier current of f c/s is amplitude modulated by an audio frequency of q c/s, the modulation factor being m%. Sketch the resulting waveform, assuming that f is much greater than q, and calculate the frequency components which it contains. Calculate the relative energy values for 100% depth of modulation.*

Q. 8. *With reference to suitable curves, describe the meaning of permeability, hysteresis loop, remanence and coercivity for a magnetic material, and show how the energy lost in hysteresis can be calculated.*

Tests on a sample of magnetic material gave a hysteresis loop area of 15·5 square centimetres when plotted to a scale of 1 cm. = 1,000 gauss vertically and 1 cm. = 10 oersteds horizontally. Calculate the hysteresis loss in watts per cubic centimetre of the material when it is used in a coil operating on a supply of frequency 100 c/s.

Q. 9. *Explain the function of the screen grid in a tetrode valve, and show why the addition of a suppressor grid is desirable in valves intended for use in H.F. amplifiers. Include in your answer sketches of anode-current/anode-voltage characteristic curves typical of a tetrode and a pentode.*

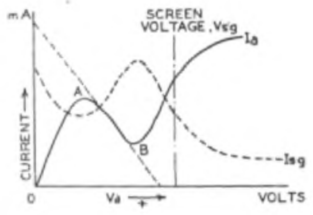
A. 9. The advantage of the tetrode valve over the triode as an amplifier at high frequencies, from the point of view of self-oscillation, is fully covered in the October, 1949 Supplement, Telecomms. (Principles) III, A. 10.

A further disadvantage of the triode valve for use as an amplifier at high frequencies is also caused by the inter-electrode capacitances.

It can be shown that the effective capacitance between grid and cathode of a triode valve at high frequencies is, $C \simeq C_{gc} + C_{ga}(1 + \mu_e)$, where C_{gc} is the actual capacitance between grid and cathode, C_{ga} is the actual capacitance between grid and anode $\gg C_{gc}$ and μ_e is the effective amplification factor of the valve $(= \mu R/(R_a + R))$. Whereas at low frequencies the effect of this capacitance can be neglected, at high frequencies the reactance $(1/\omega C)$ is quite low and will impose a load on the input circuit. This is most serious, when, as is often the case at H.F., the input circuit is tuned to resonance. With a triode the tuning would be affected by the anode load and R_a.

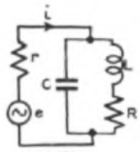
With a screen grid the effective capacitance between control grid and cathode is much smaller, being equal to the sum of the direct capacitances between the control grid and cathode and the control grid and screen.

However, the screen grid introduces another undesirable feature. In sketch (*a*) the anode current/anode volts characteristic for a tetrode has been drawn. It will be noticed that, provided the potential of the screen grid is fixed at a suitable positive value, the anode current increases initially as the potential difference between anode and cathode, V_a, is increased positively with a corresponding decrease in screen current. However, at quite a low value of V_a, the anode current, I_a, begins to decrease—point A on the characteristic—and continues to do so until point B is reached after which the anode current increases again as the positive potential applied to the anode is increased. Thus, the working range of V_a should never have a value less than V_{sg} but, also between the points A and B, the anode resistance (dV/dI_a) has a negative value.

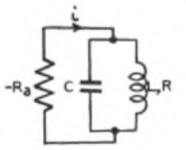


(*a*)

This phenomenon is caused by secondary emission of electrons from the anode to the screen grid. As the anode potential is increased so also will the velocity of the electrons arriving at the anode increase. Thus, the anode is being continuously bombarded by a fast-moving stream of electrons and the force of their impact is sufficient to dislodge far more secondary electrons than the number of primary electrons arriving. These secondary electrons are attracted to the screen grid which is at a higher positive potential, under these conditions, than the anode.



(*b*)



(*c*)

To examine the effect of this consider sketch (*b*). It will be apparent that :—

$$i = \frac{e}{r + \dfrac{(R + j\omega L)\,\dfrac{1}{j\omega C}}{R + j\omega L + \dfrac{1}{j\omega C}}}$$

$$= \frac{e}{r + \dfrac{R + j\omega L}{(1 - \omega^2 LC) + j\omega CR}}$$

When *e* is 0 and *r* has a positive value, $i = 0$. But, if *r* has a negative value $(= -R_a)$ and, if, in addition,

$$-R_a + \frac{R + j\omega L}{(1 - \omega^2 LC) + j\omega CR} = 0$$

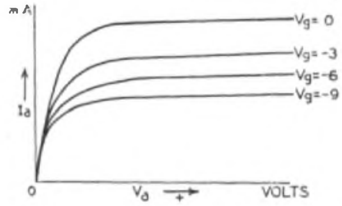
then, when *e* is 0 (sketch (*c*)), $i = 0/0$, which is indeterminate and the circuit will oscillate. This is the principle of the dynatron oscillator, for which:—

$$R_a\,(1 - \omega^2 LC) + j\omega CRR_a = R + j\omega L$$

$$\text{i.e.} \quad -R_a = -L/CR$$

$$\text{and} \quad \omega^2 = \frac{1}{LC}\left(1 - \frac{R}{R_a}\right).$$

To avoid this tendency to oscillate, the secondary emission from the anode must be prevented. This is achieved by inserting an earthed screen, known as the suppressor grid, between the screen grid and anode, so that the valve has now five electrodes and is called a pentode. Typical anode current/anode voltage characteristics for a pentode are given in sketch (*d*). It will be seen that the "kink" has been removed and that, above a comparatively low value of anode voltage, the anode current increases very slowly with anode voltage, that is, the anode resistance is very high—of the order of megohms—so that the pentode is effectively a constant current device and most suitable for a tuned anode load.



(*d*)

Q. 10. *The e.m.f. of an alternator which has negligible internal impedance is given by the expression*

$$e = \sqrt{2}\, \sin \frac{1}{2}\, 10^5 t + \frac{1}{\sqrt{2}} \cos 10^5 t$$

where t is in seconds and e is in volts.

This alternator is connected across the circuit given in Fig. 3.

Fig. 3.

Calculate the r.m.s. values of :—

(a) the applied voltage,
(b) the circuit current,
(c) the voltage across the capacitance.

Obtain an expression for the voltage across the resistance.
What is the total power dissipated in the circuit ?

A. 10. R.M.S. value of applied voltage

$$= V_{RMS} = \sqrt{1^2 + \left(\frac{1}{2}\right)^2} = \sqrt{\frac{5}{4}} = \underline{1{\cdot}118 \text{ volts.}}$$

Impedance of circuit

(i) For $\omega = \frac{1}{2} \times 10^5$ radians/sec.

$$Z = 400 + j\,.\,\frac{1}{2} \times 10^5\,.\,2 \times 10^{-3} - j\frac{10^8}{1/2 \times 10^5 \times 5}$$

$$= 500\diagdown\overline{36^\circ\ 52'}$$

(ii) For $\omega = 10^5$ radians/sec.

$$Z = 400 + j200 - j200 = 400 \text{ ohms}$$

$$\therefore i = \frac{\sqrt{2}}{500\diagdown\overline{36^\circ\ 52'}} \sin\frac{1}{2}10^5 t + \frac{1}{\sqrt{2}\,.\,400} \cos 10^5 t$$

and voltage across resistance

$$V_R = \left\{\frac{\sqrt{2}}{500\diagdown\overline{36^\circ\ 52'}} \sin\frac{1}{2}10^5 t + \frac{1}{400\sqrt{2}} \cos 10^5 t\right\}400$$

$$= \underline{0{\cdot}8\sqrt{2}\sin\left\{\frac{1}{2}10^5 t + 0{\cdot}642\right\} + \frac{1}{\sqrt{2}}\cos 10^5 t}$$

R.M.S. value of circuit current,

$$I_{RMS} = \sqrt{\left(\frac{1}{500}\right)^2 + \left(\frac{1}{800}\right)^2} = \underline{2{\cdot}358\text{mA.}}$$

Power dissipated in circuit,

$$W = (I_{RMS})^2 R = \left(\frac{2{\cdot}358}{1{,}000}\right)^2 \times 400 = \underline{2{\cdot}224 \text{ mW.}}$$

Voltage across capacitor,

$$V_c = \frac{i}{j\omega C} = \frac{400\diagdown\overline{90^\circ} \times \sqrt{2}}{500\diagdown\overline{36^\circ\ 52'}} \sin\frac{1}{2}10^5 t + \frac{200\diagdown\overline{90^\circ}}{400\sqrt{2}} \cos 10^5 t$$

$$\text{R.M.S. value} = \sqrt{0{\cdot}8^2 + 0{\cdot}25^2} = \frac{\sqrt{281}}{20} = \underline{0{\cdot}84 \text{ volt.}}$$

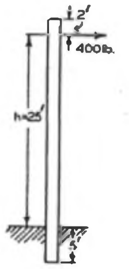
LINE PLANT PRACTICE II, 1951

Q. 1. *An overhead route is to be carried on sawn timber supports of square cross-section. These supports are 32 ft. long set 5 ft. in the ground, and the maximum wind loading is estimated to produce an equivalent load of 400 lb. acting at a point 2 ft. from the top of the support. What must be the minimum length of side of the square cross-section if the maximum fibre stress at the ground line is not to exceed 2,000 lb./in.? (Assume that each support is to be set with two faces parallel to the line of route.)*

A. 1. Height of application of equivalent load above ground, $h = 32' - (5' + 2') = 25'$.

Maximum BM at ground line = 400 × 25 lb./ft.

Since from the usual bending formula $f/y = M/I$ then $I/y = M/f$; while, $I = bd^3/12$ and $y = d/2$ for a rectangular section.



$$\therefore \frac{bd^3}{12}\Big/\frac{d}{2} = \frac{M}{f}$$

But for a square section $b = d$

$$\therefore b^3/6 = M/f$$

$$\text{and } b^3 = \frac{400 \times 25 \times 12 \times 6}{2{,}000} \text{ cu. in.} = 360 \text{ cu. in.}$$

i.e. $b = 7\frac{1}{8}$ in. approx.

The minimum length of side of square section of timber ≏ $\underline{7\frac{1}{8}\text{ in.}}$

Q. 2. *A 60-yard span of 100-lb./mile copper wire is so regulated that at 20°F it would have a tension of 80 lb. At what temperature would the tension be reduced to 60 lb.? (Assume E = 17·5 × 10⁶ lb./in.; coefficient of expansion L = 0·0000092 per °F; cross-sectional area of 100-lb. wire = 0·00196 in².)*

Q. 3. *Explain these two statements by reference to the theory of earth pressure—*

(a) A retaining wall sustaining pressure from dry earth is under a pressure of about ⅔rds. of that which would be exerted on it if it were subjected to water pressure to the same depth.
(b) It is common when shoring the walls of a deep shaft to use the same section timber for shoring the walls at the bottom as at the top.

A. 3. (*a*) The magnitude of the static earth pressure on a retaining wall may be calculated by Rankine's formula:—

$$P = Wh\frac{1 - \sin\phi}{1 + \sin\phi}$$

where P is the pressure in lb./sq. ft. at depth h ft., W is the mass of earth in lb./cu. ft., ϕ is the angle of repose of the soil, and h is the depth.

The expression for P is based on the assumption that the earth is a dry granular mass of indefinite extent, wholly devoid of cohesion, and possessing internal friction only, as shown by the natural angle of repose.

Typical values of W and ϕ are 120 lb./cu. ft. and 30° respectively, giving:—

$$P = 120\,h\,\frac{1 - \sin 30^\circ}{1 + \sin 30^\circ} = 40h \text{ lb./sq. ft.}$$

This value of lateral pressure is thus about ⅔ that produced by water at the same depth, since for water $P = 62\frac{1}{2}\,h$ lb./sq. ft.

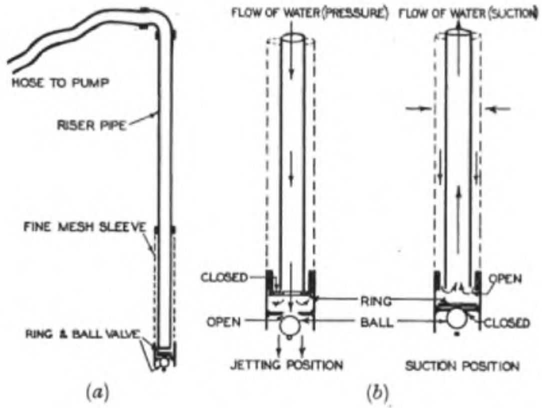
(*b*) The effects of cohesion, excluded in (*a*) above, become more important with increasing depths—say exceeding about 10 ft. Such depths are remote from the effects of weathering and traffic vibration, and derive considerable cohesion from compaction and retention of moisture. The pressure will usually increase uniformly with depth down to about 10 ft., but below 10 ft. will often not rise appreciably above the value reached at 10 ft. It is thus common practice to shore the walls of a deep shaft with the same section of timber at the bottom as near the top.

Q. 4. *A large manhole has to be constructed as quickly as possible in waterlogged soil. Describe a suitable method of construction detailing the equipment and materials that would be needed, apart from those needed for construction in normal subsoils. What saving in time would you expect to obtain from the method described as compared with alternative available methods.*

A. 4. When constructing a large manhole in waterlogged soil two major problems arise that are additional to those encountered with normal soils, namely, the prevention of water from (*a*) interfering with the constructional work, and (*b*) subsequently entering the manhole.

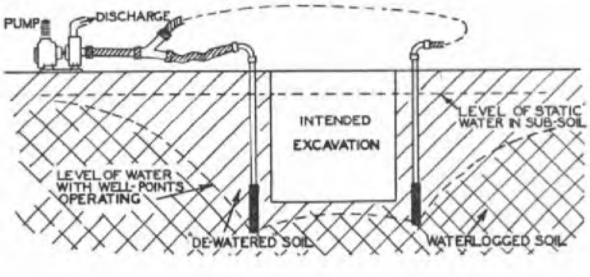
(*a*) This may be done expeditiously by the use of the well-point system of ground-water lowering. The de-watering plant used consists of a number of well-points sunk into the ground at approximately 5 ft. intervals around the perimeter of the intended excavation and approximately 5 ft. from it. The well-points are connected to pumps and the water pumped away.

Each well-point consists of a 10 ft. length of 2-in. diameter pipe having a fine mesh sleeve around and spaced from the bottom 2 ft. length which is terminated by a ring-and-ball-type valve, as in sketch (*a*). The function of the valve is to facilitate the sinking of



the well-point into the soil by permitting water that has been pumped *down* the pipe to issue from the bottom in the form of a jet. This jet of water washes away the soil immediately below the pipe and allows it rapidly to sink under its own weight to the required depth. On reversing the hose connection on the pump, i.e., connecting it to the suction side, the ring in the valve descends, thus opening the path for water to pass through the screen and up the pipe, to be pumped away. At the same time, the ball rises and closes the end aperture, thus preventing unfiltered material from also being removed. The action of the valve is shown in sketch (*b*).

Each well-point is thus able to remove water from its immediate vicinity, and, when several are used around an intended excavation, the area becomes "de-watered," as in sketch (*c*). The extent over which the effect is operative is governed by the porosity of the subsoil so that, when once the main volume of water has been removed, several well-points may be connected together via a common header pipe, or through Y-pieces, to permit a single pump to cope with the water filtering through the soil from the drainage area.



(*c*)

(*b*) To prevent the water from entering the completed manhole, rapid hardening cement should be used in the mixing of the concrete, or, alternatively, the concrete should include a waterproofing agent.

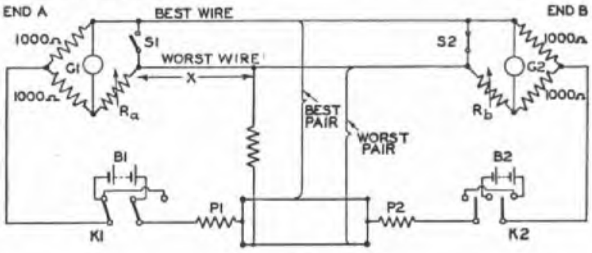
The total saving in cost by using the above methods when compared with other methods in similarly waterlogged conditions is approximately 75 per cent. This saving results primarily from the saving of the costs of digging and refilling independent sump holes and providing hard-core drainage, together with the increased speed at which the work may be performed in dry conditions.

Q. 5. *A twelve-way duct is to be laid in tunnel to avoid interference with traffic at a road junction which carries heavy traffic, including tramways. Describe the work involved in the tunnelling, duct laying and tunnel filling and closing, including any special measures necessitated by the presence of the tramways.*

Q. 6. *Explain how an earth fault on a H.V. overhead power line can give rise to an induced voltage in neighbouring overhead and underground telephone line plant. What governs the magnitude of the induced voltage?*

Q. 7. *Describe a suitable test for locating a fault which has affected all pairs of paper-core telephone cable to some extent, but the insulation resistance of a few pairs in the centre is still about four times that of the worst affected pairs.*

A. 7. The most suitable test for locating a fault of this nature is the Double-Ended Varley, for which two precision Wheatstone bridges, one at each end of the faulty section of cable, are required. The pair from the centre of the cable having the best insulation resistance between its wires, and another pair chosen because it has the worst insulation, are connected to the bridges in the manner shown in sketch (*a*).



(*a*)

The precision bridges have equal ratio arms, usually 1,000 + 1,000-ohm arms are suitable. G1 and G2 are sensitive galvanometers. S1 and S2 are high-grade short-circuiting switches used in turn for looping the "best" and "worst" wires when a test is made from the distant end. B1 and B2 are batteries as nearly equal as possible and, if necessary, with voltages as high as 500 to give the requisite sensitivity on faults of high resistance. K1 and K2 are battery control switches for connecting and disconnecting the battery from the bridges. P1 and P2 are protective resistors to limit the current should unintentional contacts arise on the line, testing leads or testing equipment. All the items of equipment must have an insulation which is high compared with the resistance of the fault to be located. K1 and K2, and S1 and S2 are shown set for a test to be made from end A.

If the "best" and "worst" wires are sensibly of the same conductor resistance, and if the "best" and "worst" pairs have similar insulation resistances between the wires at all points other than the fault point, then the distance, X, to the fault is expressed by the formula

$$X = \frac{R_b}{R_a + R_b} \cdot L$$

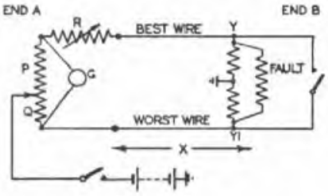
where X = distance in miles of fault from end A
R_a = Varley balancing resistance at end A
R_b = Varley balancing resistance at end B
L = length in miles of cable between A and B.

In carrying out the test S2 is closed, K1 is operated to connect the battery B1 to line, and B2 is disconnected by the operation of K2. The bridge at end A is then balanced by adjusting the bridge arm R_a. Because of the line capacitance if the value of the fault is high, it may take considerable time to reach the true steady value of R_a.

When R_a has grown to its steady maximum value a test from end B is made as quickly as possible so that the fault value and general insulation conditions are sensibly the same. To this end battery B2 is switched on before battery B1 is disconnected, so that the line does not discharge in the interval between the tests. When B1 is disconnected, S2 is opened, S1 closed and R_b is adjusted to balance the bridge.

It is advisable to repeat the measurements several times to obtain good mean values for R_a and R_b.

It will be noted that in the test described the batteries B1 and B2 are shown connected via P1 and P2 to other wires in the cable rather than to earth. Under some conditions, tests using earth for the battery return are possible, but the arrangement described tends to minimise the effects of inductive disturbances.



(*b*)

An alternative to the Double-Ended Varley is the Poleck Test, the connections for which are shown in sketch (*b*).

The ratio of P to Q and also the value of the rheostat R are adjusted together so that their settings balance the bridge whether the end B is "opened" or "closed." Some skill is required in finding the settings. If the condition of the end B does not affect the balance of the bridge, the potential at Y must be equal to the potential at Y1 and it follows, if the wires are of the same resistance, that

$$P/Q = (R + X)/X$$

Subtracting 1 from both sides

$$(P - Q)/Q = R/X$$

or

$$X = QR/(P - Q)$$

where X is the resistance to the fault from end A.

Q. 8. *Explain the methods used to determine which of the various available methods of providing telephone line plant to meet future growth is the most economic over a given period of years. What account must be taken of existing plant in the area concerned?*

A. 8. The alternative methods of providing telephone line plant are compared on a basis of cost. Those factors to which no monetary value can be assigned, i.e., the "irreducible" factors have also to be taken into account. An excellent example of an irreducible factor is the flexibility which a line-plant system possesses.

Cost comparisons cannot be based on initial cost or capital cost alone, since different plant provided under the various available schemes requires differing amounts of maintenance. Also, instalments of plant may be provided at different periods of time throughout the costing period. Some basis of comparison which takes account of these and other factors has, therefore, to be used and it is the practice to assess the annual charges to be incurred at various times under the various schemes and to find the present value of the annual charges over the costing period; that is, the sum of money that, if invested now at compound interest, would be just sufficient to enable the calculated annual charges to be met each year during the costing period.

The annual charges to be assessed are made up of the following:—

(a) *Interest* on the capital expended on installing the plant.

(b) *Depreciation* of the plant throughout its life. This is provided for by a uniform annual sum spread over the life of the plant to accumulate a sum equal to the sum required to replace it, assumed in practice to be the same as the initial cost less its residual value. Items of plant having different lengths of life, e.g., ducts and cable, are dealt with separately.

(c) *Maintenance.* This is assessed as the average cost of maintaining the plant throughout its life, even though in its early years it may require less, and in its later years, more than the average amount spent on it.

These annual charges are then capitalised as stated above, the full costing period of years—usually 20—being used for line plant installed at the outset and the balance of the 20-year period for plant added at a later date. Twenty years is chosen as the costing period because forecasts of numbers of probable telephone subscribers that the plant is designed to serve are usually made for 5, 10, 15 and 20 years ahead.

The principle underlying the method used to capitalise the annual charges, i.e., to calculate their present value, is simple. The sum which would at a given rate of compound interest amount to £1 after a given number of years is readily calculable from the ordinary compound interest law. By an extension of this process the sum required to provide an annual payment for each of the years of the 20-year costing period can also be calculated and this sum, say £x, represents the present value of £1 per annum for 20 years. If the annual charges on the plant installed initially on a scheme are, say, £100 per annum, then the P.V. of those charges will be £100x. Similarly, if the annual charges on plant added as a second instalment after 10 years are assessed at £50 and the present value of £1 per annum for 10 years is £y, then the present value of these charges is £50y and the total for the whole scheme over the 20 years (assuming no further instalments of plant) is £100x + £50y.

A calculation of this sort made for any other design of plant for the same scheme provides a fair basis of comparison provided the same costing period is used in each case.

When there is some plant already existing which it is possible either to incorporate in the scheme or to recover and substitute by different plant, it is necessary to make calculations of the total P.V. of A.C. incurred under each alternative. Thus if, on an underground development scheme, some overhead plant exists in the area to be served, it may be decided either to retain it until the end of its economic life and then replace it by underground, or to recover it and replace by underground now.

Where existing plant is to be retained for a period of years the P.V. of the annual charges on it for that period of, say, x years must be included, plus the P.V. of the "wastage" cost x years hence (the "wastage" cost being the depreciated value *in situ* + the cost of recovery—value of recovered stores), plus the P.V. of the annual charges on the replacing underground plant for the balance of the 20-year period.

Where the existing overhead plant is to be recovered at once the actual wastage on the overhead plant, as defined above, must be added to the P.V. of A.C. of the replacing underground plant for the full costing period of 20 years.

As mentioned at the outset, the irreducible factors may well sway the decision as to which type of plant shall be installed, especially if between schemes showing little difference on P.V. of A.C. basis there is a marked difference in the flexibility provided, or one scheme is much more acceptable to a local authority, or takes fewer men to maintain it.

Q. 9. *Give details of one method of determining the tension in an overhead span which does not involve cutting the wire. If the method were applied to a 72-yd. span of 40 lb./mile cadmium copper wire, the sag of which is 6 in., what result would you expect to obtain? Explain how any formula you may use is derived.*

A. 9. One method of determining the tension in an overhead wire without cutting it is known as the "Ping-Pong" method. Briefly, a transverse wave is started along the wire and the time required for the vibration to travel backwards and forwards after reflection at the two ends, a convenient number of times, is taken.

The wave may be started by sharply striking or pulling the wire sideways about 18 in. from the insulator. The return of the waves can be felt by resting the hand lightly on the wire a few inches from the insulator. A stop-watch should be used to time a given number, say, 20 waves.

If t = time between return to starting point of two successive waves, in secs.
T = tension in the wire in lb.
l = span of wire in ft.
v = velocity of the wave along wire in ft./sec.
w = weight of wire in lb./ft.
g = acceleration due to gravity = 32·2 ft./sec.^{2}.

the distance travelled in time t is $2l$, so that $v = \frac{2l}{t}$.

Now, the velocity of a transverse wave along a wire is given by the equation

$$v = \sqrt{\frac{Tg}{w}}$$

and since $v = 2l/t$

$$\frac{2l}{t} = \sqrt{\frac{Tg}{w}} \qquad \text{or } T = \frac{4l^2w}{gt^2} \quad \dots\dots\dots\dots (1)$$

$$\text{or } t^2 = \frac{4l^2w}{Tg} \quad \dots\dots\dots\dots (2)$$

From the data of the question,
w = 40 lb. per mile = 0·00758 lb./ft.
l = 72 yds. = 216 ft.
d = 6 in. = 0·5 ft.

$$\text{then, } T = \frac{wl^2}{8d}$$

$$= \frac{0{\cdot}00758 \times 216^2}{8 \times 0{\cdot}5} \text{ lb.} = 78{\cdot}4 \text{ lb.}$$

Inserting this value in (2)

$$t^2 = \frac{4 \times 216^2 \times 0{\cdot}00758}{78{\cdot}4 \times 32{\cdot}2} = 0{\cdot}56$$

whence t = 0·75 sec. and time for 20 waves = 0·75 × 20
= 15 secs.

Thus, for the span quoted in this question, one would expect the time of travel and reflection of 20 waves to be 15 sec., and hence the time t of one wave to be 0·75 sec., and inserting this value in equation (1) would obtain a value of 78·4 lb. for the tension in the wire.

It is to be noted that this method is not affected by cross winds as is the alternative Pendulum method and it is easy to produce true waves.

Q. 10. *(a) What are the factors governing the economic size of a telephone area?*

(b) What are the main considerations affecting the choice of site for a telephone exchange? How are the "theoretical centre" and "practical centre" determined?

A. 10. (a) the factors governing the economic size of a telephone exchange area are:—

(i) *Line plant costs.* These are reduced as the size of the area is decreased and the number of exchanges increased. In the past, line plant costs have been the predominant factor and the one with the greatest variation.

(ii) *Building costs.* Expressed in £ per subscriber, these costs are higher for the smaller areas.

(iii) *Type of Exchange.* With manual working operating costs as well as site and building costs have to be taken into account in comparison with subscribers' line plant costs. With larger areas and fewer exchanges, increases in line plant costs are offset by savings in operating and accommodation costs. In the more rural areas line plant considerations generally govern the situation.

With automatic working operating costs are largely eliminated and, broadly, smaller exchange areas become economical. With the smaller exchanges, however, the costs per subscriber are increased, owing to less efficient use of the common apparatus.

(iv) *Junction costs.* With smaller and more numerous exchange areas, many calls are junction calls that would be local calls with larger areas and the junction circuit requirements are increased.

(v) *Site costs.* In more congested areas site costs are high and maximum use must be made of them. Since in such areas telephone density is high and the size of the telephone areas would normally be small and their number correspondingly increased, site and building costs per subscriber are kept down by locating two full exchanges in one building. Usually they have a common main distribution frame so that any subscriber may be connected to either exchange.

Thus in the individual case it is necessary to balance line plant, including junction costs against site, building and exchange apparatus costs.

In addition, it has to be remembered that with larger exchange

LINE PLANT PRACTICE II, 1951 (*continued*)

areas it is possible to provide simplified directories.

(*b*) The main considerations affecting the choice of a site for a telephone exchange are:—

- (i) Cost of site.
- (ii) Building cost. This is influenced by shape and levels of site, type of subsoil.
- (iii) Line plant costs. The site must be as near as possible to the practical centre of the area to be served, i.e., a location such that over the 20-year planning period these costs, on a Present Value of Annual Charges basis, are a minimum.
- (iv) Services. Drainage, sewage and electricity services must be readily available and the site must have good road access.

The theoretical centre of an exchange area is that position which would give the minimum mileage for subscribers, junction and trunk lines, assuming that these could be provided radially and the numbers of each were adjusted to equivalent numbers of one gauge of conductor. A convenient method of finding it is to so choose the positions of a horizontal and of a vertical axis on the exchange area plan that the number of circuits adjusted for gauge, as mentioned earlier, is the same on either side of each axis. The point of intersection of these axes then gives the position of the centre.

The practical centre is determined by considering the routes available for new plant, the theoretical centre at the ultimate planning date and the 11th year (or any alternative critical date) being used as guides, and taking into account existing line plant. This centre is determined without regard to the availability of sites, and "out of centre" line plant costs for each possible site are calculated and compared with those for an exchange at the practical centre.

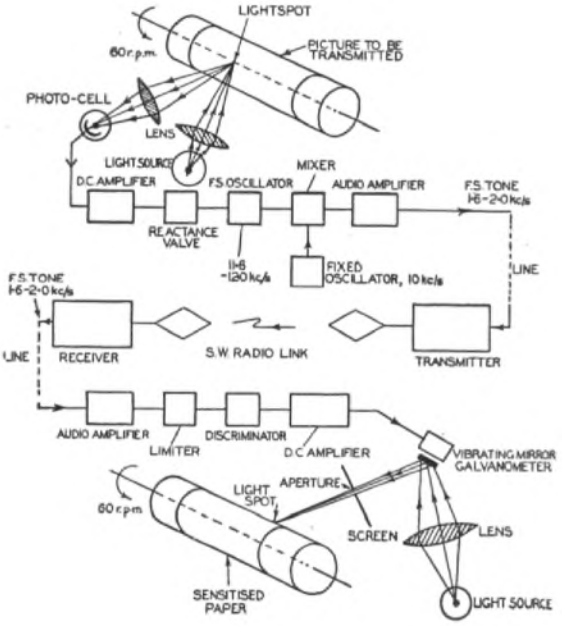
RADIO III, 1951

Q. 1. *Give an outline description of a system for facsimile transmission over a long-distance short-wave radio link.*

What factors affect the bandwidth of the transmission?

A. 1. One of the most effective systems for facsimile transmission over long-distance short-wave radio links is that employing frequency-shift (F.S.) modulation; the ability of this system to reduce the effects of fading due to multiple-path transmission, random noise and interference has caused it to supersede older systems employing amplitude modulation in the form of constant frequency variable-width dots.

The basic elements of a F.S. facsimile system are shown in the sketch. The picture to be transmitted is secured to a cylinder rotating at 60 r.p.m.; it is scanned with a light spot of about 1/100 in. diameter, the scanning being achieved by slowly moving the cylinder in an axial direction so that the light spot traces a continuous helix on the cylinder. Light reflected from the picture at the point where the light spot falls on it is collected by a lens and focused on a photo-cell, thus giving rise to a direct current, the strength of which varies according to the density of the picture along the scanning line. A voltage, proportional to the direct current from the photo-cell, is amplified in a D.C. amplifier and is made to vary the frequency of an oscillator from 11·6 kc/s (black) to 12·0 kc/s (white). The output of this F.S. oscillator is mixed with a constant frequency of 10 kc/s from a second oscillator, thus producing a F.S. tone varying from 1·6 kc/s (black) to 2·0 kc/s (white), suitable for transmission by land-line to the short-wave transmitter.



The F.S. tone may be applied as modulation to a double-sideband transmitter, or it may be transmitted in one channel of a single-sideband transmitter; the latter arrangement is preferred because it still further reduces the effects of selective fading, noise and interference.

A corresponding tone, with a certain amount of fading and noise superimposed on it, is produced at the output of the distant short-wave receiver. This tone, after transmission by land-line to the facsimile receiver, is amplified and applied to a limiter to remove amplitude variations due to fading. It is then fed to a discriminator, the direct voltage output from which is proportional to the frequency of the tone at any instant. The output of the discriminator is amplified and applied to a mirror galvanometer that functions as a light modulator. A narrow pencil of light is reflected from the mirror of the galvanometer, passes through an aperture in a screen, and forms a narrow spot of light on a rotating cylinder, similar to that at the transmitter, but carrying a sheet of sensitised paper and rotating in a light-tight enclosure. The mirror vibrates in sympathy with the varying direct current applied to the galvanometer, and thus varies the intensity of the light spot by causing a smaller or larger proportion of the light beam to be intercepted by the screen. After completion of the scanning process, the sensitised paper is developed and fixed by normal photographic processes. It is, of course, essential to have the receiving cylinder rotating in synchronism with the transmitting cylinder; in some systems this is achieved by operating both drums from synchronous motors driven, or controlled, by high-stability quartz-crystal-controlled oscillators. Pulses, generated once per line as the transmitting light spot crosses a black bar marking the top and bottom of the picture, are also used to ensure synchronous operation of the transmitting and receiving cylinders.

The bandwidth allowed for the F.S. signal must be at least the frequency-shift plus twice the maximum "keying" frequency to allow for first-order sidebands due to modulation by the facsimile signal; the keying frequency is given by,

$$\frac{\text{Circumference of drum in inches} \times \text{lines per inch} \times \text{r.p.m.}}{60 \times 2}$$

Typical values are:—

Frequency-shift	400 c/s
Circumference of drum	11 in.
Lines per in.	100
R.p.m.	60
"Keying" frequency	550 c/s
Bandwidth of F.S. signal	1,500 c/s

The overall bandwidth of a double-sideband transmission is twice the sum of the highest shift frequency (2 kc/s) and the keying frequency (550 c/s), i.e., 5·1 kc/s. The overall bandwidth of a single-sideband transmission, including the pilot carrier, is half that for a double-sideband transmission, i.e., 2·55 kc/s.

Q. 2. *Describe a direction-finder in which the bearing is indicated on a cathode-ray oscilloscope.*

What are the advantages and disadvantages of this method compared with the aural-null technique?

(to be continued)

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