Supplement

to

The Post Office Electrical Engineers' Journal

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.

CITY AND GUILDS OF LONDON INSTITUTE EXAMINATIONS, 1931.

VI. RADIO-COMMUNICATION, GRADE 1 : QUESTIONS AND ANSWERS.

By A. C. WARREN, B.Sc., A.M.I.E.E.

Q. 1. Give a circuit diagram and brief description of a radio telephone transmitter. Show clearly how the output is modulated by speech currents.

A. 1. A simple form of telephony transmitter is illustrated in sketch (a). The oscillator consists of a valve V_0 fed from the H.T. supply E through a speech choke L_s and a high frequency choke L_{hf}.
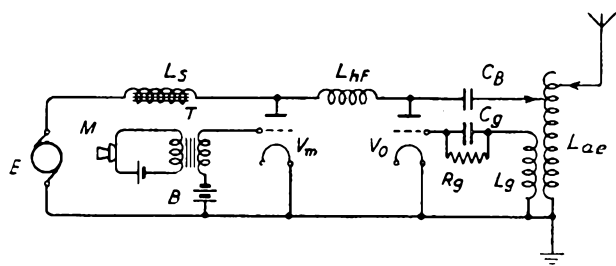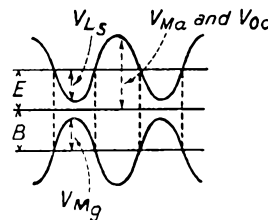

QUESTION 1. SKETCH (a).

The aerial is parallel fed through the blocking condenser C_b which serves to prevent the H.T. supply from being short-circuited through L_{ae}. Coupling from the anode circuit to the grid circuit is by inductive coupling *via* L_g. A grid leak and condenser R_g and C_g are provided to ensure the efficient generation of oscillations. The anode voltage system of modulation (choke control) is shown, the modulator valve V_m being connected across the supply after the speech frequency choke L_s. The microphone M is coupled through a transformer T and if necessary through a number of sub-modulator stages to the grid of the modulator. Suitable grid bias (a value exceeding the peak value of the modulation) is provided by a battery B. If no speech is applied to the microphone, the modulator valve will

take a steady current I_m and the oscillator a current I_0. If by the application of speech the grid of the modulator valve swings positive with regard to its static position, the anode current will increase. This tendency will be opposed by the speech frequency choke across which a back E.M.F. will be set up in opposition to the applied voltage; thus the voltage across V_m and hence across V_0 will fall. Similarly if the grid of the modulator valve swings negative, the modulator valve will pass less current and the back e.m.f. set up across the speech choke will endeavour to maintain the current, *i.e.*, the voltage across V_m will rise.

The effects of modulation on the valves is illustrated in sketch (b). The modulator valve V_m should be operated only over the straight portion of its characteristic and with the grid negative to the filament.

QUESTION 1. SKETCH (b).

Q. 2. A condenser of 4 mf. is connected in series with a resistance of 400 ohms. This combination is connected in series with two inductances in parallel of values 10 henries and 5 henries respectively. What current will flow through the resistance when an E.M.F. of 100 volts R.M.S. at 50 periods per second is applied to the circuit?

A. 2.
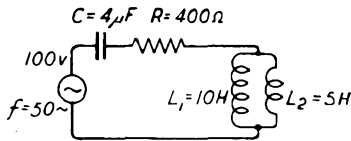
QUESTION 2.

$$L = \frac{L_1 L_2}{L_1 + L_2} = \frac{10 \times 5}{15} = 3.33 \text{ H.}$$

It is assumed that the examiner intended the capacity to be 4 microfarads.   Then

$$I = \frac{E}{\sqrt{R^2 + \left(\omega L - \frac{1}{\omega C}\right)^2}} =$$

$$\frac{100}{\sqrt{400^2 + \left(314 \times 3.33 - \dfrac{1}{314 \times 4 \times 10^{-6}}\right)^2}}$$

$$= \frac{100}{\sqrt{16 \times 10^4 + (1047 - 796)^2}} = \frac{100}{4.72 \times 10^2}$$

$$= 0.212 \text{ ampere.}$$

It would have been equally correct to have taken the capacity as 4 millifarads.   By the same method, the current in this case would be .066 ampere.

Q. 3. Describe the action of a three electrode thermionic valve.   How is it used (a) as an amplifier, (b) as a detector?   What is meant by amplification factor, A.C. impedance, and mutual conductance?

A. 3.   The three electrode valve consists of a filament or cathode, a grid or control electrode, and an anode or plate.

If the filament is heated, electrons are emitted and since these are negatively charged they will repel each other and hence those already in the space around the filament will repel and drive back those being emitted from the filament.

If now a positive potential is applied to the anode, it will tend to overcome the space charge and to attract the electrons.   As this positive potential is increased, the attraction will increase and the number of electrons passing from filament to anode will increase until finally the electrons are attracted to the anode as rapidly as they are emitted and the valve is said to be saturated.   A further increase in the anode potential cannot result in an increase in the anode current (a passage of electrons from filament to anode constitutes a flow of current from anode to filament).   If the filament is brightened, the number of electrons emitted, and hence the saturation current, increases.   The anode has to overcome the space charge, but if now a potential is applied to the grid, which is fitted between anode and filament, it will serve to control the space

charge, to assist it if the potential is negative and to overcome it if the potential is positive.   The grid, as its name implies, is of open mesh or spiral construction and provided that the mesh is sufficiently close, its control of the space charge and hence of the anode current will be very much greater than that of the anode, *i.e.,* a charge of one volt on the grid will produce a far greater change in anode current than a charge of one volt on the anode.

Typical valve characteristics are illustrated in sketch (a).

Amplification Factor is the voltage ratio $\dfrac{\partial v_a}{\partial v_g}$ given by the change in anode volts ∂v_a necessary to maintain the anode current constant when the grid voltage is changed by a very small amount ∂v_g.

A.C. Impedance is the resistance of the valve to small changes in anode current when the grid voltage is maintained constant, *i.e.,* the ratio $\dfrac{\partial v_a}{\partial i_a}$ where ∂i_a is the change in anode current due to a small change ∂v_a in the anode volts, the grid volts being kept constant.

Mutual Conductance is the ratio $\dfrac{\partial i_a}{\partial v_g}$ where ∂i_a represents the change in anode current for a small change in grid volts whilst the anode volts are maintained constant.   It is often expressed in milli-amperes per volt.

The valve may be used as an amplifier as indicated in sketch (b).   Z should preferably be greater than the A.C. impedance of the valve and may be in the form of a resistance, inductance, transformer or tuned circuit.   The valve may be used as a detector as in sketches (c) and (d).

(a)   (b)
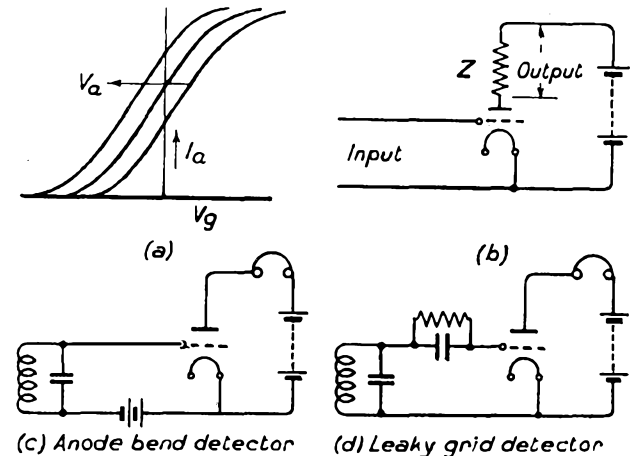
(c) Anode bend detector   (d) Leaky grid detector

QUESTION 3.

Q. 4. Describe, with sketches, the construction and principle of operation of an alternator suitable for the generation of currents of 500 periods per second.   What factors determine the frequency generated by such a machine?

A. 4. One of the common forms of alternator for the generation of frequencies of the order of 500 cycles/sec. is the inductor type shown diagrammatically in the sketch. In this alternator, the rotor is unwound and both field and armature windings are wound on the stator frame.

The rotor is of soft iron with pole pieces so that as a pole piece passes a stator slot it reduces the reluctance of the stator field circuit across that slot. The variation of the reluctance of the gap gives a pulsating flux which sets up an alternating E.M.F. in the stator winding.
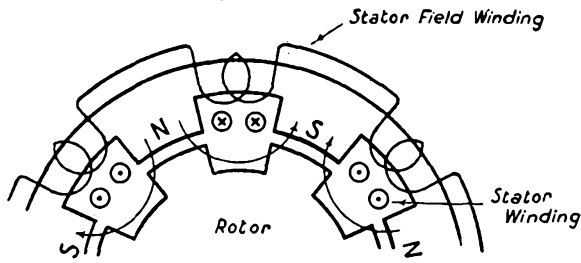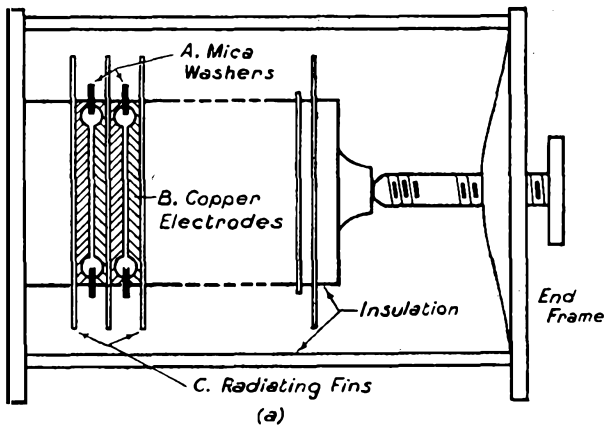

QUESTION 4.

The frequency generated will be given by the number of poles on the rotor × the number of revolutions per second of the rotor.

Q. 5. Describe the construction and action of a quenched spark gap. Give a description and wiring diagram of a $\frac{1}{4}$ kW quenched spark transmitter suitable for marine use, to work from a 24-volt battery.

A. 5. The construction of the quenched spark gap is illustrated in sketch (a). It consists of a number
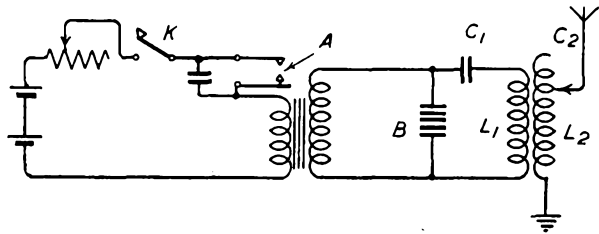

QUESTION 5. SKETCH (a).

of very short gaps in series between very well cooled metallic surfaces. The gaps are formed by mica washers inserted between copper electrodes provided with heat radiating fins. Each gap is .004″ to .01″ in length. A large number of elements are connected in series and mounted as a complete unit as shown in the sketch. The total gap length can be

adjusted by means of a clip enabling connexion to be made to any one of the cooling fins.

In order to eliminate wastage of energy in the spark gap, it is essential that the gap should be rapidly quenched or de-ionised. The utilisation of a large number of very short gaps and cold electrodes, as above, effects this.

Sketch (b) shows the essentials of a $\frac{1}{4}$ kW spark set operated from a 24-volt battery. An induction coil A is used to build up an intermittent high voltage for charging the condenser C_1. A quenched gap B is shown, the primary high frequency circuit being composed of B, C_1 and L_1. The aerial circuit is coupled through L_2. Keying is effected by means of the key K included in the supply circuit.

QUESTION 5. SKETCH (b).

Q. 6. Give a circuit diagram and brief description of a radio receiver for the reception of spark, I.C.W. or C.W. signals between 500 and 2,500 metres wavelength and possessing the following features :—
   Tuned coupled aerial circuit, one high frequency stage, one low frequency stage, separate heterodyne.

A. 6. A skeleton wiring diagram of a suitable receiver is shown in the sketch overleaf. To provide for the wide range of tuning, a series-parallel arrangement is given for the aerial circuit. For all other circuits, either tapped coils or interchangeable coils are necessary. A tuned anode circuit is used for the H.F. amplifier, resistance-capacity coupling with cumulative grid rectification being employed. This gives a simple but effective arrangement.

Transformer coupling is used for the L.F. amplifier. The separate heterodyne, which is only in use for C.W. reception, is coupled to the anode circuit of the H.F. amplifier to avoid radiation from the aerial. Grid bias batteries are omitted but may be included at the points marked GB.

Q. 7. Describe the construction and method of use of a wavemeter, suitable for use at a transmitting station, for measuring the wave-length of both spark and C.W. transmitters.

A. 7. A suitable wavemeter is indicated in the sketch. It consists of a tuning coil L, a bank of fixed condensers C, a variable condenser C_v, and a piezo-electric crystal N (normally cut out of circuit) coupled to the grid of a valve detector V. In the anode circuit of V is a sensitive milli- or micro-ammeter. The valve is selected and biased if neces-
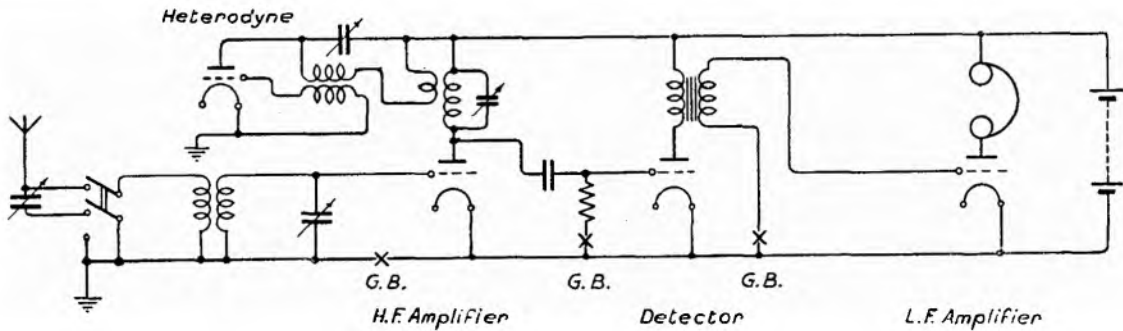
QUESTION 6.

sary so that it is operated on the bend of the anode current-grid volts characteristic.

If the wavemeter is loosely coupled to the transmitter and C and C_v are adjusted until a maximum deflection is obtained, the wavemeter will then be in resonance with the transmitter and the wave-length can be read from the wavemeter calibration chart.
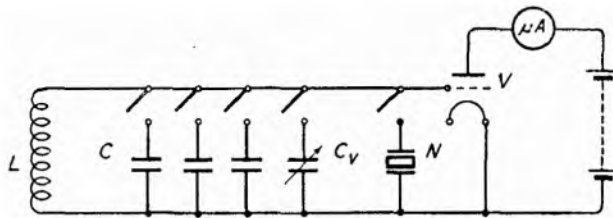
QUESTION 7.

The crystal N is provided for periodically checking the wavemeter calibration. The crystal will have a quoted natural frequency. The wavemeter is set to this frequency by the calibration chart and the transmitter frequency is then varied until the micro-ammeter reading suddenly falls and then rises again if the variation is continued in the same

direction. The transmitter frequency is adjusted to the middle of this crevasse, the crystal switched out of circuit, and the condenser tuned for maximum reading. Any change in this reading must be correlated with the wavemeter calibration.

If desired the grid bias and anode batteries may be omitted, the anode being connected to the +ve of the filament supply.

Q. 8. Describe any type of directional receiver with its associated aerial system. Explain how it is used to determine the direction of a distant transmitting station.

A. 8. The wiring diagram of a typical Bellini-Tosi directional receiver is shown in sketch (a).

The loop aerials L consist of two large single turn loops or small screened multi-turn loops fixed at right angles, each loop being joined in series with one pair of coils of the goniometer G. The goniometer coils are fixed at right angles and a search coil S is fitted so that it is capable of rotation about the common axis of the fixed coils.

A vertical aerial A, for sense determination, is joined to earth through a resistance which is coupled
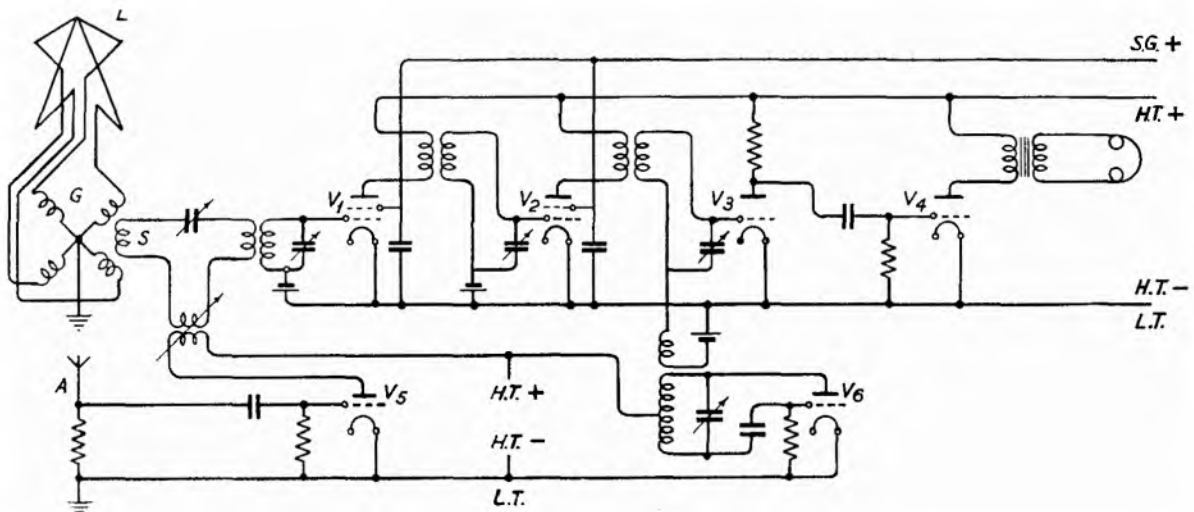
QUESTION 8. SKETCH (a).

to the grid of a valve V_5. A coil in the anode circuit of V_5 is coupled to a circuit comprised of the goniometer search coil, vertical aerial coupling coil, receiver coupling coil and tuning condenser. The receiver is a standard type of 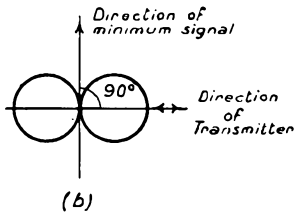selective receiver employing screen grid valves, the heterodyne oscillator V_6 being coupled to the grid circuit of V_3.

In practice further screen grid H.F. stages or transformer coupled L.F. stages may be used if necessary.

The polar diagram of a pair of loops is a " figure of eight," see sketch (b). To determine the direction of a distant transmitting station, all that is necessary is to rotate the search coil of the radio-goniometer (incorporated as a portion of the receiver) until the received signal is a minimum. The direction of the transmitting station will then be at right angles to the direction of the search coil.

Direction of minimum signal

90°

Direction of Transmitter

(b)

QUESTION 8. SKETCH (b).

In practice, of course, the loops are fixed N.—S. and E.—W. and the goniometer scale is calibrated with respect to the fixed goniometer coils, N.—S. of the scale corresponding to the plane of the fixed coil which is joined to the N.—S. loop. It can then be proved that the direction indicated by the search coil is the true direction of the wanted station.

Q. 9. Why is the high frequency resistance of an inductance coil higher than the D.C. resistance? State the methods that are adopted to reduce the high frequency resistance in coils.

A. 9. When a high frequency current is passed through a conductor, eddy currents will be set up which will tend to neutralize the flux cutting the conductor, and hence neutralize the current in the centre of the conductor. As a result, the current tends to flow in the outside of the conductor only. Since, therefore, at high frequencies the current flows in the skin only, the resistance of the conductor will be much higher.

As soon as the conductor is wound in the form of a coil, each turn will set up eddy currents in adjacent turns and will drive the current to the outer surface of the coil. Hence the resistance of the coil will exceed the H.F. resistance of an equal length of straight conductor.

Since the current is confined to the skin or only penetrates to a certain depth, the resistance of a coil can be considerably reduced by the use of conductors having the same copper cross section of the following forms :—

   (a) Copper tube.
   (b) Copper strip wound with the width of the strip (rather than the edge) along the axis of the coil.
   (c) Stranded wire.

Stranded wire cable or litzendraht consists of a large number of strands (frequently stranded $3 \times 3 \times 3 \times$), of fine wire (30 swg.-38 swg.) carefully insulated one from the next by enamel and silk insulation. The stranding is so arranged that each strand passes periodically to the outside of the cable.

In addition to conductor losses at high frequencies, losses occur in the dielectric or insulation on which the coils are wound and also in the materials (dielectric or conductor) in proximity to the coil. Therefore only dielectrics having low losses may be used and even then their volume should be reduced as low as possible. Coils should be fitted as far away from bad conductors or dielectrics as possible.

Q. 10. What is meant by resonance in a circuit? What is a resonance curve? How is the resonance curve of a circuit affected by resistance?

A condenser of 1000 micromicrofarads is connected in series with an inductance of 500 microhenries. What is the wave-length at which this circuit would resonate? If an additional condenser of 250 micromicrofarads is connected in series, what will be the wave-length of resonance?

A. 10. The impedance of a circuit consisting of a resistance R, inductance L, and capacity C is given by :—

$$Z = \sqrt{ R^2 + \left(\omega L - \frac{1}{\omega C} \right)^2 }$$

Now if $\omega L - \dfrac{1}{\omega C} = 0$, $Z = R$ and the circuit is said to be in resonance.

The impedance of a circuit can be rewritten

$$Z = R \sqrt{ 1 + \left(\frac{\omega L - \dfrac{1}{\omega C}}{R} \right)^2 }$$

and since at resonance, $\omega L = \dfrac{1}{\omega C}$, we see that Z is a function of $\dfrac{\omega L}{R}$ or $\dfrac{R}{2fL}$.

$\dfrac{R}{2fL}$ is the logarithmic decrement of the circuit and it can be shown that if we plot the curve $\dfrac{R}{Z}$ against $\dfrac{f}{f_0}$, where f is the any desired frequency and f_0 the resonant frequency, this curve is the same for all circuits which have the same decrement. It is thus possible to plot a series of curves for various values of decrement which will cover all circuits. These curves, known as resonance curves, take the form shown in the sketch for a series resonant circuit. If the resistance of the circuit is increased, the decrement

decrement increasing

$\frac{R}{Z}$

f/f_0
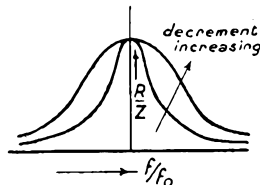
QUESTION 10.

will increase and the resonance curve will become flatter.

Resonant wave length $\lambda = 1885 \sqrt{LC}$ metres where L is in μH and C in μF.

Case 1. $L = 500 \mu$H. $C = 1000 \mu\mu$F.

$$\lambda = 1885 \sqrt{500 \times .001} = 1332 \text{ metres.}$$

Case 2. $L = 500 \mu$H. $C_1 = 1000 \mu\mu$F.
$$C_2 = 250 \mu\mu\text{F.}$$

$$C = \frac{C_1 C_2}{C_1 + C_2} = \frac{250}{1.25} = 200 \mu\mu\text{F.}$$

$$\lambda = 1885 \sqrt{500 \times .0002} = 596 \text{ metres.}$$

VII. RADIO-COMMUNICATION, FINAL: QUESTIONS AND ANSWERS.

By A. C. WARREN, B.Sc., A.M.I.E.E.

Q. 1. Two coils have inductances of 250 microhenries and 100 microhenries respectively. They are placed so that their mutual inductance is 50 microhenries. What will be their joint inductance (a) in series aiding, (b) in series opposing, (c) in parallel aiding, (d) in parallel opposing?
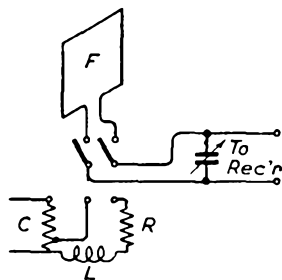
A. 1.

    (a) $L = L_1 + L_2 + 2M$
$$= 250 + 100 + 100 = 450 \ \mu\text{H.}$$

    (b) $L = L_1 + L_2 - 2M$
$$= 250 + 100 - 100 = 250 \ \mu\text{H.}$$

    (c) $L = \dfrac{L_1 L_2 - M^2}{L_1 + L_2 - 2M} = \dfrac{25000 - 2500}{350 - 100} =$
$$\dfrac{22500}{250} = 90 \ \mu\text{H}$$

    (d) $L = \dfrac{L_1 L_2 - M^2}{L_1 + L_2 + 2M} = \dfrac{22500}{450} = 50 \ \mu\text{H.}$


(b)

QUESTION 2.

Q. 2. Describe with diagrams one type of field strength measuring set. What precautions are necessary in the construction of such a set? State how the set is used to measure fields.

A. 2. A typical field measuring set is shown in sketch (a). A local oscillator A is coupled to a sensitive thermo-milliammeter in series with which is placed a calibrated attenuator B. The output is connected across the resistance C, a small portion of which is included in a frame aerial combination coupled to a receiver D.E.G. A micro-ammeter V is included in the anode circuit of the detector to act as a volume indicator.

The wanted signal is picked up on the frame F at maximum position, tuned in, and the reading of V noted. In an interval of the transmission, or with the frame turned to minimum position, the local oscillator is switched on, adjusted to the same frequency, and the attenuator adjusted until the reading of V is the same as before. The reading of the thermo-ammeter in the output of A and the attenuator reading are noted.
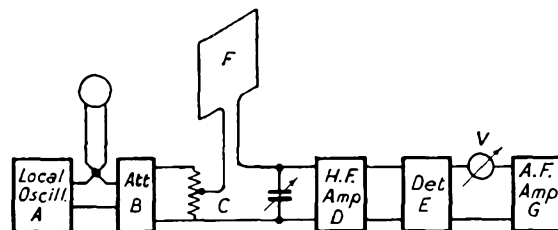
(a)

QUESTION 2.

Signals from the distant stations and the local oscillator are injected alternately until a good average reading is obtained. If intervals in the distant transmission, or a good zero on the frame, are unobtainable, the circuit may be re-arranged as in sketch (b), L and R being non-radiating elements giving the same constants as the frame aerial.

The E.M.F. induced in the frame aerial is equal to the voltage applied to C from the local oscillator and the value of this can be calculated from the readings noted. The field strength E is given by

$$E = \frac{\lambda V}{2\pi n A}$$

where A = area of the loop, metres^2.

    n = number of turns.

    λ = wave-length in metres.

    V = voltage across C.

The following precautions have to be taken in construction :—

    (1) Direct coupling between the local oscillator and the receiver must be eliminated.

    (2) Direct pick up by the receiver must be avoided.

    (3) The attenuator must be calibrated over the working range of frequencies.

(4) The constants of the frame simulating circuit (sketch b) must be identical with the frame.

Q. 3. *A high frequency ammeter is coupled to an oscillatory circuit by means of an air cored transformer. The primary winding carries 100 amperes at 10^5 cycles per second. The secondary circuit has a total inductance of 20 microhenries and a mutual inductance with the primary of 1 microhenry. If the resistance of the secondary circuit including the meter is 4 ohms, what current will flow through the meter?*

A. 3.

I_2 = current in secondary

$$= \frac{\omega M I_1}{Z_2}$$
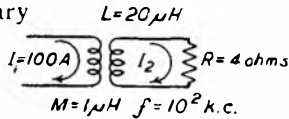
$$\omega = 2\pi f = 2\pi \times 10^5$$

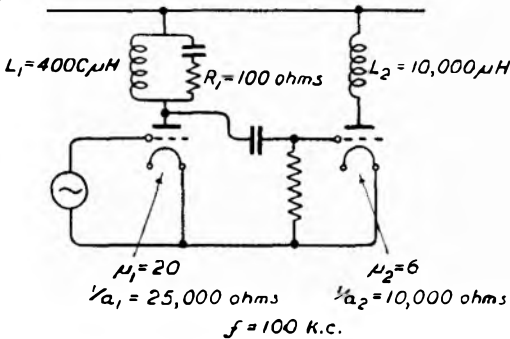$$\omega M = 2\pi \times 10^5 \times 10^{-6} = 0.2\pi \text{ ohms.}$$

$$Z_2 = \sqrt{R_2^2 + \omega^2 L_2^2} = \sqrt{4^2 + (4\pi)^2} = 13.2 \text{ ohms.}$$

$$\therefore I_2 = \frac{0.2\pi \times 10^2}{13.2} = 4.76 \text{ amperes.}$$

$L=20\mu H$ $I=100A$ I_2 $R=4 \text{ ohms}$ $M=1\mu H$ $f=10^2 k.c.$

QUESTION 3.

Q. 4. *In a two-stage amplifier the first valve has an amplification factor of 20 with a plate impedance of 25,000 ohms and a tuned anode circuit, inductance of 4,000 microhenries and resistance of 100 ohms, tuned by a variable condenser. The second valve has an amplification factor of 6, a plate impedance of 10,000 ohms and an output impedance consisting of a choke of 10,000 microhenries inductance. What will be the voltage amplification of the amplifier at a frequency of 100 kilocycles?*

A. 4. In this question, the method of coupling between valves is not quoted, but it is assumed that the whole of the voltage developed across the anode of the first valve is applied across the grid of the second valve and that the coupling medium does not reduce the amplification obtained from the first valve.

If $\dfrac{\delta v_a}{\delta v_g}$ represents the voltage amplification of a stage

$L_1 = 4000\mu H$ $R_1 = 100 \text{ ohms}$ $L_2 = 10,000\mu H$

$\mu_1 = 20$ $1/a_1 = 25,000 \text{ ohms}$ $1/a_2 = 10,000 \text{ ohms}$ $\mu_2 = 6$ $f = 100 K.c.$

QUESTION 4.

$$\frac{\delta v_{a1}}{\delta v_{g1}} = \mu_1 \cdot \frac{R_{eff}}{\dfrac{1}{a_1} + R_{eff}} \quad \text{where } R_{eff} = \frac{R_1}{\omega^2 L_1^2}$$

$$\frac{\omega^2 L_1^2}{R_1} = \frac{(2\pi \times 10^5 \times 4 \times 10^{-3})^2}{100} = 63{,}000 \text{ ohms.}$$

$$\therefore \frac{\delta v_{a1}}{\delta v_{g1}} = 20 \cdot \frac{63000}{25000 + 63000} = 14.3$$

$$\frac{\delta v_{a2}}{\delta v_{g2}} = \mu_2 \cdot \frac{\omega L_2}{\sqrt{\left(\dfrac{1}{a_2}\right)^2 + \omega^2 L_2^2}}$$

$$\omega L_2 = 2\pi \times 10^5 \times 10^{-2} = 6{,}280 \text{ ohms.}$$

$$\therefore \frac{\delta v_{a2}}{\delta v_{g2}} \times 9 = \frac{6280}{\sqrt{10^8 + 6.28^2 \times 10^6}}$$

$$= 6 \times \frac{6280}{1.18 \times 10^4} = 3.19$$

The voltage amplification of the amplifier is

$$\frac{\delta v_{a2}}{\delta v_{g1}} = \frac{\delta v_{a1}}{\delta v_{g1}} \times \frac{\delta v_{a2}}{\delta v_{g2}} = 14.3 \times 3.19 = 45.6.$$

Q. 5. *The input circuit of a radio receiver has a logarithmic decrement of 0.0314 when tuned to a frequency of 800 kilocycles. The carrier wave of a station working on this frequency is equally modulated by tones of 50 cycles and 5,000 cycles. In what ratio will these two tones be received, assuming that the remainder of the receiver has a flat response?*

A. 5. The impedance of a simple tuned circuit at a frequency f_1 close to the resonance frequency f_0 is given by

$$Z = \sqrt{R^2 + \left(2 \cdot \frac{f_1 - f_0}{f_0} \cdot 2\pi f_0 L\right)^2}$$

$$= R\sqrt{1 + \left(\frac{f_1 - f_0}{f_0} \cdot \frac{2\pi}{\delta}\right)^2}$$

where δ is the logarithmic decrement of the circuit. The current in the circuit is proportional to $\dfrac{1}{Z}$

$$\therefore \frac{I f_1}{I f_2} = \frac{Z f_2}{Z f_1} \quad \text{where } f_1 = f_0 + 50 \text{ cycles, and}$$

$f_2 = f_0 + 5{,}000$ cycles.

$$\therefore \frac{I f_0 + 50}{I f_0 + 5000} = \frac{\sqrt{1 + \left(\dfrac{5000}{8 \times 10^5} \cdot \dfrac{2\pi}{3.14 \times 10^{-2}}\right)^2}}{\sqrt{1 + \left(\dfrac{50}{8 \times 10^5} \cdot \dfrac{2\pi}{3.14 \times 10^{-2}}\right)^2}}$$

$$= \sqrt{\frac{1 + 1.25^2}{1 + 0.0125^2}} = 1.6$$

i.e., the 50-cycle tone will be 1.6 times the 5,000-cycle tone.

Q. 6. Describe with a diagram how a two-wire land line telephone circuit is connected to a radio telephone transmitting and receiving · system, in order to permit speech in both directions.

A. 6. A duplex radio circuit is, in effect, a four-wire circuit, *i.e.,* one channel is used for transmission and one for reception. This four-wire circuit may be combined by means of a hybrid coil, as shown in the sketch, for connexion to a two-wire circuit. The balancing network has, at all frequencies, the same impedance as the two-wire circuit. Speech from the radio receiver is applied across the hybrid as shown and the current will split equally, half passing to the two-wire circuit and half through the balancing network. If the coils L_1 and L_2 are equal and their coupling to the transmitting leg the same, there will be no resultant E.M.F. induced in the transmitting leg due to received speech
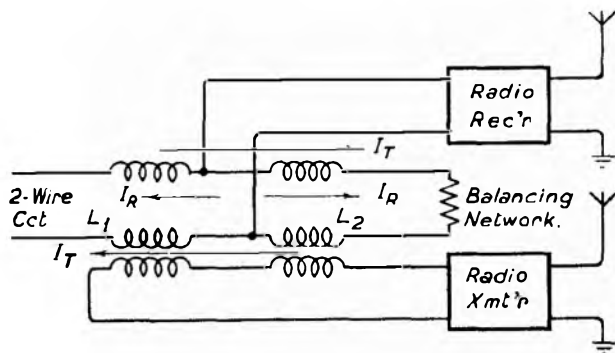
QUESTION 6.

If such an arrangement as this were not used, the received speech would pass directly to the transmitting leg and would set up " singing " round the loop consisting of both transmitters, receivers and interconnecting lines.

Q. 7. State the various types of masts and towers used to support the antennæ of land stations. Discuss the relative advantages of stayed masts versus self-supporting towers for various heights of structures.

A. 7. Aerials may be supported from two main classes of mast, (i) stayed masts, and (ii) self-supporting towers.

An intermediate form of tower can be constructed which is stayed to, say, one half its height, the remainder functioning as a self-supporting tower or cantilever.

Masts may be constructed in steel or wood and may be insulated or uninsulated. General practice is in favour of steel masts and, provided that good insulation is obtainable, insulated masts are to be preferred to earthed masts. The sole advantage of stayed masts is their cheapness. The advantages of self-supporting towers are :—

(1) The reduction in the ground space taken up

by the tower.
(2) The elimination of stays which will inevitably have a natural frequency, and hence radiating properties, and may coincide with the working frequency or with a harmonic thereof.
(3) The stays are liable to obstruct erection or maintenance work on the aerials, as it is difficult to arrange that they shall be entirely outside the area covered by the aerial.

For these reasons, self-supporting towers are universally used for short wave-lengths where masts up to 200-300 feet are used. At the present time, for all classes of transmission, self-supporting towers up to 400 feet would be recommended. Above this height, the reduced cost of stayed masts would probably outweigh other considerations.

Q. 8. What are the causes of instability in radio frequency amplifiers? How are these troubles overcome in practice? Give a circuit diagram of the radio frequency circuits of a receiver having two radio frequency amplifier stages.

A. 8. Instability in radio frequency amplifiers is due to back coupling between the stages by (*a*) magnetic coupling, (*b*) capacity coupling.

(*a*) *Magnetic coupling.* If there is magnetic coupling between the anode and grid circuits of a radio frequency amplifier, this is liable to result in loss of amplification or self-oscillation. This instability may be overcome by enclosing each coil or transformer in a perfectly screened enclosure or " can."
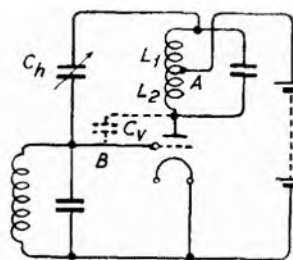
QUESTION 8.

(*b*) *Capacity coupling* may be either in the form of electrostatic coupling between components, which is eliminated either by a suitable disposition of the components or by an electrostatic screen between them, or inter-electrode capacity of the valves comprising the amplifier. Instability due to the inter-electrode capacity of the valves, which causes the amplifier to burst into self-oscillation, may be overcome by (1) the use of screened grid valves, (2) neutrodyning, (3) superheterodyne reception.

(1) *The screened grid valve* consists, in effect, in providing an electrostatic screen between anode and grid, thereby reducing the capacity between these electrodes to a negligible value, say from 20 $\mu\mu$F to

QUESTION 8. SKETCH (b).
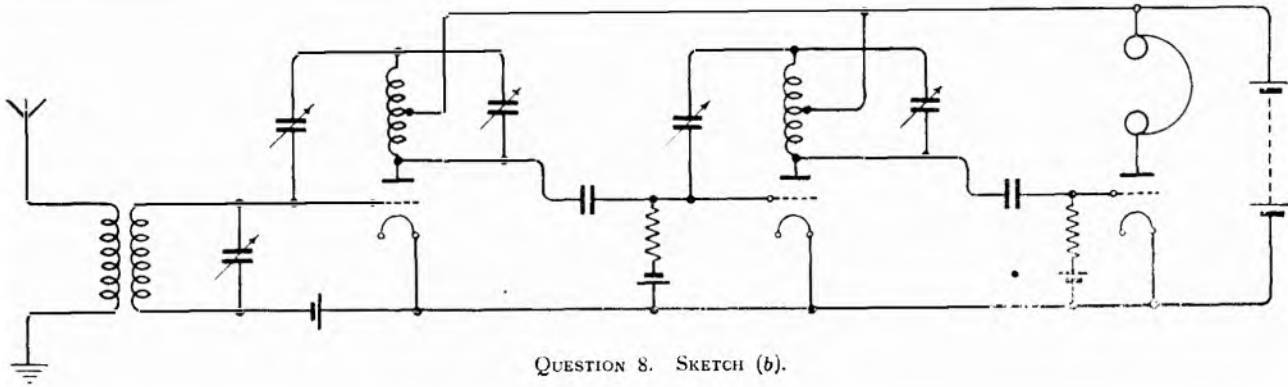
0.1 $\mu\mu$F. This screen naturally modifies the constants of the valve and necessitates the use of carefully designed circuits.

For receiving valves, the screen potential is of the order of + 80 volts, the anode potential being in excess of this value.

(2) *Neutrodyning* or neutralization consists in applying a potential on the grid 180° out of phase with that provided through the inter-electrode capacity of the valve. Referring to sketch (a), the H.T. supply is fed to the valve *via* the centre point of the anode coil, one outer being connected to the anode and the other *via* a neutralizing condenser to the grid. A bridge circuit exists consisting of L_1, L_2, C_v and C_n, L_1 and L_2 being equal. When the bridge is balanced, *i.e.*, when $C_n = C_v$, then there will be no potential difference, *i.e.*, no H.F. potential between the points A and B, due to currents in the tuned anode circuit. But the H.F. potential of A is zero and therefore the potential of the grid B will be zero, *i.e.*, there is no coupling between grid and anode circuits.

(3) *Superheterodyne reception*. In the superheterodyne receiver, the incoming signal is heterodyned at a supersonic frequency and radio frequency amplification is carried out at a relatively low fixed frequency where stable amplifiers can be built.

A wiring diagram of a receiver employing two radio frequency circuits is shown in sketch (b).

Q. 9. What are the relative advantages of Bellini-Tosi and rotating loop direction finders? How are these systems used to determine sense? To what errors are these systems liable? Can these errors be overcome? If so, how?

A. 9. The Bellini-Tosi system of direction finding involves the use of two loops fixed at right angles, frequently large single turn loops, supported from one mast 100-200 feet in height. The loops are joined in series with fixed coils of a radiogoniometer, the direction of the wanted station being obtained by the direction which the axis of a search coil in the goniometer makes with the axis of the fixed coils.

The advantages of this system are :—

(1) The radiogoniometer can be incorporated as a portion of the receiver; the coils are

small and there is therefore no large coil to rotate, so that rapid readings are obtainable.

(2) The E.M.Fs induced in the frame are large and thus accurate bearings are obtainable without an extremely sensitive receiver, thereby reducing the effect of direct " pick up " by the receiver.

The rotating loop system utilises a multi-turn frame of small dimensions. It has the advantages that :—

(1) The frame does not need an initial balancing and calibration provided that it is properly shielded or remote from absorbing structures.

(2) Periodic re-calibration is unnecessary.

(3) It is portable.

The Bellini-Tosi system enables quicker and more accurate readings to be obtained and is particularly suited to fixed station work.

A loop system may be utilised to determine sense as in sketch (a). The polar diagram of a loop is a figure of eight, A, but if this diagram is combined with that of a vertical aerial having the same maximum E.M.F., B, the resultant is a cardioid as shown at C in sketch (b). The circuit can be arranged so that when the vertical aerial is thrown

(a)   (b)

QUESTION 9.

into circuit, the direction of maximum signal (or minimum signal, as desired) indicates the sense and direction of the wanted signal. In sketch (a), the frame is utilised as a vertical aerial.

These two systems are subject to the following errors :—

	Bellini-Tosi.	*Rotating Frame.*
(1)		" Vertical effect," *i.e.,* the combination of frame and aerial circuit acts as a vertical aerial.
(2)		Direct pick up by the receiver.
(3)		" Night effect " due to the presence of a downcoming reflected wave.
(4)	Inequality of pick up and of the constants (R, L and C) of the frames.	
(5)	Similar inequalities in the goniometer.	
(6)		Proximity of absorbing materials.

These can be eliminated or reduced by—
(1) The use of earth screens between the aerial circuit and the receiver, and by earthing the centre point of the frame.
(2) By efficient screening of the receiver and supply leads.
(3) By the use of Adcock vertical aerials in lieu of a frame.
(4) and (5) By balancing or calibration.

Q. 10. Describe with sketches any type of radio frequency alternator in use at the present time. How is the frequency maintained constant? What is the degree of constancy attained in practice? What are the approximate upper limits of frequency of such machines and what imposes this limit? What are the advantages and disadvantages of alternators as compared with valve transmitters?

A. 10. The Alexanderson alternator is one in which the frequency is generated direct. The alternator is of the inductor type and is shown in section in the sketch. The rotor A is of chrome steel and slots B are cut in the rim to form teeth for the variation of the reluctance of the stator field circuit. The slots are filled with phosphor bronze to reduce windage losses. Field coils C set up a magnetic field (as shown by the arrow) in the stator frame D, the armature supports E, the laminated armature teeth F, and through the rotor A.

As the rotor is rotated, the reluctance of the gap between the armature teeth on either side of the disc varies as first a rotor tooth and then a rotor slot passes a given point. Thus, the E.M.F. induced in a conductor embedded in the stator armature will be an alternating one of frequency given by $f = t \times n$, where t = number of teeth on the rotor, and n = the revolutions per second of the rotor. The armature winding G is wave wound and for standard alternators has twice as many slots as the rotor.

The air gap between rotor and stator can be varied by means of the screw thread H which is left hand for one armature support and right hand for the other.

The speed of the rotor is from 3,500 to 20,000 r.p.m. and the air gap between rotor and stator from .02 to .004 inch.

Keying is effected by means of a magnetic amplifier, an iron cored inductance which is varied by varying the magnetization of the iron, included in the aerial circuit or in a circuit inserted between the alternator and the aerial.
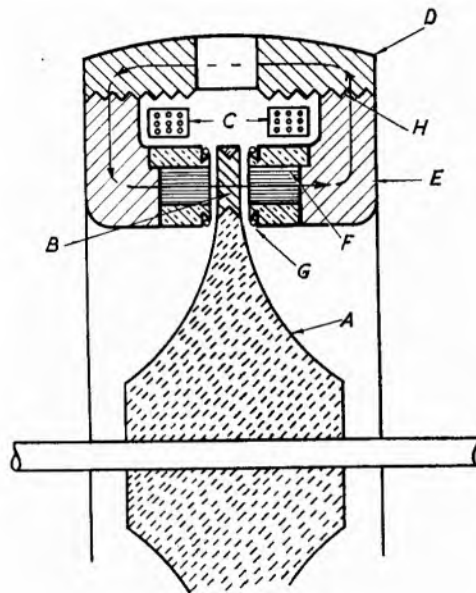
QUESTION 10.

Constancy of frequency is maintained in the following manner : Coupled to the alternator output is a tuned circuit adjusted so that the correct alternator frequency is half way up the side of the resonance curve. Thus, an increase or decrease in the frequency causes an increase or decrease in the current in this circuit. This current is rectified and utilised to vary the inductance of iron cored chokes in series with the supply to the induction motor driving the alternator. By correct adjustment, this enables the speed of the motor alternator to be maintained independent of the load. The frequency constancy obtained by this means is of the high order of .05 per cent.

Experimental radio frequency generators have been built for frequencies of 200,000 cycles/sec. and this must be regarded as the practical limit. This limit is imposed by the cost and bulk of the plant for frequencies above, say, 30,000 cycles/sec. for the relatively low power required.

The advantage of alternators over the valve transmitter is lower maintenance costs but the disadvantages are high capital cost, costliness and length of breakdowns when they do occur, and lack of flexibility as regards change of wave-length. The valve transmitter is admirably adapted for operation on a large number of frequencies, both long and short waves, and for radio telephony.

VIII. TELEPHONY, FINAL, SECTION 1—AUTOMATIC TELEPHONY. QUESTIONS AND ANSWERS.

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

Q. 1. Distinguish between a line finder and a line switch, giving simple circuit diagrams. (30 marks).

A. 1. A line finder is a selector arranged to find and connect to a particular circuit out of a group of circuits. So far as subscribers' lines are concerned, line finders permanently cabled to selectors—or obtaining access to them through secondary allotters—are used to find a calling line and connect it to a selector in readiness for dialling. In the step-by-step system, line finders may be either uniselectors
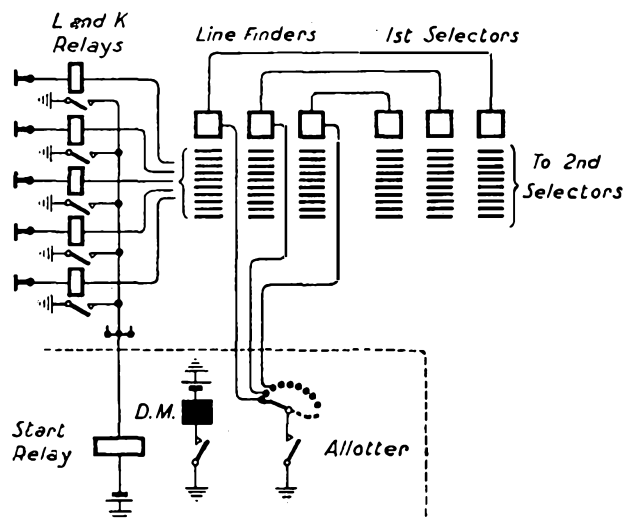
QUESTION I. SKETCH (a).

or 2-motion selectors as in sketch (a), which shows 200-outlet selectors in use as line finders. The 200 subscribers' lines are multipled over the banks of the line finders serving the group. A free line finder is pre-selected by the allotter—an 8-level, 50-point
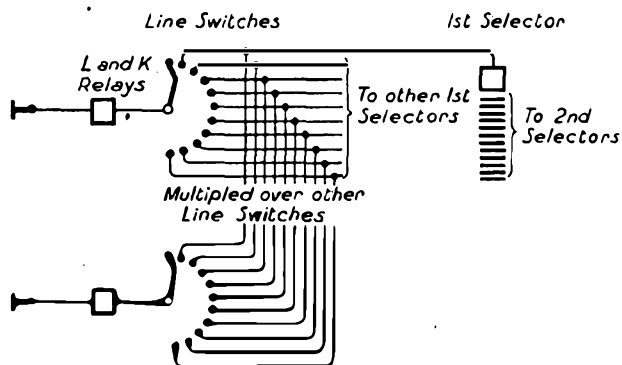
QUESTION I. SKETCH (b).

uniselector—associated with the line finder group. When this line finder operates owing to the receipt of a call from one of the subscribers, the next free line finder is pre-selected by the allotter and deals with the next call originated in the group. The seizure of a calling line by a line finder causes a first selector to be associated and prepared for the reception of the dialled impulses.

A line switch is permanently connected to a subscriber's line and is usually a uniselector, although line switches of the plunger type are in use. In the step-by-step system of the Post Office, the line switch is a 25-point uniselector and the wipers normally rest upon the home bank contacts (sketch b). When a call is originated, the wipers are swept round the bank contacts in search of a free first selector. When one is found, rotation ceases and the line is extended to the seized selector in readiness for dialling. The group of trunks outgoing to the first selectors are multipled over the banks of a number of line switches.

Q. 2. Distinguish between Resistance, Capacitance, Leakance, Reactance, Impedance, Conductance and Admittance and show what effect these have upon the wave-form of an impulse. (30).

A. 2. *Resistance* is the property possessed by substances of opposing the flow of an electric current. It is expressed in ohms (Ω) and is symbolized by R.

Capacitance, or electro-static capacity, is the property possessed by the dielectric separating two conductors of holding an electric charge. It is expressed in farads (F) and symbolized by C.

Leakance is the reciprocal of insulation resistance, and is usually expressed in micromhos.

Reactance is the effective resistance offered to an alternating current and may be either capacitive or inductive. It is a component of impedance and is expressed in effective ohms. It is symbolized by X.

Impedance is the opposition offered to the passage of an alternating current. Where reactance is present, the impedance, Z, is given by $Z = \sqrt{R^2 + X^2}$

Conductance is the reciprocal of resistance and is symbolized by G. It is expressed in mhos.

Admittance is the reciprocal of impedance and is expressed in mhos. It is symbolized by γ.

The presence of resistance diminishes the amplitude of an impulse wave, whilst distributed capacitance tends to make the wave form oscillatory. Leakance, by providing a shunt path for the current during the break period, retards the fall of the current. The effect of reactance depends upon whether the capacitive or inductive elements predominate. If the reactance is inductive, the rise of current is

delayed and the decay of current prolonged. The presence of capacitance somewhat mitigates this effect. As impedance is the combined effect of resistance, inductance, and capacitance, it diminishes the amplitude of the wave and may also make it oscillatory.

Q. 3. Describe a Private Automatic Branch Exchange and show how it differs from a Private Automatic Exchange. (30).

A. 3. A Private Automatic Branch Exchange (P.A.B.X.) is an exchange which is usually installed on the premises of a subscriber and is connected to a public exchange; it is operated on an automatic basis. The exchange equipment consists of three
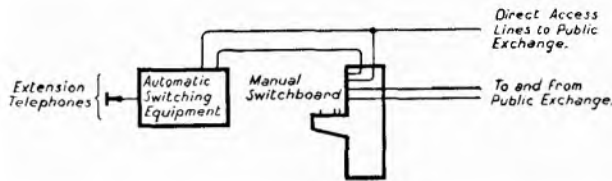
QUESTION 3.

portions; the automatic switching equipment for completing calls between the extension instruments; the manual switchboard for completing calls from the extension instruments to the public exchange, and for answering all calls incoming to the P.A.B.X.

from other subscribers; and the power plant required for the supply of direct current for speaking and signalling, and of alternating current for ringing and tone signals. In certain cases, some of the extension instruments may be provided with facilities for gaining direct access to the public exchange by dialling a specified digit, (see sketch); if the code digit be dialled from extension instruments not provided with such facilities, they are connected to the manual switchboard. For night service, specified extension instruments are connected each to one of the exchange lines, each such instrument becoming virtually a direct exchange line. By these means, service is given during the period that the manual switchboard is left unattended.

A Private Automatic Exchange (P.A.X.) is an exchange which serves a business or other organization and is not connected to a public exchange; it is operated on an automatic basis. The exchange equipment consists of the necessary automatic switching apparatus and the power plant, a manual switchboard being unnecessary. P.A.Xs. often incorporate a number of facilities not found on P.A.B.Xs., as, for example, executive priority, conference facilities, and staff call devices.

Q. 4. Describe the circuit and operating processes involved in dialling-out to a Manual Exchange. (30).

A. 4. A diagram of the connexions of a dialling-out circuit to a C.B. manual exchange is shown in sketch (a). The calling subscriber dials the 2-digit

QUESTION 4. SKETCH (a).

code allotted to the manual exchange, and the 2nd selector extends the connexion to a relay-set forming the outgoing junction termination. Relays L and HJ operate to prepare the booster metering circuit by the operation of relay J; to guard the connexion by earthing the P-wire; and to give the calling signal at the manual exchange by connecting battery to the B-wire, so operating relay L. Ringing tone is connected to the calling subscriber over the A-wire of the junction. When the B-operator answers, relay S operates to disconnect the calling signal. The cord circuit used differs from that employed on ordinary jack-ended B-positions in that when the operator places the key in the speaking position, battery is not connected to the R-wire of the answering cord; the marginal relay in the sleeve circuit of the answering cord only operates when the plug is inserted in a subscriber's jack. Having ascertained the number required, the B-operator completes the connexion. The calling cord sleeve relay operates to prepare for the metering condition. When the called subscriber answers, the operation of the calling supervisory relay connects battery to the R-wire of the answering plug, and thence *via* the A-wire to operate relay D in the relay-set. This relay operates relay DD, so providing booster metering conditions during the slow-releasing period of relay J. A skeleton diagram of the connexions of the cord circuit is shown in sketch (b).

QUESTION 4. SKETCH (b).

The twin calling lamps and answering jacks at the manual exchange provide for following-on calls. When a calling subscriber clears, the relay-set is freed immediately, but the B-operator may leave the answering plug in the jack for some little time before clearing. Should a call seize the outgoing end of the circuit while it is in this condition, the calling signal is received on the alternative calling equipment. When a calling subscriber clears, the release of relays L and B at the manual exchange operates relay CO, which disconnects the regular lamp and jack and connects the alternative equipment. A following-on call received under these conditions lights the alternative calling lamp; the operation of relay B locks relay C●, so holding the connexion through to the alternative equipment. Similar conditions are set up should an answering plug be left in the alternative jack. The provision of these facilities obviates the need for busying the circuit at the outgoing end until such time as the B-operator has cleared the connexion; in addition, the traffic-carrying efficiency of the junctions is increased, so reducing the number of circuits required.

Q. 5. If a fault of " wrong translation " is reported on a Director exchange, where would you look for the possible sources of the trouble? (35).

A. 5. Some of the possible causes of the trouble are :—

(a) Incorrect cross-connexion on the translation field of a director.
(b) Faulty dial or a fault on a subscriber's line.
(c) Incorrect stepping of the A-digit selector or of the BC-digit selector in a director.
(d) Too short a period for the inter-digit pause during pulsing-out from the director, due to incorrect adjustment of relays SA and SZ.
(e) Code or tandem selector seized before it had fully released.

Q. 6. Give a skeleton diagram showing how a junction circuit from a Rural Automatic Exchange is connected at the parent Manual Exchange and give details of the facilities provided by the circuit. (35).

A. 6. Junctions to a Rural Automatic Exchange (R.A.X.) are operated on a bothway basis; the diagram shows the connexions of the junction termination at a C.B., C.B.S. No. 2, or Auto-manual Switchboard. The facilities provided by the circuit are :—

(i) Lights the calling lamp on receipt of a generator ringing current from the R.A.X.
(ii) Provides a test key whereby the operator is enabled to distinguish between a call from (a) a regular subscriber, and (b) a coin box line.

QUESTION 6.

(iii) Extinguishes the calling lamp, trips the ringing, and connects the line for conversation when the C.C.B. test key is operated.

(iv) Provides an alternative answering jack for use in the completion of reverted calls.

(v) Provides for loop dialling to the R.A.X.

(vi) Gives standard lamp supervisory signals to the cord circuit.

Q. 7. Give an outline of the system of operation known as Call Indicator Working. (35).

A. 7. A schematic diagram of the apparatus required for Call Indicator Working, using coded signals, is shown in the sketch. The C.C.I. relay-set is seized from a level of a code selector; this causes the coder finder to search for and seize a free
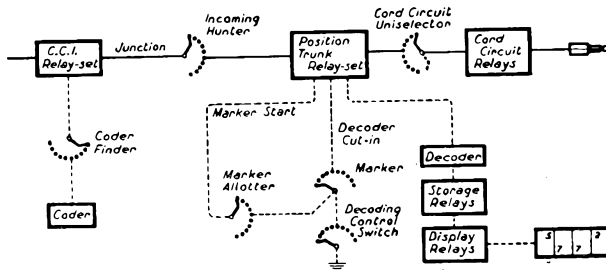
QUESTION 7.

coder. Until a coder is seized, the director is restrained from pulsing out the numerical portion. When pulsing-out is resumed, the numerical digits are stored in the coder pending their transmission in coded form.

With the receipt of the units digit, the coder loops the A and B wires of the junction, so causing the incoming hunter to search for and seize a free position trunk relay-set. The hunter, which is a uniselector, has access to position trunk relay-sets in each position of the call indicator suite, but only those free relay-sets in one particular position can be seized at any given instant; this condition is controlled by the position allotter, a uniselector which artificially busies the free relay-sets in all but one of the staffed positions. When a relay-set in the position being held open is seized, the allotter places a busying earth to the P-wire of the remaining free relay-sets in that position and removes the artificial busying earth from the free relay-sets in the next position. By this means, the cyclic distribution of incoming calls over the suite of staffed positions is ensured. Unstaffed positions are busied to the allotter.

Each call indicator position has some 40 trunk relay-sets. The common apparatus consists of two markers, one marker allotter, one decoding control switch, decoding relays, storage relays, display relays, and display panel. When a trunk relay-set is seized, one of the markers pre-selected by the allotter hunts for the relay-set. Having found it,

hunting ceases and the marker awaits the next stages of the call. Meanwhile, the decoding control switch is dealing with calls received prior to the one under consideration; when these have been cleared, the decoding control switch steps to the bank contacts of the marker which previously marked the trunk relay-set. A signal is now sent over the decoder cut-in wire and causes the decoding relays to be associated with the trunk relay-set and so with the junction and the coder at the distant exchange. The numerical portion dialled by the calling subscriber is now discharged from the coder in the form of positive and light and heavy negative current impulses. These current pulses cause the operation of storage relays, through the medium of the decoding relays, and, when decoding is completed, the marker, decoder and decoding control switch are ready to be released. This is done when the preceding display is cleared, so releasing the display relays and enabling them to receive the stored number from the storage relays. The marker is now released, and the decoding control switch steps to the next marker and proceeds to set up decoding conditions for the call received after the one being considered.

When the operator sees the display, she tests the called subscriber's line and if it is free connects to it. This causes the cord circuit uniselector to hunt for the trunk relay-set from which the display was received. When it is found, ringing current and ringing tone are connected and the connexion is completed for conversation when the called subscriber answers. Should the called subscriber's line be busy, the operator depresses the busy key; this causes the trunk relay-set from which the display was received to connect busy condition to the junction and thence to the calling subscriber. This facility results in the cords on the call indicator positions being used only for effective connexions, so decreasing the number of occasions on which all the cords are in use simultaneously, and the position closed to traffic in consequence.

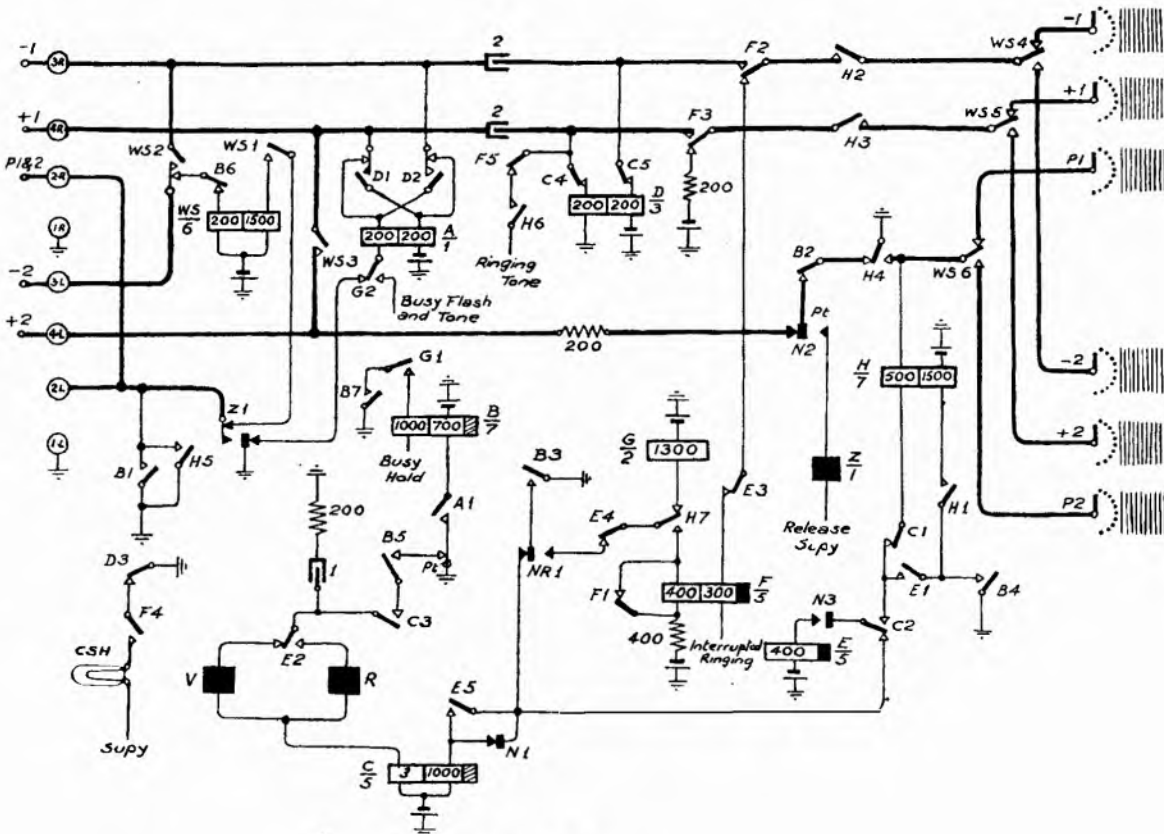*Q. 8. How would you time the operation and release of a relay? (35).*

A. 8. The most satisfactory method of measuring the operating and releasing lags of relays is by means of an oscillograph. This instrument consists of three (or five in some instruments) reflecting galvanometers, each reflected beam of light being focussed to a spot by means of a system of lenses. The spots of light from the galvanometers fall upon a drum, capable of revolution and carrying sensitized photographic paper on its outer surface. The speed at which the drum revolves is capable of adjustment. A tuning fork operating a shutter permits a flood of light to be thrown right across the photographic paper at intervals of 10 mS; this produces a series of straight lines across the oscillogram, so enabling the time between successive operations as shown by the lines traced out by the spots of light, to be calculated. To measure the operating lag of a relay, the current flowing through the relay coil is

passed through one galvanometer, whilst a contact of the relay is connected in series with the second galvanometer and a battery. From the resulting oscillogram, the operating lag is readily obtained. The releasing lag is obtained in a similar manner.

Q. 9. A ringing machine has a virtual voltage of 75 at a frequency of 16 cycles per second. The machine is applied to an electro-magnet having an effective resistance of 40 ohms and an inductance of 2 henries. What is the virtual current? Calculate the time lag between the current and the E.M.F. (40).

A. 9.

$$I = \frac{E}{Z} = \frac{E}{\sqrt{R^2 + \omega^2 L^2}} = \frac{75}{\sqrt{(40)^2 + (100^2 \times 2^2)}}$$

*Q. 10. Give a circuit diagram of a final selector having 200 outlets. (40).*

A. 10. See the sketch on this page.

Q. 11. Describe a method of keysending from an " A " position. (40).

A. 11. A block schematic diagram of the apparatus employed in one method of keysending from A-positions is shown in the sketch. Each A-position is provided with a strip of ten digit keys, a combined start and cancel key, and the necessary relays for associating them with any calling cord. An alternator generating frequencies of 500, 600, 750, and 900 p.p.s. provides voice frequency current for the exchange, each position being served through U-links.

When a calling plug is inserted into a junction jack outgoing to an automatic exchange, a signal is sent

QUESTION 10.

$$= \frac{75}{\sqrt{41,600}} = \frac{75}{204} = .367 \text{ mAs.}$$

Phase angle $\phi = \tan^{-1} \dfrac{\omega L}{R} = \dfrac{200}{40} = 5.$

$$\phi = 79°.$$

Time lag $= \dfrac{79 \times 1,000}{16 \times 360} = \dfrac{79,000}{5,760}$

$$\fallingdotseq 14 \text{ microseconds.}$$

from the junction relay-set over the start wire to the outlet relay-set to cause the junction finder to find the junction and the sender hunter to search for a free sender. When a free sender is found, the voice frequency relay-set hunter searches for a free relay-set. The junction and a free voice frequency relay-set having been found, a pip-pip tone of 400 p.p.s. is sent back to the A-operator and the calling supervisory lamp of her cord circuit is darkened. The operator depresses the start and cancel key, to wipe out any storage in the sender which might have been
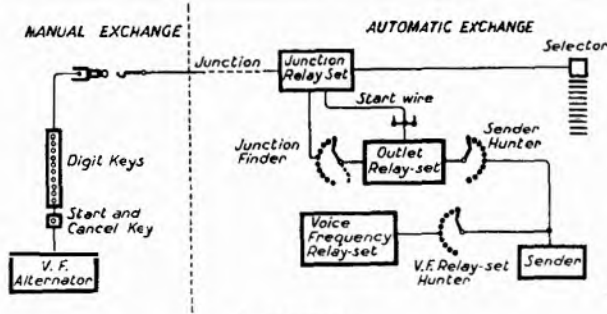
QUESTION 11.

caused by extraneous currents of voice frequency, and then depresses the digit keys in turn, tapping out the number of the called subscriber. The frequencies sent out and the sender digit storage relays operated for each digit are :—

Digit.	Frequency Combination.	Storage Relays.
1.	900	W
2.	750	X
3.	900,750	W,X
4.	600	Y
5.	500	Z
6.	900,500	W,Z
7.	750,500	X,Z
8.	900,600	W,Y
9.	600,500	Y,Z
0.	750,600	X,Y

The start and cancel signal employs three frequencies, 900, 750 and 500, operating storage relays W, X and Z.

The voice frequency relay consists of a tuned reed coupled to the armature of a receiver. When the frequency to which the relay is tuned is received, the armature vibrates and the reed, being tuned to synchronism, also vibrates. A small bobble is supported in a ring suspended from the end of the reed and the oscillations of the reed suffice to break the electrical circuit through the bobble and its suspension. This permits the operation of a relay, normally short circuited by the bobble, which in turn operates the relative storage relay in the sender. An alternative scheme is to employ valve detectors associated with tuned circuits and employing rectified reaction for the operation of the associated relays.

Having keyed the number, the operator restores the keys and the sender at the automatic exchange pulses out the impulse trains. This done, the sender is released, leaving the connexion through for conversation. All other apparatus is then free to deal with other calls.

Q. 12. Draw a circuit diagram of an " A " digit selector. (40).

A. 12. The required diagram is shown in the sketch below.
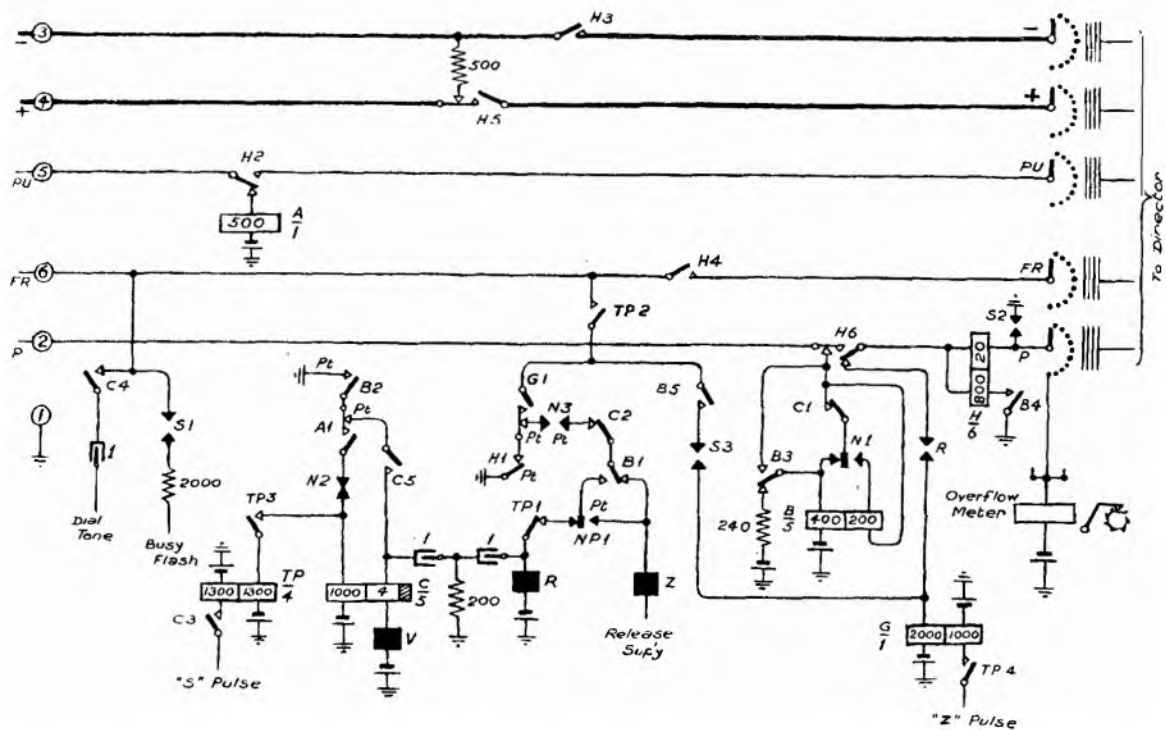
QUESTION 12.

IX. TELEPHONY, FINAL EXAMINATION—SECTION 2—TRANSMISSION.

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Q. 1. Define (a) Sending allowance, (b) receiving allowance, (c) cross-talk, (d) propagation constant, (e) attenuation constant, (f) wave-length, (g) phase distortion, (h) impedance. (30 marks).

A. 1. *Sending allowance* is the transmitting efficiency on a volume basis in comparison with the Department's standard C.B. No. 1 telephone on zero local line when the transmitter feed current is obtained from a 22v C.B. No. 1 cord circuit.

Receiving allowance is the receiving efficiency on a volume basis in comparison with the Department's standard C.B. No. 1 telephone on zero local line.

Cross-talk. (i) Quantitatively, it is the ratio, at the frequency specified, which the cross-talk current at the near or far end of the disturbed circuit bears to the current entering the disturbing circuit, taking into account the impedance difference which may exist between the two circuits concerned. This ratio is usually expressed in millionths, one millionth being known as one cross-talk unit.

(ii) The attenuation which would be measured, at the frequency specified, between the terminal of the disturbing circuit at which the disturbing tone is entering and the near or far end of the circuit upon which the cross-talk is observed; this attenuation may be expressed either in bels or nepers.

Propagation constant. The vectorial sum of the attenuation constant and the wave-length constant at a specific frequency. The propagation constant is a vector expressing the change in magnitude (attenuation constant) and phase (wave-length constant) per unit length of a transmission line.

Attenuation constant. (i) The attenuation constant of a uniform line of infinite length at a specific frequency is defined as the attenuation between points separated by unit length.

(ii) The attenuation constant of a line of periodic recurrent structure is defined as the attenuation at a specific frequency between corresponding points divided by the length of line separating those points.

(iii) In a network of periodic recurrent structure the attenuation constant is conveniently expressed as the attenuation per section; that is, the attenuation measured between successive corresponding points.

Wave-length constant. (i) The wave-length constant of a uniform line of infinite length at a specific frequency is defined as the change of phase, expressed in radians, of the current or voltage between points separated by unit length.

(ii) The wave-length constant of a line of periodic recurrent structure is defined as the change in phase of the current or voltage between successive corresponding points divided by the length of the line separating those points.

(iii) In a network of periodic recurrent structure the wave-length constant is conveniently expressed

as the phase change per section; that is, the phase change measured between successive corresponding points.

Phase Distortion. The distortion due to unequal transmission times obtaining at different frequencies.

Impedance. The ratio of the R.M.S. voltage across a circuit or circuit component to the R.M.S. current is that circuit or component.

Q. 2. Describe a modern C.B. hand-micro telephone, giving a circuit diagram. (30).

A. 2. The hand micro-telephone used in modern C.B. instruments consists of an immersed electrode transmitter and a receiver contained in a moulded bakelite handle. The transmitter is of the inset type and consists of a thin aluminium double-cone diaphragm, the two cones being clamped upon an annulus of silk; the diaphragm is rigidly coupled to
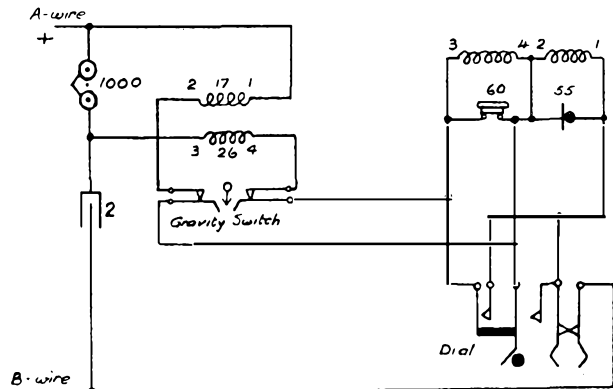
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a piston moving in the granule chamber and completely immersed in granules. The mouthpiece of the transmitter is designed to secure acoustic efficiency in view of the fact that the sound waves from the speaker's mouth have to be deflected approximately through a right angle in order to reach the diaphragm. The micro-telephone possesses practically the same efficiency in whatever position it is used and has the advantage of ensuring that the speaker's lips shall be maintained at a reasonable distance from the transmitter. The average position of the lips is known as the modal position; a distance of 0.5 inch further away introduces a loss of about 4.0 db. whilst when this distance is increased to one inch, the loss becomes approximately 8.5 db.

The base of the telephone contains the gravity switch, the anti-side tone transformer and, in automatic exchange areas, the dial. The moulded micro-telephone rest contains a horizontal bar which is depressed by the weight of the instrument, so operating the gravity switch.

The sketch shows the connexions of the instrument used in automatic exchange areas.

Q. 3. What are the approximate sending and receiving allowance for (a) a C.B. telephone, (b) a Local Battery telephone associated with a mile of twin 6½ lb. cable conductor? State exactly what the transmission losses comprise. (30).

A. 3. (a) Assuming a C.B. No. 1 telephone and a 22v C.B. cord circuit, the sending allowance is approximately 9.2 db. and the receiving allowance about 2.4 db.

(b) The sending allowance of a local battery telephone depends upon the number of primary cells used for the transmitter feed battery. For a No. 10 inset transmitter used in conjunction with a Bell Set No. 5 and two primary cells, the sending efficiency is 7.5 db.; this is decreased by 2 db. for each primary cell added to a maximum of four cells. The transmission equivalent of one mile of 6½ lb. cable is approximately 2 db. Hence the sending allowance for the telephone specified using two primary cells is 9.5 db.; using three cells, it is 7.5 db.; and using four cells, it is 5.5 db. The receiving allowance is approximately 2.0 db. better than for No. 1 C.B. conditions, giving an allowance of 0.4 db. under the conditions of the question.

In the C.B. case, the sending allowance comprises (i) a loss depending upon the value of the direct current fed to the transmitter; (ii) the transmission equivalent of the exchange and extension lines; and (iii) the audio frequency transmission loss introduced by the transmission bridge at the main exchange and at the private branch exchange, and by any other series or bridged apparatus in circuit.

The receiving allowance comprises (i) the transmission equivalent of the main and extension lines; and (ii) the audio frequency transmission loss due to series or bridged apparatus in circuit.

In the Local Battery case, the sending allowance comprises (i) the transmission equivalent of the main and extension lines; (ii) the audio frequency transmission loss due to series or bridged apparatus in circuit; and (iii) a fixed allowance for the sending efficiency of the local battery telephone instrument, added to correlate the transmission efficiency with C.B. transmission conditions.

The receiving allowance comprises (i) the transmission equivalent of the exchange and extension lines; (ii) the audio frequency transmission loss due to series or bridged apparatus in circuit; and (iii) a fixed allowance for the receiving efficiency of the local battery telephone instrument, added to correlate the receiving efficiency with C.B. transmission conditions.

Q. 4. Describe the balancing and jointing of a main underground quad cable. What are the objects of cable balancing? Define near-end and far-end cross-talk. How is cross-talk measured? (30).

A. 4. The 176-yard cable lengths are jointed together in pairs and the resulting cable lengths are tested for insulation resistance, conductor resistance, and capacity unbalance within and between quads. From the results of the capacity unbalance tests, selected joints are scheduled and made between successive cable lengths in order to ensure that the capacity unbalance over the length of cable between the loading points shall not be greater than a specified value. The final joint to be made is the one at the centre of the loading section and here tests are made for mutual electro-static capacity and resistance unbalance, any inequalities found being smoothed out by suitable crosses.

The objects of cable balancing are (i) to limit the amount of cross-talk between pairs within a quad and between quads, and (ii) to ensure a reasonably smooth length distribution of resistance and mutual electrostatic capacity in order to obtain as close an approximation to the smooth mean curve of impedance/frequency as possible, where 2-wire repeatered circuits are required; this is necessary in order that the deviation between the smooth mean curve simulated by the line balancing network and that provided by the line itself shall not be so great as seriously to limit the maximum gain of the repeater by introducing a tendency to sing.

Near-end cross-talk is the amount of cross-talk measured when the source of disturbance and the listener are located at the same end of the circuits under test. Far-end cross-talk is the amount of cross-talk measured when the current is applied to the disturbing circuit at one end and the cross-talk is measured at the other end.

Cross-talk is measured by applying a source of alternating current—usually a reed hummer or valve oscillator delivering a current of 1,000 p.p.s.—to one circuit and listening on the disturbed circuit by means of a bell receiver. By means of switching keys, the tone heard from the line can be compared with a tone tapped off the disturbing source; a suitable rheostat is graded in millionths and is used to vary the volume until it is the same as that on the line. The reading of the rheostat then indicates the number of millionths of disturbing current heard in the circuit disturbed.

Q. 5. Describe, with the aid of a schematic diagram, a single channel bothway carrier current telephone circuit. Define modulation. (35).

A. 5. The sketch shows a schematic diagram of the apparatus at one terminal of a single channel bothway carrier current telephone circuit. The carrier circuit and the normal voice frequency channel are separated by high and low pass filters. In the arrangement shown, a carrier frequency of 10,300 p.p.s. is used in one direction whilst a carrier frequency of 6,870 p.p.s. is employed in the other. The transmitting and receiving bands are separated by the band filters. Both transmission and reception is carried out with the lower side-band, the
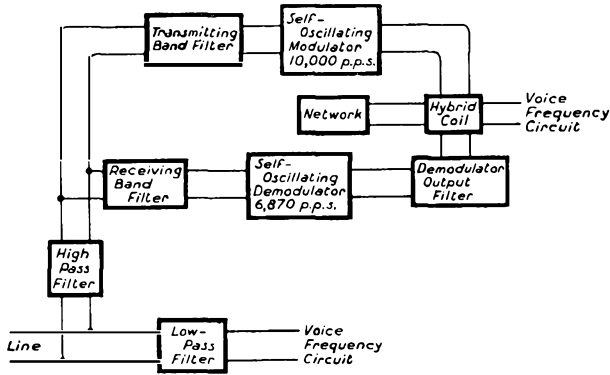
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carrier being suppressed, and the apparatus caters for the range of voice frequencies from 150-2,800 p.p.s.

The input from the voice frequency circuit is applied to a hybrid coil and thence to the input of a self-oscillating modulator producing the carrier frequency. The products of modulation—the upper and lower side-bands—together with the carrier frequency are applied to the transmitting band filter (7,500-10,150 p.p.s.) where the carrier frequency and the upper side-band are suppressed. The output from the band filter passes through the high pass filter to the line.

Reception is carried out with the lower side-band of 4,070-6,720 p.p.s. The output of the receiving band filter is applied to the self-oscillating de-modulator which re-introduces the carrier frequency of 6,870 p.p.s. which was suppressed at the sending end. Among the products of de-modulation is the original voice frequency current and the de-modulator output filter suppresses all but this current, which passes through the hybrid coil and thence to the voice frequency circuit.

The arrangement at the distant terminal point is similar, except for the different filter values due to reception on the band 7,500-10,150 p.p.s. and transmission on 4,070-6,720 p.p.s.

Modulation is the alteration in the amplitude of a fixed frequency carrier current by the voice frequency current; this effects the translation of a band of frequencies from the voice frequency range to some other range depending upon the fixed carrier frequency. If a voice frequency band, s, is applied to a single frequency carrier current, p, the resulting products include the band of frequencies $p + s$ known as the upper side-band; the frequency band $p - s$ known as the lower side-band; and the carrier frequency. Since both side-bands each contain the characteristics of the original voice frequency current, there is no necessity for both to be transmitted. Further, the carrier frequency can be re-introduced at the receiving end during the process of de-modulation. Hence, either the upper or the lower side-band is all that it is necessary to transmit; unwanted frequencies are suppressed by means of suitable band-pass filters.

Q. 6. Describe a typical line transformer for a 2-wire repeater circuit and state the electrical requirements for transmission at audio frequencies and at 16 cycles per second, and also for superposition. (35).

A. 6. The core consist of toroidal stampings and in the case of the coils used with 2-wire repeaters has a suitable air-gap or a gap filled with a suitable material of low permeability. The core stampings are suitably insulated to prevent eddy currents. The complete core is covered with a double thickness of cotton tape over which the coils are wound. A final layer of cotton tape is wound around the finished windings. The coils are impregnated and placed in a drawn steel case, which is then filled with an insulating compound. The windings are brought out to terminals, as shown in the sketch, and an earthing tag is provided on the case.

The transmission efficiency of the transformer at audio frequencies is governed by the *resistance* of the windings. The performance at 16 cycles per second is governed by the *inductance* of the wind-
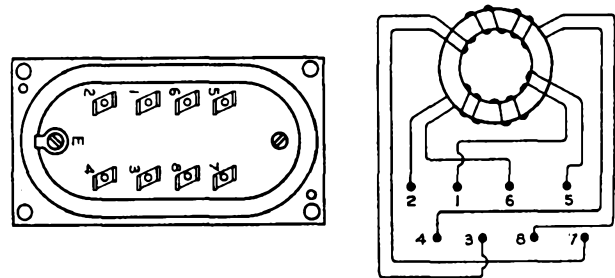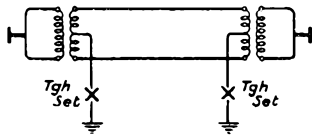

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ings. In the design of a transformer it is necessary, therefore, to compromise between a high inductance and large number of turns, with correspondingly higher resistance, and the resistance necessary for efficiency at audio frequencies, which is the more important requirement. The transmission loss in transformers ranges from 0.3 db. to 1 db., according to the turns ratio selected for matching apparatus and line impedances.

The essential requirements of the transformer for superposition are equality of resistance of the line windings, and balance of capacity between the line windings and between these windings and the core. The line windings are joined in the series-aiding condition and the junction led to the superposed circuit.

Q. 7. Describe, briefly, the methods of combined telephone and telegraph working by superposition and compositing. Explain how mutual interference is prevented between telephone speech and signalling currents and telegraph signals. What effects have such methods upon the speed of telegraph signalling? (35).

A. 7. A telegraph circuit can be superposed on a metallic telephone circuit by means of repeating coils as shown in sketch (*a*). Speech currents pass

QUESTION 7.   SKETCH (*a*).

through the primary winding and induce corresponding currents in the secondary, which, in turn, pass through the secondary of the distant repeating coil; these induce currents in the primary winding, so affecting the distant telephone. The centre points of the two secondary windings are connected to telegraph sets which are connected in the ordinary manner. The telegraph currents divide equally through the secondary windings; as these two halves oppose each other, there is no current induced in the primary winding. The current passes along both wires in parallel, re-uniting at the distant end and operating the distant telegraph receiver. Provided that the two wires have equal resistance, leakance and capacitance, there is no interference between telegraph and telephone circuits.

In composited working, high and low pass filters are used (see sketch *b*) to prevent mutual interference
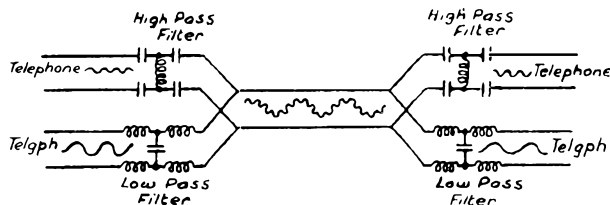
QUESTION 7.   SKETCH (*b*).

between the circuits. The high pass filter in the telephone circuit cuts off all frequencies below about 200 p.p.s., whilst the low pass filters in the telegraph circuits cut off all frequencies above about 40 p.p.s.; the low pass filter therefore suppresses the high frequency components of the currents from the telegraph circuit, so preventing noise in the telephone channel. A Morse telegraph speed of 62.5 words per minute with double current working produces an alternating current closely approximating to one of 25 p.p.s. The action of the low pass filter in suppressing the higher harmonics results in the production of a rounded wave-form, so enhancing the similarity to a sinusoidal alternating current.

On account of the introduction of high-pass filters in the telephone channel, ordinary generator ringing current (17 p.p.s.) cannot be used; instead, a current of 500 p.p.s. is employed.

The use of repeating coils for superimposing a telegraph circuit on a telephone line has little effect on the speed of telegraph signalling. The com-

posited method, on the other hand, limits the maximum speed to 100 words per minute since this speed produces an alternating current of 40 p.p.s., the cut-off point of the low-pass filter. In addition, the KR of a composited circuit is greater than that of a superimposed circuit, so reducing the telegraph speed still further.

Q. 8. Describe, briefly, the routine transmission testing of telephone repeater equipment and lines. State the object of each test described. (35).

A. 8. *Repeatered Lines.* Routine tests of the overall transmission equivalent at 800 p.p.s. are made to ensure that the value does not rise or fall below that allotted to the circuit; corrections are made by adjusting repeater gains. Two-wire and four-wire circuits are tested for open circuit stability to ensure that a stability margin of at least 2 db. is maintained, thus preventing the circuit from singing. A speaking test is made, using standard transmission circuits at each end, to ensure that the circuit is satisfactory commercially. Finally, the overall transmission equivalent is measured at a number of frequencies depending upon the type and characteristics of the circuit; this ensures that the circuit remains as when it was first lined up, the test results being compared with those obtained when the circuit was first brought into use.

Repeaters. The plate, filament and grid battery voltages are checked each day to ensure that the repeaters are being fed at correct potentials. The repeater gains are checked at 800 p.p.s. after confirming that the gain controls are correctly set; this test ensures that any valves, which are nearing the end of their useful life as indicated by a decreased gain, shall be detected and such valves are then subjected to a rejection test.

Q. 9. Describe a typical loading coil used for main underground cables. What factors determine the weight of conductor, the loading inductance and the loading coil spacing? Why is the spacing of loading coils kept constant? (40).

A. 9. A section of a typical loading coil is shown in the sketch. The core consists of seven rings of finely-powdered electrolytic iron, insulated with shellac by treatment in a whirling barrel, and compressed to ring form under heavy pressure. The resulting dust-core is capable of recovering after the magnetic effect of a comparatively heavy current flowing in the coil; in consequence, the inductance of the coil is more constant than that of the earlier wire-cored coils. The plates are covered with a canvas wrapping over which the coils are wound; over these, an outer canvas wrapping is applied. The overall diameter of a loading coil is about 10 cms., whilst its overall height is about 8.5 cms.

The factors governing the choice of weight of conductor, loading inductance and loading coil spacing are (i) the transmission equivalent of the circuits between repeater stations, (ii) the permissible

Core
Plates

Canvas
Wrapping

Coil
Windings

Red Fibre
Separators
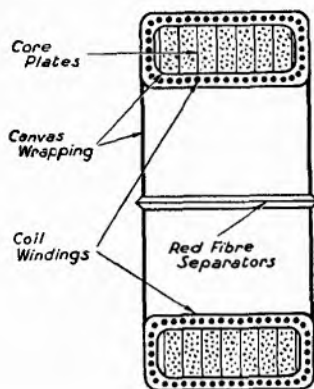
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cut-off point of the circuits, and (iii) the fact that the projected cable route may already serve a loaded cable, so determining the loading coil spacing on economic grounds. In practice, the standard loading coil spacing is 2,000 yards; the cut-off requirements are first met by a suitable choice of loading inductance; finally, the weight of conductor is chosen to meet the transmission requirements.

The spacing of loading coils is kept constant in order to avoid reflection losses which would otherwise occur.

Q. 10. Define " singing point." A long cable circuit has a maximum impedance, deviation of 5 per cent. from the mean impedance curve. What singing point would be obtained on repeaters work on the cable? How would the singing point be modified by a pronounced impedance irregularity at a point 5 decibels from the repeater? (40).

A. 10. *Singing Point.* (i) Of a 2-wire repeater, is a measurement of the stability of a repeater against oscillation and harmful effect due to back coupling brought about by inexact balance between the balancing network and the line.

(ii) Of a long line, is the attenuation corresponding to the ratio of the power transmitted to the line at some specified frequency and the power returned to the sending end by reflection from irregularities.

The singing point of a two-wire repeater is the loss between the output of one amplifying element and the input of the other, less the energy dividing losses when the outgoing power divides between the line and balancing network, and when the return energy divides between the input and output elements of the repeater. These losses total about 7 db., giving the singing point as the loss across the transformer (output to input) less 7 db.

The singing point is given by the formula

$$20 \ \log \ \frac{Z_0 + Z_T}{Z_0 - Z_T},$$

where Z_0 is the repeater impedance and Z_T is the impedance of the line. Let $Z_0 = 1000$ (say). Then for a 5% impedance deviation, $Z_T = 950$.

Singing point $= 20 \ \log \ \dfrac{1000 + 950}{1000 - 950} = 20 \ \log \ \dfrac{1950}{50}$

$= 20 \ \log \ 39 = 20 \times 1.59$

$= 31.8$ db.

Suppose that the pronounced impedance irregularity is due to a short circuit at a point 5 db. from the repeater. The singing point at the irregularity would be $20 \ \log \ \dfrac{1000 + 0}{1000 - 0} = 20 \ \log \ 1 = $ zero, since $\log 1 = 0$.

That is, the ratio of power transmitted to power returned at the irregularity is unity. But there is a loss of 5 db. to the irregularity and a loss of 5 db. to the repeater, giving a singing point at the repeater of 10 db. The singing point at the repeater is therefore given by the singing point at the irregularity plus twice the transmission equivalent between the repeater and the irregularity.

Q. 11. Describe, briefly, the procedure of localising—

    (a) a high resistance fault,
    (b) a high insulation fault,
    (c) an impedance irregularity.

State the theory upon which procedure (c) is based. (40).

(a) Assuming that the high resistance fault is a complete disconnexion and that a good pair is available for the purpose of the test, a galvanometer, galvanometer key, double-pole 6-terminal key, a slide wire and a battery of 2-10 volts are connected as shown in sketch (a). The double-pole switch is moved from the " charge " to the " mix " position and then the galvanometer key is closed; the time allowed for mixing varies with the circuit under test. In the condition of balance,

$$x = \frac{Q}{P + Q} \ 2l.$$

On account of the difficulty of obtaining stable test results with methods employing direct current, an A.C. impedance test, as described in (c) below, is preferable.

(b) A double-ended test is made and the testing bridges are connected as in sketch (b). The short-circuiting keys, K_1 and K_2, are provided to enable one end of the line to be looped whilst a test is being made from the other. After the line has become charged—and this may take considerable time for a long cable—tests are made from each end of the cable in turn. The distance to the fault is then given by

$$x = \frac{R_b}{R_a + R_b} \ l.$$

(c) On the assumption that the impedance irregularity is a contact, an impedance/frequency test, sketch (c), is made on the cable and the bridge resistance is plotted against frequency. The distance, x, to the fault is then $\dfrac{K}{f}$, where f is the
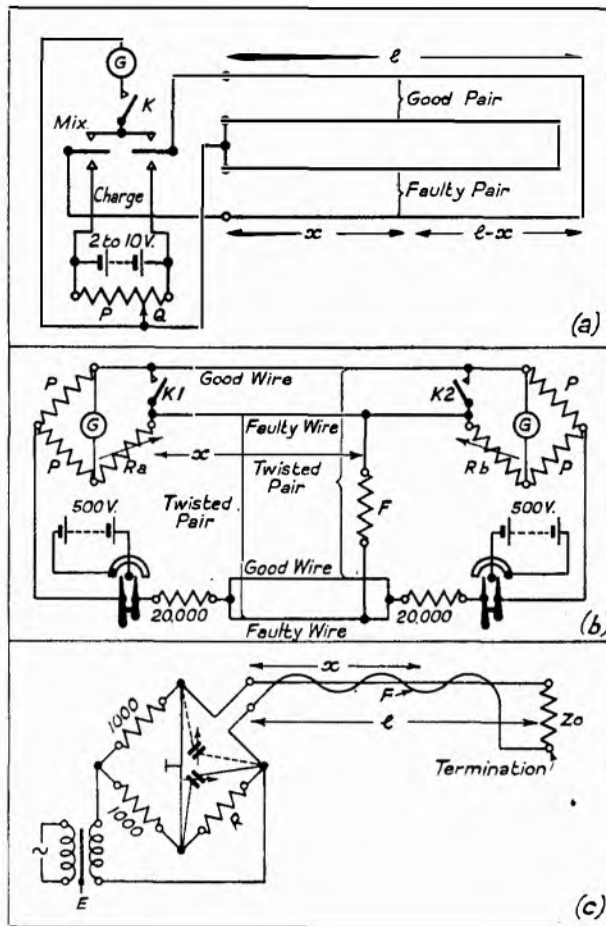
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mean frequency interval between successive maximum points on the curve and K is an empirical constant. K is determined by introducing a known contact resistance into a similar circuit at a known distance, l, away—generally the length of the line—and plotting the impedance/frequency curve to determine the resulting mean frequency interval, f_1, between successive maximum points. The constant K is then determined from $K = lf_1$. For loaded cables, $K = \dfrac{1}{2\sqrt{LC}}$ where L is the inductance in henrys and C is the capacitance in farads per mile loop.

The theory of this method of fault location is based upon the reflection occurring from an impedance irregularity. When the reflected waves return to the source, they will differ in phase from the transmitting wave by an angle depending upon

the frequency, the distance to the irregularity, and the characteristics of the line. When the reflected and transmitted waves are in phase at the testing end, the current will be a maximum and the impedance a minimum. Similarly when the two waves oppose one another, the current will be a minimum and the impedance a maximum. Hence, in an impedance/frequency run the impedance will show maximum and minimum values at the points. In practice, it suffices to plot only the bridge resistance readings for purposes of fault localization.

Q. 12. A cable has the following constants :—

$R = 88, \quad C = 0.054, \quad L = 0.001, \quad G = 5 \times 10^{-6}$.

What inductance per mile must be added to make the circuit distortionless? If coils of 175 millihenries are used, what spacing will be necessary? Calculate the transmission equivalents per mile of the circuit before and after loading (neglect resistance of loading coils).

A. 12. In the theoretically distortionless condition, which has no practical application, $RC = LG$, where R, C, L and G are the primary constants per mile. If L be increased to meet the distortionless condition its value would be $L = \dfrac{RC}{G}$ where $R = 88\,\Omega$; $C = 0.054 \times 10^{-6}$ F; and $G = 5 \times 10^{-6}$ mhos.

$$L = \frac{88 \times 0.054 \times 10^{-6}}{5 \times 10^{-6}} = 0.95 \text{ H.}$$

The added inductance per mile would be $0.95 - 0.001 = 0.949$ H or 949 millihenries. The coil spacing, using 175 mH coils would be $\dfrac{0.175}{0.949} = 0.1845$ mile.

[NOTE : In practice, the maximum added inductance per mile is 222 mH and for present day cables it is 106 mH or less. The standard coil spacing is 1.136 miles.]

Before loading, the approximate formula for the attenuation of unloaded cable circuits would apply, viz., $\beta = \sqrt{\tfrac{1}{2}\omega CR}$ nepers.

Then, at the representative testing frequency of 800 p.p.s. ($\omega = 5,000$) :—

$$\beta^2 = \frac{5000 \times 88 \times 0.054 \times 10^{-6}}{2} = 11,890 \times 10^{-6}$$

$\beta = 109 \times 10^{-3} = 0.109$ nepers per mile.

In the theoretical distortionless condition, neglecting the effective resistance of the loading coils which would greatly increase R,

$\beta^2 = RG = 88 \times 5 \times 10^{-6} = 440 \times 10^{-6}$

$\beta = 21 \times 10^{-3} = 0.021$ neper per mile.