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QUESTIONS AND ANSWERS

The following answers generally give more detail than would be expected in the time available under examination conditions but, to conserve paper, arithmetical working has been abbreviated.

RADIO II, 1950

Q. 1. The inductance of an air-cored solenoid of negligible self-capacitance is given approximately by the formula :—

$$L = \frac{r^2n^2}{10\ (r + l)}\ \textit{microhenries}$$

where n is the number of turns and r and l the radius and length of the solenoid in inches.

If r=l=1 inch how many turns are required on the coil if it is to tune to 1 Mc/s when connected in parallel with a 400μμF capacitor ?

A. 1. It is first necessary to calculate the inductance that tunes to 1 Mc/s when connected in parallel with a 400μμF capacitor, from the expression :—

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where f = resonant frequency, c/s
L = inductance, henries
C = capacitance, farads.

This formula may be rearranged :—

$$L = \frac{1}{4\pi^2 f^2 C}$$

and substituting the given values :—

$$L = \frac{1}{4\pi^2 \times 10^{12} \times 400 \times 10^{-12}} = \frac{1}{1{,}600\pi^2}\ \text{henries}$$
$$= \frac{10^6}{1{,}600\pi^2} = \frac{10^4}{16\pi^2}\ \text{microhenries.}$$

Again, on substituting the dimensions of the solenoid in the formula given in the question :—

$$L = \frac{1^2 \times n^2}{10\ (1 + 1)} = \frac{n^2}{20}\ \text{microhenries.}$$

So that,

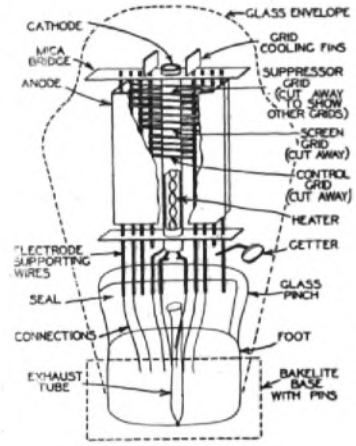
$$\frac{n^2}{20} = \frac{10^4}{16\pi^2}$$

$$\text{or}\quad n = \sqrt{\frac{20 \times 10^4}{16\pi^2}} = \frac{100}{4\pi}\sqrt{20} = 35{\cdot}5 \text{ approx.}$$

Therefore, 36 turns will be required.

Q. 2. Describe with a sketch the main constructional features of an indirectly heated pentode valve for use in the output stage of a broadcast receiver.

A. 2. The sketch shows the main constructional features of an output pentode valve. The cathode is an oval nickel tube coated with a mixture of barium and strontium oxides to give a copious electron emission at relatively low temperatures (about 1,000°K). The cathode is heated internally, the tungsten wires being insulated from the nickel tube with alumina. The cathode is surrounded by the control grid, which is an elliptically shaped winding of fine molybdenum wire wound in notches on thicker nickel supporting wires. At greater distances from the cathode are the screen grid and suppressor grid, both basically of similar construction to the control grid, and surrounding the whole assembly is the anode, which usually takes the form of a rectangular nickel box.



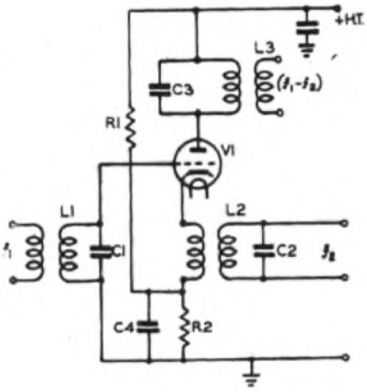
The electrode supports are braced by two mica bridges and are mounted on the glass pinch into which the electrode connections are sealed, using copper-clad iron wire which has a coefficient of thermal expansion similar to that of the glass. The pinch is formed on the end of a wide glass tube known as the foot of the valve, to which is sealed the glass envelope, after the electrodes have been mounted on the pinch. The air is exhausted by vacuum pump, and during the pumping the electrodes are heated by eddy currents to release occluded gas : the exhaust tube is then sealed and a small piece of magnesium, known as the getter, is volatilised by eddy current heating to absorb residual gas and so to improve the vacuum. An output pentode valve has to pass a relatively large anode current —perhaps 50 mA at 250 V—and thus has a larger cathode and anode than the average receiving valve. Again, as the valve is intended for use at audio frequencies, anode-grid capacitance is not so important as in radio-frequency stages, and the screen grid will have a relatively open mesh. The suppressor grid is often internally connected to the cathode.

Q. 3. Explain, with the aid of a circuit diagram, how a valve having a square law anode-current/grid-voltage characteristic could be used as a frequency-changer.

A. 3. The sketch shows the circuit diagram of a triode valve arranged as a square-law or "additive" frequency changer. The valve is biased, by resistors R1, R2, to operate near anode current cut-off, in which region its anode current (i_a) grid-cathode voltage (e_g) characteristic may be represented approximately by :—

$$i_a = a + be_g + ce_g^2 \ldots . (1)$$

The signal input, of carrier frequency f_1, is applied to the grid of the valve by the tuned trans-



former L1, C1, and the local oscillator, of frequency f_2, is coupled into the cathode circuit by the tuned transformer L2, C2. These two radio-frequency voltages are thus applied in series between grid and cathode, so that the alternating component of the grid-cathode voltage is given by

$$e_g = E_1 \sin 2\pi f_1 t + E_2 \sin 2\pi f_2 t \quad \ldots\ldots\ldots\ldots\ldots (2)$$

hence the name, additive mixing.

The resultant anode current may be obtained by substituting from (2) in (1), thus :—

$$i_a = a + b\,(E_1 \sin 2\pi f_1 t + E_2 \sin 2\pi f_2 t) + c\,(E_1 \sin 2\pi f_1 t + E_2 \sin 2\pi f_2 t)^2.$$

In this expression, a represents the standing current and the second term, of coefficient b, represents terms of frequencies f_1 and f_2; the third term, however, may be expanded thus :—

$$c\left[E_1^2 \sin^2 2\pi f_1 t + E_2^2 \sin^2 2\pi f_2 t + 2E_1E_2 \sin 2\pi f_1 t \sin 2\pi f_2 t\right]$$

and from the trigonometrical identities

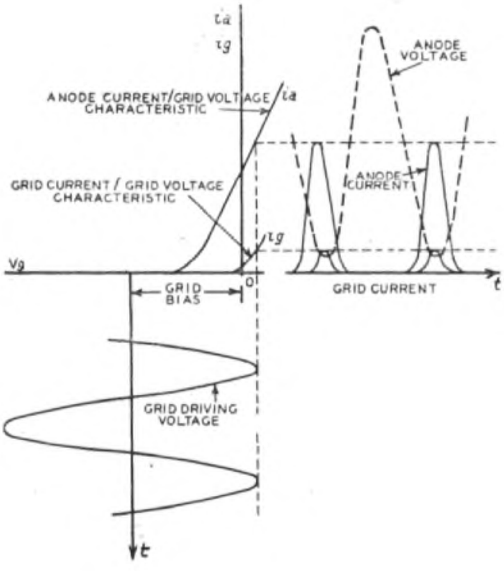
$$\sin^2 A = \tfrac{1}{2}(1 - \cos 2A) \text{ and } 2 \sin A \sin B = \cos(A - B) - \cos(A + B)$$

it is clear that the first two terms represent components of frequencies $2f_1$ and $2f_2$, and the third term represents components of frequencies $(f_1 - f_2)$ and $(f_1 + f_2)$. Thus, the anode current contains components of the sum and difference frequencies, of amplitude proportional to the coefficient c in equation (1), and so a circuit L3, C3 tuned to $(f_1 - f_2)$ may be connected as the anode load to extract the required output.

This circuit differs from the more common triode-hexode mixer which operates as a multiplicative mixer, having an anode current proportional to the *product* of the voltages on g_1 and g_3, and which does *not* depend on a square-law characteristic.

Q. 4. What is meant by the "class C" operation of a radio-frequency amplifier? The final class C amplifier of a transmitter takes a mean anode current of 400 mA at 1,200 V and delivers a current of 0·75A (r.m.s.) to a load of 600 ohms resistance. What is the efficiency of the stage?

A. 4. "Class C" operation of a radio-frequency amplifier is the condition in which, with a sinusoidal excitation, anode current flows in the form of pulses lasting less than half a cycle. The valve has a grid bias voltage that is two or three times the anode current cut-off point, and a large radio-frequency voltage is applied to the grid. The anode load is a tuned circuit, which converts the anode current pulses into a sinusoidal voltage variation. The sketch shows the voltage and current relations in a class C amplifier. Class C operation is characterised by high efficiency, perhaps 60-80 per cent., due to the fact that anode current flows only when the anode voltage is at its lowest value, thus minimising the power loss at the valve anode.



The efficiency of a class C amplifier is given by :—

$$\frac{\text{R.F. power output}}{\text{D.C. power input}} \times 100 \text{ per cent.}$$

$$\begin{aligned}\text{R.F. power output} &= I^2R \\ &= 0{\cdot}75 \times 0{\cdot}75 \times 600 \\ &= 337{\cdot}5 \text{ watts,}\end{aligned}$$

$$\begin{aligned}\text{and the D.C. power input} &= E_aI_a \\ &= 1{,}200 \times 0{\cdot}4 \\ &= 480 \text{ watts.}\end{aligned}$$

$$\therefore \text{Efficiency} = \frac{337{\cdot}5}{480} \times 100 = \underline{70{\cdot}3 \text{ per cent.}}$$

Q. 5. A superheterodyne receiver is required to cover the wave-band 200 to 500 metres, and the intermediate frequency is to be 450 kc/s. Calculate

(a) the maximum and minimum frequencies of the beating oscillator,

(b) the maximum capacitance of the oscillator tuning capacitor assuming that the minimum value is 100μμF.

A. 5. (*a*) The frequency, wavelength and velocity of a radio wave are related by the formula :

$$f\lambda = c$$

where f = frequency, c/s, λ = wavelength, metres, c = velocity, metres/sec. = 3×10^8 (approx.).

Whence the frequency corresponding to :—

(i) 200 metres = $3 \times 10^8/200 = 1{\cdot}5 \times 10^6$ c/s,

(ii) 500 metres = $3 \times 10^8/500 = 0{\cdot}6 \times 10^6$ c/s.

i.e., 1,500 and 600 kc/s respectively.

Now, the beating oscillator frequency must be set so that it is 450 kc/s away from the signal frequencies, i.e., it may be :—

(i) 1,500 + 450 = 1,950 kc/s, or 1,500 − 450 = 1,050 kc/s.

(ii) 600 + 450 = 1,050 kc/s, or 600 − 450 = 150 kc/s.

If the oscillator were set above the signal frequency in each case, the extreme values would be 1,950, and 1,050 kc/s, a frequency ratio just less than 2/1, but if set below the signal frequency the frequency ratio would be 1,050/150, which is 7/1. These two frequency ranges would require tuning capacitance ratios of about 4/1 and 49/1 respectively, and the latter is not practicable. Hence the maximum and minimum frequencies of the beating oscillator are : <u>1,950 kc/s and 1,050 kc/s.</u>

(*b*) The frequency of an oscillator is given by the formula

$$f = 1/2\pi\sqrt{LC}$$

where f = frequency, c/s, L = inductance, henries, C = capacitance, farads, and so if C_1 and C_2 are the tune capacitances corresponding to frequencies f_1 and f_2, using the same inductor, then

$$\frac{f_1}{f_2} = \sqrt{\frac{C_2}{C_1}} \quad \text{or} \quad \frac{C_1}{C_2} = \left[\frac{f_2}{f_1}\right]^2$$

In the question, C_1 is unknown, C_2 = 100μμF, f_1 = 1,050 kc/s, f_2 = 1,950 kc/s, and so :—

$$\frac{C_1}{100} = \left[\frac{1{,}950}{1{,}050}\right]^2$$

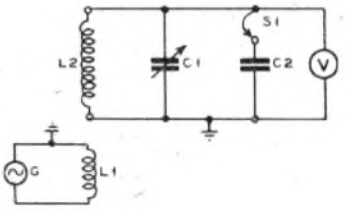
$$\text{or } C_1 = 100\left[\frac{13}{7}\right]^2 = \underline{344{\cdot}9\mu\mu\text{F.}}$$

Q. 6. Describe how, with the aid of a signal generator and a cathode-ray oscilloscope, you would locate the source of amplitude distortion in a broadcast receiver.

A. 6. First, consider the likely sources of amplitude distortion in a broadcast receiver : amplitude distortion in a stage is most likely to be the result of either (*a*) incorrect grid bias, (*b*) excessive grid voltage swing, or (*c*) low anode or screen voltage. Again, the signal voltages increase greatly as they pass through the receiver from, perhaps, a few millivolts in the aerial circuits to several volts at the grid of the output valve, and so overloading is most likely to occur in the later stages of the set, and it would be prudent to check these first.

Any receiver will, of course, show amplitude distortion if too large a signal is applied to it, and the receiver should be tested at a power output level within its rated limit. Disconnect the loudspeaker and connect a resistance of suitable value in its place, then connect the Y-plates of the oscilloscope across this resistor. The X-plates of the oscilloscope should be connected to a linear (sawtooth) time base. It is assumed that the signal generator may be relied upon to have a sine-wave audio output, and a R.F. output modulated by a sine wave without distortion : these points may, of course, be checked, using the oscilloscope. The first objective is to locate the faulty stage. Connect the audio output of the signal generator, through a blocking capacitor (0·1μF), to the grid circuit of the output valve, and set its frequency to 400 c/s and its amplitude to produce the rated voltage across the load resistor—as judged by the oscilloscope deflection. Adjust the oscilloscope time base to display one or two waves, and if these are of sine waveform there is no distortion : if amplitude distortion is present, the positive or negative peaks of the wave (or both) will be flattened. If no distortion is present, transfer the signal generator to the grid of the preceding stage, probably a double-diode-triode detector-amplifier; the generator output should, of course, be reduced to provide the same output voltage from the receiver. In a similar manner the detector, intermediate frequency and signal frequency stages can be checked using a radio-frequency output from the signal generator 30 per cent. modulated by 400 c/s and the appropriate amplitude in each case. The fault may lie in the mal-operation of the automatic gain control, and so when testing the I.F. and R.F. stages the input signal should be varied in amplitude, up to the maximum likely to be met in practice. This procedure should suffice to locate the distorting stage, and the next objective is the location of the faulty component. First, replace the valve with another of the same type—as this is easily done—and, if the distortion persists, check the valve anode current with no signal applied, the result should be compared with the maker's data. A high anode current suggests a low-resistance cathode bias resistor, screen dropping resistor, anode feed resistor or a short-circuited cathode bias capacitor. A low anode current suggests that these resistances may be too high or that the screen or anode decoupling capacitors have low insulation. High anode current may also be caused by a leaky coupling capacitor from the preceding anode. When the faulty component or connection has been located and corrected, the absence of distortion should be checked with the oscilloscope, to ensure that there was not more than one source.

Q. 7. *Describe how you would measure capacitance (about* $300\mu\mu F$*) at a radio frequency by comparison with a calibrated variable capacitor.*



A. 7. The circuit diagram shows a suitable arrangement for the measurement of a capacitance C2 in terms of a calibrated variable capacitor C1. A signal generator, G, is loosely coupled by a coil, L1, to a second coil, L2, which is tuned by the variable capacitor to resonance at the generator frequency, as shown by a maximum deflection on the valve voltmeter V. The inductance of L2 and frequency of G are chosen so that resonance is obtained with C1 near its maximum capacitance, e.g., if f = 1,000 kc/s, L = 50 microhenries, C1 = $507\mu\mu F$. The unknown capacitor C2 is then paralleled with C1 and C1 readjusted for resonance. Since resonance is obtained with the same total capacitance in each case, it follows that the reduction in the capacitance of C1 is equal to the added capacitance of C2, which may thus be derived from the calibration of C1.

The following precautions are necessary to avoid errors :—

- (*a*) The lead S1, used to connect C2, should be moved as little as possible to connect or disconnect C2, and the other terminal of C2 should remain joined to earth: in this way the stray capacitances are kept constant.
- (*b*) The frequency of G should be constant.
- (*c*) The coupling between L1 and L2 should not be altered and should be weak to avoid errors due to a doubly-humped response.
- (*d*) The inductor L2 should have a high Q so that a sharp resonance is obtained and an accurate adjustment made.

This method has the advantage that a knowledge of the precise values of frequency, inductance or stray capacitance is not necessary. A comparison accuracy of better than 1 per cent. is easily obtained.

Q. 8. *A loop aerial consists of 20 turns of wire on a square of 50 cm. side. A transmission on 400 metres wavelength produces a series e.m.f. of 1·5 millivolts in the loop when the latter is in the direction of maximum response. What is the field-strength of the transmission?*

A. 8. The series E.M.F., induced in a loop aerial set for maximum response, is given by :—

$$e = \frac{2\pi FAN}{\lambda} \text{ volts,}$$

where F = Field Strength, volts/metre, A = Loop Area, square metres, N = Number of turns in loop, λ = Wavelength of signal, metres.

Substitute the given values :—

$$1{\cdot}5 \times 10^{-3} = \frac{2\pi F \times 0{\cdot}5 \times 0{\cdot}5 \times 20}{400}$$

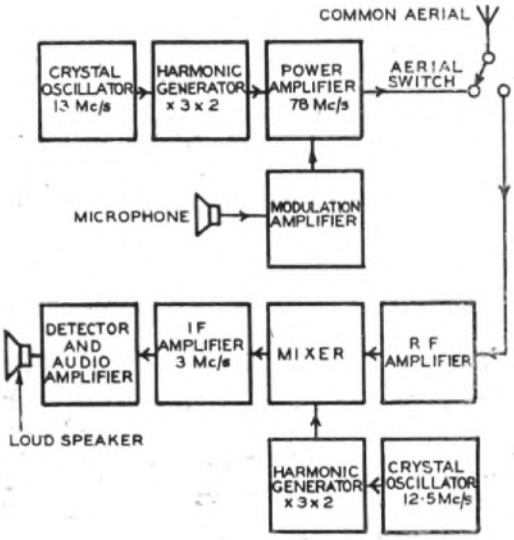
$$\text{or } F = \frac{400 \times 1{\cdot}5 \times 10^{-3}}{2\pi \times 0{\cdot}5 \times 0{\cdot}5 \times 20}$$

$$= \frac{6}{100\pi} \text{ volts/metre,}$$

$$\text{or Field Strength} = \underline{19{\cdot}1 \text{ millivolts/metre.}}$$

Q. 9. *Describe, with the aid of a block schematic diagram, a simple radio-telephone equipment for communication between two vehicles over a distance of up to 20 miles.*

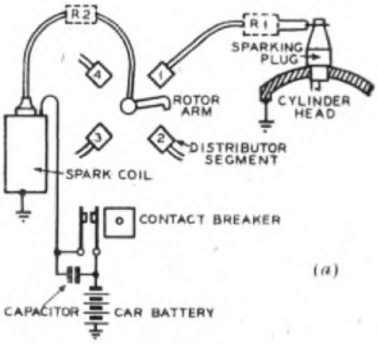
A. 9. Radio-telephone equipment for use between two vehicles up to 20 miles apart might use frequencies either in the range 5-30 Mc/s or 50-100 Mc/s; the second range is more likely to be used, as interference with other services is less likely and small aerials may be made to be more efficient. However, for use in hilly country or among tall buildings the lower frequencies might be preferable. The schematic diagram shows one vehicle's equipment for a simplex circuit on a frequency of 78 Mc/s; the transmitter and receiver share a common aerial, and a non-locking switch located on the microphone operates relays to silence the receiver when "pressed-to-talk," and removes the transmitter H.T. supplies when the switch is released; the aerial connection might also be switched, as shown in the diagram.



The transmitter consists of a 13-Mc/s crystal-controlled low-power oscillator driving a trebler and doubler stage, giving an output of 13 × 3 × 2 = 78 Mc/s for the modulated power amplifier stage. This stage would deliver some 5-10 watts to the aerial.

The receiver is a simple superheterodyne type, with a crystal-controlled beating oscillator to avoid tuning troubles; it might incorporate noise suppression circuits as well as A.G.C. Power supplies would be derived from batteries, probably 12 volts, the receiver H.T. supplies being produced by a vibrator and those for the transmitter by a rotary converter. Short vertical aerials would probably be used. The emphasis in the design would be on robustness and power economy rather than on high speech quality.

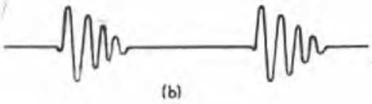
Q. 10. *Explain briefly how the ignition system of a car may cause interference with radio reception and state how the interference can be minimised.*



A. 10. The ignition system of a car is shown diagrammatically in sketch (*a*). The spark or induction coil has two windings, a low-tension winding of few turns supplied via a mechanically operated contact breaker from the 6-V or 12-V car battery, and a high-tension winding of several thousand turns that provides an impulsive voltage of some 5-10 kV when the contact

RADIO II, 1950 (*continued*)

breaker operates. This high voltage is led to the rotor arm of the distributor and from thence it passes in turn to the sparking plugs, screwed into the cylinder heads. A small spark gap exists between the rotor arm and the distributor segments—to avoid rubbing and wear—and a larger gap between the plug points. The high-voltage impulse thus causes a spark to pass between the rotor arm and the distributor segment, and between the plug points. It can be shown that when a spark passes in a circuit containing resistance, inductance and capacitance—as all circuits do —the current which flows takes the form of a damped oscillation, as shown in sketch (*b*). Such an oscillation may be regarded as a modulated high-frequency wave, and when the damping is heavy, as in the example, then the sidebands generated extend over a very wide frequency range. In the car ignition system the inductance and capacitance are those of the leads mainly, since the high inductance of the spark coil will be effectively shunted by its large self-capacitance, and the resultant oscillation is radiated from the leads and is mainly effective in causing interference in the band 10-100 Mc/s. The interference is best minimised by reducing the oscillatory currents by added resistances, of about 5,000-10,000 ohms in series with the plug and rotor arm leads, as shown at R1 and R2 in sketch (*a*). Resistances of this magnitude have a negligible effect on the car's performance. Other measures include the use of screened leads for the ignition H.T. circuits, a matched and screened downlead at the receiving aerial, and of noise-suppression circuits in the receiver.


(b)

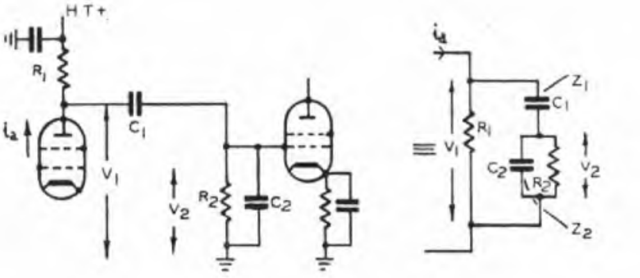
RADIO III, 1950

Q. 1. *The coupling network between the two valves of a resistance-capacitance amplifier is as follows :—*

Anode resistance	10,000 *ohms*
Grid resistance	100,000 *ohms*
Anode-grid coupling capacitance	$0{\cdot}1\mu F$
Total stray capacitance to earth	$25\mu\mu F$

Calculate the ratio of the signal voltages appearing at the anode of the first valve and the grid of the second valve for frequencies of 10 *c/s*, 5 *kc/s, and* 2 *Mc/s.*

A. 1. The valve circuit shown on the left of the sketch is equivalent to the network shown on the right. Thus, it can be seen that the grid voltage V_2 is determined by the potential division of the anode voltage V_1 by the impedances Z_1 and Z_2. Hence,



$$\frac{V_2}{V_1} = \frac{Z_2}{Z_1 + Z_2}$$

where, $Z_1 = 1/j\omega C_1$ and, $Z_2 = \dfrac{R_2/j\omega C_2}{R_2 + 1/j\omega C_2}$.

In the present case, $C_1 = 0{\cdot}1\mu$F, $C_2 = 25\mu\mu$F, and $R_2 = 100{,}000$ ohms.

Response at 10 *c/s*.—The values of the impedances at this frequency are :—

$$Z_1 = 1/j\omega C_1 = \frac{10^6}{j2\pi \times 10 \times 0{\cdot}1} = -j\ 1{\cdot}59 \times 10^5 \text{ ohms}$$

$$R_2 = 10^5 \text{ ohms}$$

$$\frac{1}{j\omega C_2} = \frac{10^{12}}{j2\pi \times 10 \times 25} = -j\ 6{\cdot}38 \times 10^8 \text{ ohms.}$$

In this case, $1/j\omega C_2$ is much greater than R_2, hence $Z_2 \doteqdot R_2$.

$$\text{Thus, } \frac{V_2}{V_1} \doteqdot \frac{R_2}{R_2 + 1/j\omega C_1} = \frac{10^5}{10^5 - j\ 1{\cdot}59 \times 10^5}$$

$$= \frac{1}{1 - j\ 1{\cdot}59} \approx \frac{1}{\sqrt{3{\cdot}52}} \approx \underline{0{\cdot}53\ (-5{\cdot}5 \text{ db.})}.$$

Response at 5 *kc/s*.—The values of the impedances at this frequency are :—

$$Z_1 = \frac{1}{j\omega C_1} = \frac{10^6}{j\,2\pi \times 5{,}000 \times 0{\cdot}1} = -j\ 0{\cdot}318 \times 10^3 \text{ ohms}$$

$$R_2 = 10^6 \text{ ohms}$$

$$\frac{1}{j\omega C_2} = \frac{10^{12}}{j\ 2\pi \times 5{,}000 \times 25} = -j\ 1{\cdot}28 \times 10^6 \text{ ohms.}$$

In this case, $1/j\omega C_1$ is much less than R_2, and $1/j\omega C_2$ is much greater than R_2.

$$\text{Thus, } \frac{V_2}{V_1} \doteqdot \frac{R_2}{R_2 + 1/j\omega C_1} \doteqdot \underline{\frac{R_2}{R_2} = 1{\cdot}0}$$

Response at 2 *Mc/s*.—The values of the impedances at this frequency are :—

$$Z_1 = \frac{1}{j\omega C_1} = \frac{10^6}{j2\pi \times 2 \times 10^6 \times 0{\cdot}1} = -j\ 0{\cdot}785 \text{ ohms}$$

$$R_2 = 10^5 \text{ ohms}$$

$$\frac{1}{j\omega C_2} = \frac{10^{12}}{j2\pi \times 2 \times 10^6 \times 25} = -j\ 3{\cdot}18 \times 10^3 \text{ ohms.}$$

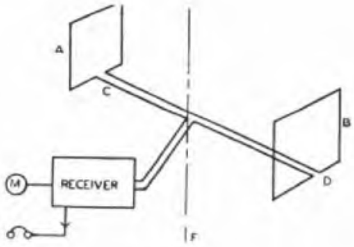
In this case, $1/j\omega C_2$ is much less than R_2, and $1/j\omega C_1$ is much less than $1/j\omega C_2$.

$$\text{Thus, } \frac{V_2}{V_1} \doteqdot \frac{1/j\omega C_2}{1/j\omega C_1 + 1/j\omega C_2} \doteqdot \underline{\frac{j\omega C_2}{j\omega C_2} = 1{\cdot}0}$$

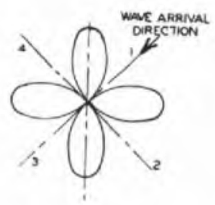
Note.—In practice, the response, expressed as the ratio of the grid voltage of one stage to that of the preceding stage, would decrease as the frequency is increased, because of the shunting effect of the grid capacitance on the anode load.

Q. 2. *Describe with the aid of sketches the construction and principles of operation of a spaced-loop direction finder for use in the frequency band* 10 *to* 30 *Mc/s. Why is the polarisation error small in this type of direction finder ?*

A. 2. A spaced-loop direction finder consists of two loop aerials (A, B) arranged on a common horizontal axis with their planes parallel, as shown in sketch (*a*). Their outputs are connected in series-opposition and applied to the input of a radio receiver covering the required frequency range of 10 to 30 Mc/s. The receiver is equipped with headphones for the usual aural-null D.F. technique, or in some instances with a meter or an oscilloscope for visual indication of the signal level. The loop aerials are normally square, 1-metre side, and are spaced some 2 to 3 metres apart. The loop aerials are electro-statically screened, as also is the horizontal member (C, D) and the wiring to the receiver input. Gaps are left in the screens at the aerials to prevent the aerials from being short-circuited by the screens.



(*a*)



(*b*)

In operation the aerials, receiver and usually the operator are rotated about the vertical axis F, the input to the receiver varying with angle of rotation, as shown by the horizontal plane polar diagram, sketch (*b*). It will be seen that there are four null positions, but only two of these (nulls 1, 3) are stable and sharp when receiving ionospherically reflected signals. The other two (nulls 2, 4) correspond to wave directions normal to the planes of the individual loops, and these have the instability usually found when attempting short-wave direction finding with a single loop aerial.

The spaced-loop direction finder has a very small polarisation error when properly erected. This is due to the manner in which the system operates, which is as follows. When orientated for a null, such as 1 or 3, sketch (*b*), E.M.F.s are induced in the vertical wires of the loops, but not in the horizontal wires of the loops. The resultant loop E.M.F.s are equal in magnitude but, being connected in series-opposition, cancel at the receiver input. The absence of E.M.F.s in the horizontal wires of the loops avoids the polarisation error which occurs when direction finding with a single loop aerial. Furthermore, although the horizontal component of an incoming wave induces E.M.F.s in the screen surrounding the horizontal connecting wires (C, D), the currents which flow in the screen cannot induce E.M.F.s in the loops. This avoids a source of polarisation error which occurs to some extent in the buried-U Adcock type of direction finder.

Q. 3. *State, with reasons, the carrier frequencies suitable for television broadcasting. Give typical values for the radius of the service area to be expected, indicating the factors which determine the radius.*

A. 3. The carrier frequencies most suitable for television broadcasting are in the range 40 to 200 Mc/s, approximately. The reasons for this are as follows :—

(*a*) Television broadcasting requires modulation frequencies up to some 3 Mc/s; this necessitates carrier frequencies exceeding 40 Mc/s in order that the modulation bandwidth shall be less than a few per cent. of the carrier frequency. With a large percentage bandwidth, the design of aerials, transmitters and receivers becomes difficult.

(*b*) Frequency allocations below 40 Mc/s are required for other services; in any case, the use of frequencies in the short-wave band would give rise to intolerable interference problems due to the long-distance propagation of such waves by ionospheric reflection.

(*c*) Frequencies in the range 40 to 200 Mc/s enable good coverage to be achieved by means of the ground wave, thus ensuring stable, reliable reception. Frequencies towards the low frequency end of this range are particularly satisfactory, since they avoid the "shadows" due to hills, buildings, etc., which become more serious as the frequency is increased.

(*d*) The attenuation of the ground-wave, due to the finite conductivity of the ground and scattering by obstacles, increases with the frequency, so reducing the coverage.

(*e*) Transmitters and receivers become more complex and costly as the frequency is increased.

Factors (*c*), (*d*) and (*e*) set an upper limit of frequency which, for present purposes, may be regarded as about 200 Mc/s; however, in the U.S.A. it is possible that the need for more television channels may make it necessary to use even higher frequencies in spite of the limitations already noted. The use of higher frequencies has certain compensatory advantages, e.g., less ignition interference and lower levels of echo signals, due to the greater directivity of the receiving aerials at such frequencies.

The radius of the service area for consistent, good-quality reception may be taken as about 40 miles at 40 Mc/s, decreasing to about 20 miles at 200 Mc/s. These figures are approximate only; much will depend on factors such as the following :—

(*a*) Transmitter power.

(*b*) Height and gain of transmitting and receiving aerials.

(*c*) Path between transmitter and receiver, e.g., extent of obstruction by hills, buildings, etc.

(*d*) Levels of ignition and other noise sources in the vicinity of the receiver.

(*e*) Level of noise inherent in receiver due to valves, etc.

Q. 4. *The ratio of the received to the transmitted power for a radio link over an optical path is given by :—*

$$\frac{W_R}{W_T} = G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2$$

where W_T *is the transmitted power,*
W_R *is the received power,*
G_T *is the power gain of the transmitting aerial,*
G_R *is the power gain of the receiving aerial,*
λ *is the wavelength in metres,*
and d *is the length of the link in metres.*

Calculate the received signal-to-noise ratio in decibels if
$W_T = 10$ *watts,*
$G_T = G_R = 30,$
and $d = 40$ *kilometres,*
given that the operating frequency is 1,000 Mc/s and the equivalent noise power input of the receiver is −120 db. relative to 1 watt.

A. 4. The ratio of the received to the transmitted power is given by :—

$$\frac{W_R}{W_T} = G_T G_R \left(\frac{\lambda}{4\pi d}\right)^2$$

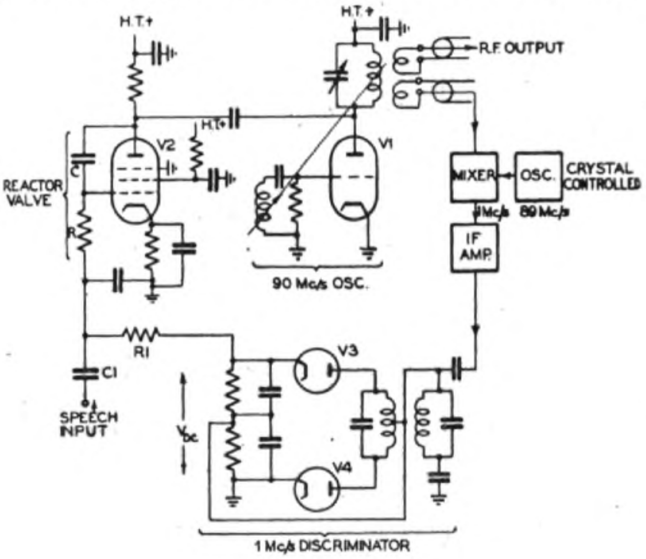
where $\lambda = 0{\cdot}3$ m. (corresponding to $f = 1{,}000$ Mc/s),
$W_T = 10$ watts,
$G_T = G_R = 30$
and $d = 40$ km.

$$\text{Hence } W_R = 10 \times 30 \times 30 \times \left(\frac{0{\cdot}3}{4\pi \times 40 \times 10^3}\right)^2$$
$$= 0{\cdot}32 \times 10^{-8} \text{ watts.}$$

The received power is therefore :—
$10 \log_{10} (0{\cdot}32 \times 10^{-8}) = -85$ db. relative to 1 watt.
The noise power is −120 db. relative to 1 watt.
The signal-to-noise is therefore :—
$-85 - (-120) = \underline{35{\cdot}0 \text{ db.}}$

Q. 5. *Describe, with a circuit diagram, a method for generating a 90 Mc/s carrier and modulating it in frequency by speech signals. Indicate a means for stabilising the mean frequency of the carrier.*

A. 5. Sketch (*a*) shows the circuit diagram of a 90-Mc/s frequency-modulated carrier generator and the associated automatic frequency control circuit.

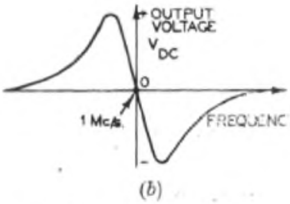


(*a*)

The oscillator shown employs a conventional earthed-cathode triode, V1, with a tuned-anode and inductively coupled grid circuits; in practice, an earthed-grid triode might be employed with coaxial-line circuits if good frequency stability is required. Alternatively the oscillator would operate on a sub-multiple of 90 Mc/s, and a frequency-multiplier be used to raise the frequency to the required value.

In order to frequency-modulate the oscillator a reactor valve, V2, is connected effectively in parallel with the oscillator tuned circuit. The R.F. voltage applied to the grid of the reactor valve is arranged to lead the R.F. anode voltage by approximately 90° by means of an RC phase-shifting circuit connected between anode, grid and earth. The anode current thus leads the anode voltage by approximately 90°, and the reactor valve operates as a capacitor connected across the oscillator tuned circuit. The value of the capacitor, C_e, is approximately proportional to the mutual conductance g_m of the reactor valve ($C_e \doteqdot g_m RC$); thus, if the mutual conductance is varied, for example, by varying the grid-bias of the valve, the frequency of the oscillator may be varied by a corresponding amount. If the grid-bias is varied by an alternating speech voltage, applied through capacitor C1 in sketch (*a*), the 90-Mc/s carrier is modulated by speech, the frequency deviation being approximately proportional to the speech voltage. In practice, the reactor valve circuit is more complex than that shown in sketch (*a*) since due allowance must be made for the unavoidable stray and valve capacitances.

Sketch (*a*) also shows a method for stabilising the mean frequency of the carrier. A portion of the R.F. output of the 90-Mc/s oscillator is applied to a mixer together with a stable 89-Mc/s carrier derived from a crystal-controlled oscillator. The 1 Mc/s beat frequency is amplified in an I.F. amplifier and applied to a Foster-Seeley discriminator. The latter consists of a pair of diode valves, V3, V4, energised from the balanced secondary winding of an I.F. transformer, the centre point of the secondary being connected to the high potential side of the primary. The action of the discriminator is such that the rectified voltage, V_{DC}, across the resistance-capacitance load circuits of the diode valves varies with frequency, as shown in sketch (*b*). This rectified voltage is fed to the grid of the reactor valve through a suitable smoothing circuit which removes the alternating speech voltages resulting from frequency modulation of the carrier. The residual direct voltage varies the frequency of the 90-Mc/s oscillator and tends to stabilise the frequency at a value equal to 89 Mc/s plus the frequency (1 Mc/s) corresponding to the centre point of the discriminator characteristic.

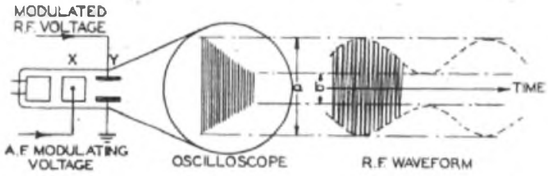


(*b*)

Q. 6. *Explain how you would use a cathode-ray oscilloscope to measure the modulation factor of an amplitude-modulated wave.*

If a carrier of amplitude 1 *volt* (*r.m.s.*) *is modulated sinusoidally and the peak value of the resultant wave is* 2 *volts, what is the modulation factor?*

A. 6. A convenient arrangement for measuring the modulation factor is shown in the sketch. The modulated R.F. voltage is applied to the Y-plates of the cathode-ray oscilloscope and the A.F. modulating voltage is applied to the X-plates. If there is a negligible phase shift between the A.F. modulating voltage and the envelope of the modulated R.F. wave, then the pattern shown on the oscilloscope consists of a trapezium, as shown on the left-hand side of the sketch. The long vertical side, *a*, of the trapezium corresponds to the peak-to-peak amplitude of the R.F. wave, and the short vertical side, *b*, corresponds to the trough-to-trough amplitude, as shown on the right-hand side of the sketch.



$$\text{The modulation factor, } m = \frac{a-b}{a+b}$$

For 100 per cent. modulation $b = 0$ and $m = 1{\cdot}0$.
For 0 per cent. modulation $a = b$ and $m = 0$.

Example: The peak value of the unmodulated carrier is $1/0{\cdot}707 = 1{\cdot}414$ volts.

The peak value of the modulated wave is 2·0 volts.

$$\text{Hence the modulation factor} = \frac{2-1{\cdot}414}{1{\cdot}414} = \underline{0{\cdot}415.}$$

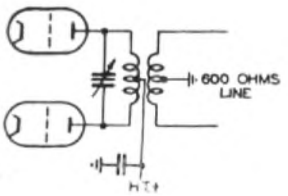
Q. 7. *Describe with circuit diagrams the arrangements for matching the final tuned circuit of a telephony transmitter to—*

(*a*) *an open-wire transmission line of* 600 *ohms resistive im pedance*
(*b*) *a coaxial feeder of* 100 *ohms resistive impedance.*

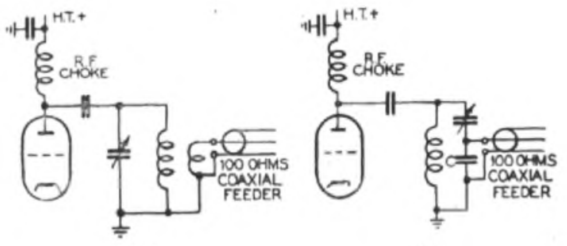
Given that the power output of the transmitter, unmodulated, is 10 *kW, calculate the peak voltages applied across the feeders in* (*a*) *and* (*b*) *when the modulation factor is* 50 *per cent.*

A. 7. For operation with a balanced open-wire line, it is usual to employ a balanced output stage with two valves driven in push-pull, as shown in sketch (*a*). The line is then energised from a small centre-tapped coupling coil located near the earthed centre of the main tuning coil and with the number of turns adjusted to give the required impedance transformation ratio.

A similar arrangement, but using only a single-valve output stage and with the coupling coil located near the earthed end of the main tuning coil, may be used to energise an unbalanced coaxial feeder, as shown in sketch (*b*). Alternatively a relatively large fixed capacitor, C, may be connected in series with the tuning capacitor, and the coaxial feeder energised from the fixed capacitor, as shown in sketch (*c*). In the latter case the impedance transformation ratio is determined by the size of the fixed capacitor.



(*a*)



(*b*) (*c*)

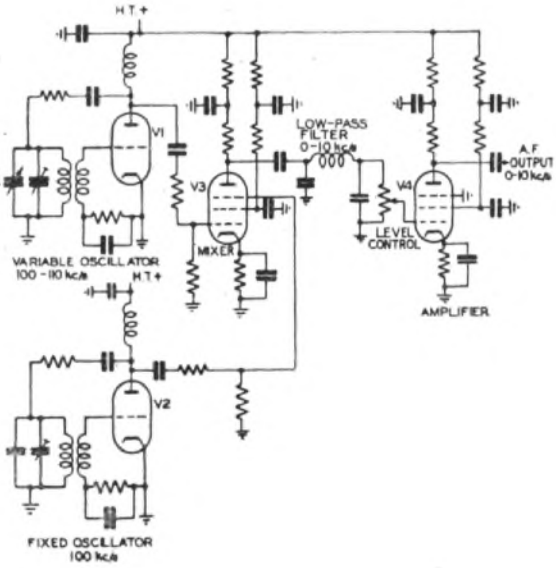
Example.

The peak power output of the transmitter when modulated is $1{\cdot}5^2 \times 10 = 22{\cdot}5$ kW. A peak voltage, V, across a load of resistance, R, corresponds to a peak power of $V^2/2R = W$.

Hence, $V^2 = 2RW$.
In case (*a*), $R = 600$ ohms and $W = 22{\cdot}5$ kW.
Hence, $V = \sqrt{2 \times 600 \times 22{\cdot}5 \times 10^3} = \underline{5{,}200 \text{ volts.}}$
In case (*b*), $R = 100$ ohms and $W = 22{\cdot}5$ kW.
Hence, $V = \sqrt{2 \times 100 \times 22{\cdot}5 \times 10^3} = \underline{2{,}120 \text{ volts.}}$

Q. 8. *Give the circuit diagram, and state the principles of operation, of a beat-frequency oscillator of good frequency stability and low harmonic content, suitable for the range* 10 *c/s to* 10,000 *c/s.*

A. 8. In a beat-frequency oscillator, voltages obtained from two radio-frequency oscillators operating at slightly different frequencies are applied to a mixer valve and an audio-beat frequency is obtained. The circuit of a typical beat-frequency oscillator is shown in the sketch. The fixed frequency oscillator, V2, operates at 100 kc/s, and the variable frequency oscillator, V1, is arranged to cover 100 to 110 kc/s; thus, the beat frequency may be varied from 0 to 10 kc/s simply by adjustment of the variable capacitor, C. The two oscillators are designed to be of good frequency stability and, in the example shown, are of the resistance-stabilised feedback type. In order to minimise drift of the beat frequency, the oscillators are made as similar as possible so that changes of temperature and supply voltages produce equal changes of frequency in both oscillators, and these cancel so far as the beat frequency is concerned.



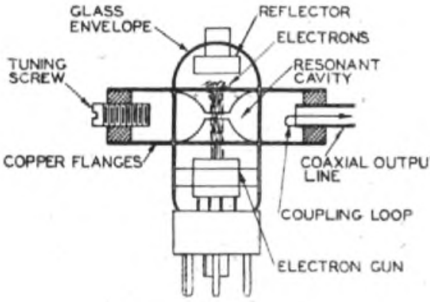
In the circuit shown, a pentode valve is used as a mixer, the variable oscillator output being applied at low level to the signal grid and the fixed oscillator output being fed to the suppressor grid at high level. The screening action of the valve helps to prevent coupling between the oscillators, which would otherwise cause a distorted waveform at low beat frequencies. The oscillators are individually screened and the supplies are separately filtered in order further to reduce coupling. The use of a low level of variable oscillator voltage on the signal grid of the mixer reduces the level of unwanted intermodulation products and harmonics of the wanted beat frequency; the use of relatively high radio frequencies also helps to avoid these unwanted signals.

The beat-frequency output of the mixer is separated from the radio-frequency components by means of a low-pass filter, and is then amplified to the required level. A level control, in the form of a variable potentiometer, is provided at the output of the low-pass filter.

Q. 9. *Describe with the aid of sketches the operation of a valve oscillator suitable for the generation of oscillations of frequency 3,000 Mc/s and explain its mode of operation.*

A. 9. A reflex klystron oscillator, suitable for generating oscillations of frequency 3,000 Mc/s (wavelength, 10 cm.), is shown in the sketch.

The oscillator comprises an electron gun, a single resonant cavity and a reflector electrode. The electron gun is usually of a simple type, with an indirectly heated cathode and a cylindrical focusing electrode, the resonant cavity itself forming the anode. The resonant cavity is formed by two thin copper flanges which pass through the walls of the glass envelope of the valve and which are sealed to the glass by a vacuum-tight copper-glass joint. The two copper flanges terminate in a brass ring which provides the outer wall of the cavity; the centres of the flanges form a conical aperture and the electron beam passes through the gap so formed, as shown in the sketch. The reflector electrode is held at a negative potential with respect to the anode, and this causes the electrons to be repelled, reversed in direction and eventually to be collected by the anode, the reflector itself taking no current. Many of the electrons pass through the gap a second time and this is an important feature in the operation of a reflex klystron oscillator. The resonant frequency is determined by the dimensions of the cavity and thus may be controlled, over a limited range, by tuning screws which vary the effective volume of the cavity. R.F. power is abstracted from the cavity by means of a small loop placed in the oscillating magnetic field and feeding a coaxial output line.

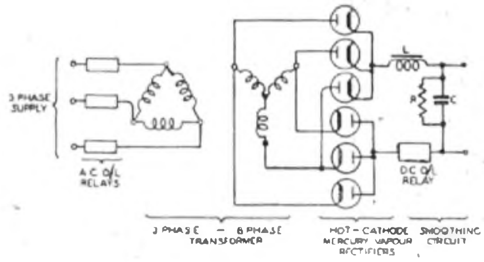


The principles of operation are as follows. When the cavity is in oscillation, a relatively strong oscillating electric field exists across the central gap and the electrons passing through the gap are velocity-modulated. Some electrons are accelerated when the electric field is in one direction, and other electrons are retarded when the electric field reverses. As has already been pointed out, a proportion of the electrons pass through the gap a second time and during the interval between the first and second transits of the gap the electron beam becomes bunched, due to fast electrons overtaking slow electrons and vice versa. If the bunches are so timed that they give up energy to the oscillating electric field in the gap, they will maintain the valve in oscillation; the frequency of oscillation, in fact, adjusts itself so that the conditions necessary to maintain oscillation are satisfied. Thus, if the time interval between the first and second transits of the gap is varied by varying the potential of the reflector electrode, and thus the path length between the transits, the frequency is also varied. This feature, by which the frequency can be adjusted over a range of some tens of megacycles per second by altering the reflector voltage by ten to twenty volts, is useful for electronic tuning and for frequency modulation purposes.

Q. 10. *The final stage of a short-wave radio telegraph transmitter (frequency-shift keying) is rated to feed 50 kW to the aerial transmission line. Describe the power supply arrangements which would be necessary for this final stage, outlining the safety precautions which would be necessary.*

A. 10. (*i*) *High Voltage Supply.*

Since the transmitter is of the frequency-shift type, it provides a constant load for the high voltage supply and good regulation is therefore not an essential requirement. A 50-kW transmitter might require some 75 kW from the high voltage supply, say 7·5 A at 10 kV. For safety, a load current of 10 A would be assumed for design purposes. Such a supply could be obtained from 415 V, 3-phase mains by means of a 3 phase-6 phase rectifier, the basic circuit of which is shown in the sketch. The 6-phase output wave is an advantage, since it reduces the amount of smoothing required. Mercury-vapour, hot-cathode rectifier valves are usually employed, because of the high efficiency, low first cost and good regulation as compared with high-vacuum valves. The smoothing circuit could consist of a 5H oil-filled choke, L, of 10 A rating, and a 2μF oil-filled capacitor, C, of 20 kV rating. A "bleeder" resistor, R, is sometimes connected across the capacitor to discharge the latter when the mains supply is switched off. A.C. overload relays are provided in all three phases of the mains supply, and a D.C. overload relay, set to trip at 10 A, is included in the output circuit.



(*ii*) *Safety Precautions.*

The high-voltage supply is usually installed in a cubicle with door interlock switches, so that the opening of the door disconnects the mains supply; it is also arranged that the supply cannot be switched on unless the door is locked and the key is returned to a container associated with the mains switch. A similar interlock system is fitted to the transmitter power amplifier cubicle. It is also usual to provide an earthing stick so that, on entering the cubicle, components such as capacitors may be checked for the presence of high voltages by earthing them.

(*iii*) *Filament Supplies.*

The filament supplies required for the main amplifiers of the transmitter are some 100A per valve at about 20V. This supply can be single-phase A.C. and it is usual to provide a filament transformer for each valve. Facilities for adjusting the filament voltage precisely to the value recommended by the valve manufacturers is desirable in the interests of long valve life.

(*iv*) *Bias Supplies.*

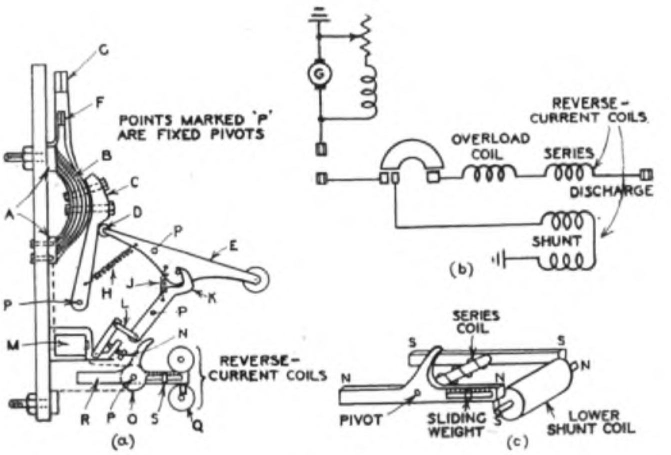
A telegraphy transmitter should incorporate a "holding" bias supply for the grids of all the main amplifier valves to ensure that they are biased beyond cut-off in the absence of a drive. Such a bias supply is usually obtained from a single-phase rectifier with a suitable smoothing circuit. In the event of a failure of the bias supply, it is arranged that the high-voltage supply is automatically removed from the main amplifier to avoid damage to the valves.

(*v*) *Water Supply.*

The main amplifier valves would probably be water-cooled triodes, the water supply to the anodes being through rubber tubes some 15 ft. long to provide a high resistance path from the anodes to earth. In the event of failure of the water supply, it is arranged that the high-voltage supply is automatically disconnected from the valves.

Q. 1. *Describe, with the aid of sketches, the construction and operation of a combined overload and reverse-current circuit-breaker. Explain how, by means of mechanical adjustments, the values of overload and reverse currents which will operate the circuit-breaker may be varied.*

A. 1. The combined overload and reverse-current circuit-breakers usually employed in telephone exchange power plants are of the open type, and the construction of a typical circuit-breaker is shown in sketch (*a*).



It consists of an iron frame which carries the pivots of a trigger mechanism controlling a copper brush in conjunction with contacts, and overload and reverse-current magnets and armatures, arranged so that on operation the trigger mechanism is tripped. The iron frame has been omitted from the sketch so that the construction of the mechanism may be more clearly seen.

The main contacts consist of two copper plates, A, and a heavy brush, B, of laminated copper carried on an arm, C, pivoted at the base and operated by a roller, D, attached to the end of a hand-operated lever, E. The arm also carries copper blades, to which auxiliary copper, F, and carbon contacts, G, are attached. The carbon contacts which make before, and break after, the main contacts reduce sparking at the latter, and the auxiliary copper contacts are arranged to complete the circuit of the shunt coils of the reverse-current magnet. The roller on the lever is held against the arm by a helical spring, H, and another helical spring, J, connects the lever to the trigger. The lever is pivoted near the roller so that when it is operated the roller rides up the arm and forces the auxiliary and main contacts to close; the trigger, which is pivoted near its centre, engages with a stud on the lever to hold it in the operated position. The lower end of the trigger is connected by a link, L, to the armature of the overload magnet, M. The armature is provided with an adjustable screw backstop, N. The reverse-current series, O, and shunt coils, Q, are mounted in the lower portion of the frame and control a rocking armature, R, pivoted near its centre, and provided with a projection which operates against the lower end of the trigger. The rocking armature is provided with a sliding balance weight, S.

Most modern circuit breakers are provided with the "loose-handle" feature, so that the breaker cannot be incorrectly held in by hand.

The electrical connections of the circuit-breaker coils are shown simply in sketch (*b*), and its operation is as follows :—

The breaker is closed by hand and held closed by the trigger mechanism. The overload coil carries the full circuit current, and if the overload value is reached the armature is attracted and the armature link causes the trigger to become disengaged from the stud on the lever. The spring between the lever and the arm causes the roller to ride down the arm, allowing the brush to break from the contacts. The reverse-current magnet consists of a series coil carrying the full current of the breaker and two shunt coils connected, in series, across the circuit. The series coil polarises the rocking armature, and the shunt coils, through which the current always flows in the same direction, have a constant polarity. With the current through the series coil in the correct direction, the polarities are as indicated in sketch (*c*), and the rocking armature is held down against the rest attached to the core of the lower coil. If the current in the series coil is reversed, the polarity of the rocking armature reverses and the right-hand end moves up, causing the projection to strike the lower end of the trigger which trips and allows the breaker to open.

The value of overload current which trips the breaker is varied by adjustment of the overload armature screw backstop. The closer the armature is set to the magnet core, the smaller will be the overload current. The value of reverse current which will operate the breaker is determined by the adjustment of the position of the sliding balance weight on the rocking armature. The nearer the weight is to the pivot of the armature, the smaller will be the reverse current operate value.

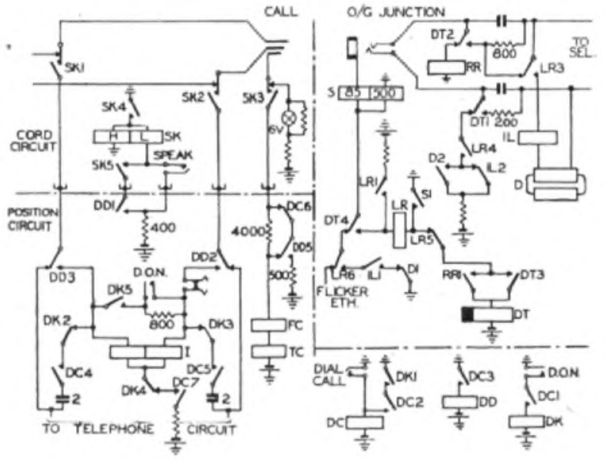
Q. 2. *Describe and illustrate with circuit diagrams how circuits outgoing from the automanual switchboard to the automatic equipment in a non-director exchange are operated,* (*a*) *when the automanual switchboard is in the same building as the automatic equipment, and* (*b*) *when the automanual switchboard is in a remote building.*

A. 2. (*a*) Circuits outgoing from the automanual switchboard to the automatic equipment in a non-director exchange are operated on a loop dialling basis and, when the switchboard is in the same building as the automatic equipment, usually, comprise groups of circuits to :—

- (*a*) 1st and 2nd selectors for obtaining access to the junction network,
- (*b*) penultimate selectors for completing calls to subscribers on the non-director exchange, and
- (*c*) trunk-offering selectors to provide the operator with the trunk-offering facility.

For groups (*a*) and (*b*), where the operators have access to 2nd and penultimate selectors, the number of digits dialled is reduced accordingly and a saving in operating time is achieved.

The circuit elements of the dialling arrangements of the sleeve control cord and position circuits, and of an outgoing loop dialling circuit, are shown in the sketch, and the operation is as follows :—



When the plug is inserted in the outgoing jack flicker-earth connected to the sleeve conductor causes the supervisory lamp to flash to indicate to the operator that the circuit is a dialling circuit, and relay S operates. The operator throws the Speak and Dial Call keys. The operation of the Speak key operates SK relay which connects the cord to the position circuit, and the Dial Call key operates DC relay. DC3 operates DD relay. DD switches the tip and ring of the cord from the normal path to the operator's telephone circuit, to the impedance coil I, but a secondary path to the telephone circuit is provided via DK and DC contacts and the 2μF capacitors to enable the operator to hear tones. Battery is extended via the impedance coil I to the tip and ring conductors, and over the tip operates relay RR in the outgoing dialling circuit. RR1 operates relay DT, which locks via its own contact to earth at S1. DT sets up the dialling conditions, by-passing the capacitors in the transmission bridge and extending the +ve and −ve to the position dialling circuit. DT4 disconnects the flicker signal and connects relay LR to the sleeve circuit, but LR does not operate at this stage because DC6 has introduced 4,000 ohms resistance in the sleeve of the cord circuit.

Immediately the dial is rotated off-normal, the dial off-normal springs operate DK relay. Contacts of DK disconnect the listening circuit and battery from the impedance coil I and, with the dial off-normal springs, short-circuit the coil so that during dialling loop impulses are transmitted via the outgoing circuit to the selectors. When the dial returns to normal at the end of each train of impulses, relay DK releases, restoring the listening circuit, but relays DC and

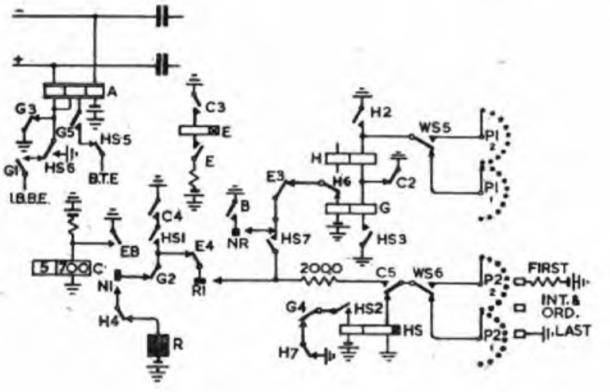
DD in the position circuit, and S and DT in the outgoing termination remain operated until dialling is completed.

When dialling is completed, relay DK releases and, when the Dial Call key is restored, relay DC releases followed by DD. During the release lag of DD, DC6 connects battery via 500 ohms to the sleeve conductor of the cord circuit, and the increased current causes the operation of relay LR in the outgoing termination. Relay LR sets up the holding, speaking and supervisory conditions, and releases relay DT. The circuit is arranged so that, if the Speak or Dial keys are restored during the last return of the dial, impulses are not lost. The dial off-normal springs hold relay DK until the end of the train, DK1 holds DC, DC3 holds DD, and DD1 holds SK.

(*b*) When the automanual switchboard is in a building remote from the automatic equipment, the circuit arrangements are the same as those described above, but it may not be economical to provide separate groups of junctions to 1st, 2nd, and penultimate selectors. The total number of junctions may be reduced by providing a common group of circuits to 1st selectors, in which case it is necessary for the operators to dial all the digits of the numbers required.

Q. 3. *With diagrams of the circuit elements concerned, describe fully how the additional facilities are provided on a 200-line final selector to make it suitable for P.B.X. 2-10 lines.*

A. 3. On a modern 200-line final selector, the additional facilities to make it suitable for P.B.X. 2-10 working are provided as follows. The number of 200-contact banks is increased from three to four and a frame and wiper carriage equipped with four pairs of wipers are employed. The ordinary P bank is termed the P1 bank and the additional bank, which provides the automatic hunting facility, is known as the P2 bank. An additional relay, HS, is provided and the additional circuit arrangement is as shown in the sketch. On the P2 bank the first line of a P.B.X. group is marked by a battery and the last line by an earth, whilst intermediate, single and spare lines are left disconnected.



The operation of the circuit element concerned with the rotary stepping can be followed by reference to the sketch.

At the end of the units train of impulses relay C releases. C2 extends earth via relay H to the P1 wiper, C5 offers relay HS to the P2 wiper, and C3 disconnects relay E. During the release lag of relay E, H tests the P1 bank and HS tests the P2 bank. If the number dialled is the first line of a P.B.X. group, HS operates to battery on the P2 bank contact.

When E releases, E8 removes the short-circuit from the 700-ohm coil of C, allowing it to re-operate.

If the first line of the group is free, H operates to the subscriber's K relay battery on the P1 bank contact during the slow release of E, and switches the −ve and +ve through in the normal way. When C re-operates, HS is disconnected at C5 and releases.

If the first line is busy, H does not operate and HS holds over its second coil to earth at H7. When C re-operates, the R magnet is energised via HS1 and C4, and the wipers step to the next line. When the R1 springs close, relay G operates via HS7 to earth at C4. G2 disconnects the R magnet.

If the second line is free, H operates in series with the hold coil of G. H4 prevents further operation of the R magnet. H2 short-circuits the hold coil of G, which releases. H7 disconnects the hold coil of HS, which releases. H switches the −ve and +ve lines through.

If the second line is engaged, relay H does not operate and G is unable to hold when the R1 springs open, disconnecting its operate coil. G releases and the R magnet is again energised via G2 to earth at C4, and the wipers step to the next line. This interaction between the R magnet and relay G continues until a free line is found or all the lines have been tested. HS is made slow to release so that it holds during the break periods of G4 while the wipers are stepping.

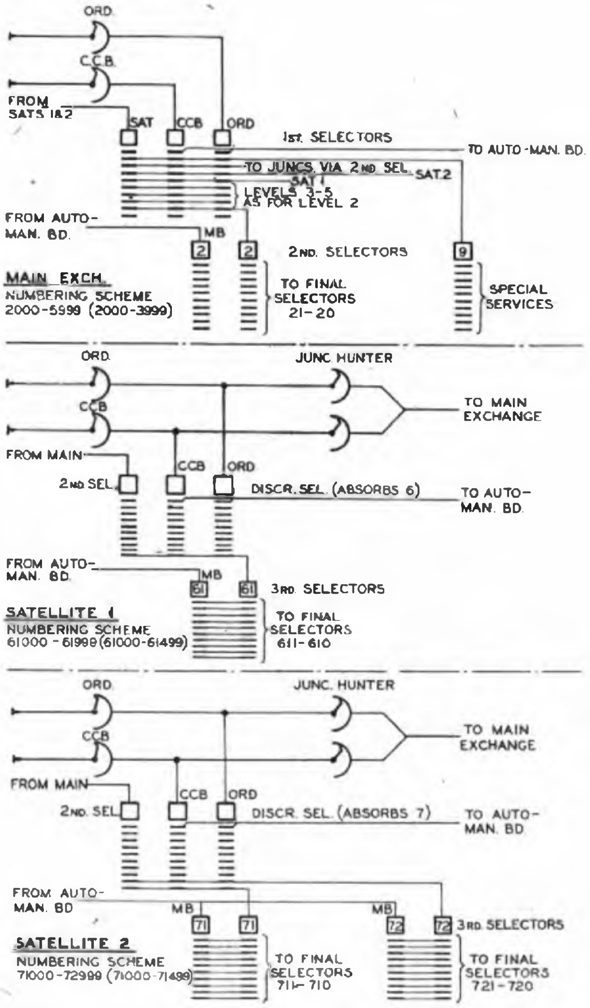
If the last line of the group is reached and is found to be engaged, relay G does not release when the R1 springs open, but holds via C5 to earth on the P2 bank contact. G4, remaining operated, disconnects HS, which releases. With G operated and HS normal, busy tone and flash is returned to the caller.

For night service, any line other than the first line of the group may be employed, the night service lines being switched through at the P.B.X. to selected extensions when the board is unstaffed. If any line other than the first is dialled, no operating path is provided for relay HS via the P2 wiper on the release of C, and automatic hunting does not take place.

Q. 4. *Draw a trunking diagram showing a suitable numbering scheme for a non-director area comprising a main exchange with two satellite exchanges. The subscribers' multiples to meet the requirements of the initial and ultimate planning periods are as follows :—*

	Initial multiple.	*Ultimate multiple.*
Main exchange	2,000	4,000
Satellite No. 1	500	1,000
Satellite No. 2	1,500	2,000

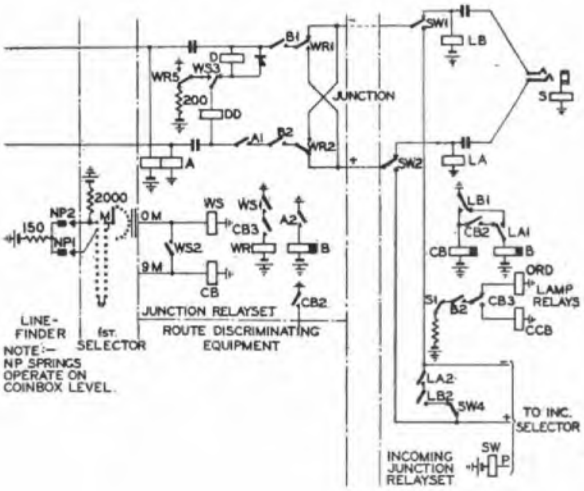
A. 4. The required trunking diagram is shown in the sketch. The numbering scheme is based on the ultimate multiple requirements, and the numbering for the initial multiple is shown in brackets.



Levels 1, 8, 9 and 0 at the main exchange are not available for subscribers' numbers, leaving six levels for this purpose and, as the ultimate multiple capacity requires 7,000 numbers, one or more of the satellites must be given 5-digit numbers. It is usual to provide a separate group of high-grade 0-level circuits from the satellites to the automanual switchboard, and this restricts the satellite numbering scheme; in view of this, both satellites have been allotted 5-digit numbers. Levels are available on the discriminating selector banks for direct junctions between the satellites if these are warranted.

Q. 5. On connections from a unit automatic exchange to an automatic parent exchange it may be arranged to route 9- and 0-level calls, both from ordinary lines and from call box lines, over common outgoing relay-sets and a common group of junctions. Explain how discrimination is effected to switch a call, according to its nature, either to the automanual switchboard or to the automatic equipment at the parent exchange. Give diagrams of the circuit elements concerned.

A. 5. The sketch shows the circuit elements of the arrangements by which 9- and 0-level calls from ordinary and coinbox subscribers on a U.A.X. are connected over a common group of junctions to the parent exchange and how discrimination is effected for the different types of call.



When 9 is dialled by an ordinary subscriber, the 1st selector is stepped to level 9, the M wire is left disconnected so that neither CB nor WS in the outgoing junction relay set is operated, and the calling condition over the junction is the loop of D and DD relays operating LA and LB at the incoming end. LA2 and LB2 seize the incoming selector with a loop, and earth returned over the P-wire operates SW. SW switches the —ve and +ve of the junction to the incoming selector, releasing LA and LB, but leaving the selector held by the loop of D and DD over the junction. Further digits dialled by the caller are repeated by the A1 contact in the junction loop to the distant selector.

When 9 is dialled by a coinbox subscriber, relay CB in the junction relay set is operated over the M-wire by battery via 150-ohm resistance in the line-finder. The junction calling condition is a loop, and the operation is as described in the previous paragraph, except that the operation of CB extends a discriminating earth to the route-discriminating equipment to arrange for the barring of routes other than those permitted to coinbox subscribers.

When 0 is dialled by an ordinary subscriber, relay WS in the junction relay set is operated over the M-wire by battery via 2,000-ohms resistance in the 1st selector, but there is insufficient current to operate CB. WS3 disconnects the loop of D and DD from the junction, and extends battery via 200 ohms to the +ve wire to operate relay LA in the manual board termination. LA1 operates B, which completes the circuit of the lamp relay controlling the "ordinary" lamp.

When 0 is dialled by a coinbox subscriber, WS is operated by battery wire via 150 and 2,000 ohms in parallel. WS2 offers CB to to the M-wire and, because of the increased current, CB operates. WS1 and CB3 operate relay WR. WR contacts reverse the junction lines and the calling condition, which is now earth via DD to the —ve line, operates relay LB in the manual board termination. LB1 operates CB, which in turn operates relay B. With relays B and CB operated, the circuit of the relay controlling the coinbox lamp is completed.

Q. 6. State the maximum number of 3-letter codes available in a director system. Explain what factors influence the choice of a name for a new exchange in a director area and state the approximate maximum limit to the number of exchange lines in such an area.

A. 6. In director areas the digit 1 is not used as the first digit of the letter code, and the digit 0 when dialled as the first digit is used for obtaining access to the automanual operator for assistance purposes, so that there remain eight different groups of letters which can be used as the initial digit of the exchange code. For second and third letter code digits, the digit 1 is not used, but the digit 0 is employed so that for these digits there are nine different groups of letters. The theoretical maximum number of 3-letter codes available is, therefore, 8 × 9 × 9 = 648, but for practical purposes only about 400 of these are suitable for exchange codes; the others do not form suitable combinations or else they bear phonetic similarity to other names.

As the maximum capacity of a director exchange is normally 10,000 lines, the theoretical maximum limit to the number of exchange lines in a director area is 648 × 10,000 = 6,480,000 lines, and the practical maximum is about 400 × 10,000 = 4,000,000.

The factors which influence the choice of a name for a new exchange in a director area are:—

(*a*) the numerical equivalent of the letters forming the 3-letter code must be different from that of the code for any other exchange in the area, for example, CAMden and BANk could not be used,

(*b*) the name should not be phonetically similar to that of any exchange in the area,

(*c*) it must not include the letters Q or Z in the 3-letter code, because these letters are omitted from the lettered dial,

(*d*) it is desirable that some geographical or historical significance be associated with the area which the exchange serves, and

(*e*) the initial letter must not be an O.

Q. 7. Describe, with the aid of diagrams, the operation of a call-office installation arranged to receive pennies, sixpences, and shillings, and connected to an automatic exchange. What arrangements are made in the call-office installation and the exchange to ensure that the full fee is paid on a multi-fee call?

A. 7. The installation at a call-office arranged to receive pennies, sixpences and shillings, and connected to an automatic exchange, incorporates a prepayment multi-coinbox which provides the following facilities:—

(*a*) insertion of the local fee (two pennies) is necessary before a number can be dialled, except for 0-level and emergency calls,

(*b*) by means of buttons, which the caller is required to operate, the fee may be deposited if the call is effective or refunded if the call is ineffective. The operation of button A deposits the fee and that of button B refunds the fee,

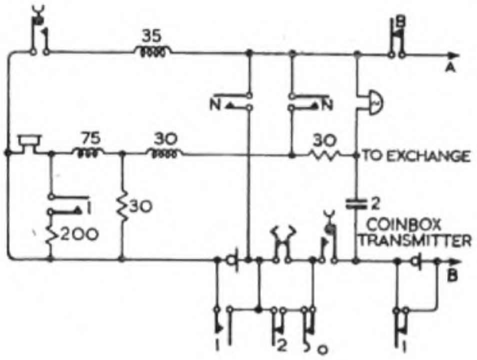
(*c*) additional fees required for multi-fee calls can be checked and collected.

The coinbox is provided at the top with three slots, marked "Penny," "Sixpence" and "Shilling," of sizes such that the use of coins larger than the correct size is prevented. Associated with each slot is a coin guide down which each coin inserted rolls, and in doing so is tilted and caused to pass over a coin gauge. If the coin is smaller than the correct size, it passes through the gauge into the refund chute. After passing the appropriate coin gauge, each coin is caused to strike either a wire gong or a bell gong. A penny strikes the wire gong once, a sixpence the bell gong once, and a shilling the bell gong twice. A coinbox transmitter is fitted inside the bell gong and transmits the sound of the striking of the gongs to the operator. After striking a gong, the coins fall down a swinging container and rest on a balance arm which is arranged to operate with the weight of two well-worn pennies.

When button A is pressed, the coin container is swung over and the coins are deposited in the cash box. When button B is operated, the coin container is swung over the refund chute which the coins then enter.

The circuit arrangements of the telephone set and the spring assemblies associated with the coinbox are shown in the sketch.

When the caller lifts the receiver, the gravity switch contacts close and the line is looped via the transmitter and the primary winding of the induction coil, but the dial impulsing contacts remain short-circuited until two pennies have been inserted. The insertion of the first penny causes the crank arm to operate spring assembly 1, which removes the short-circuit from the coinbox transmitter, short-circuits the normal transmitter and connects a 200-ohm shunt across the receiver to prevent it being used frauduently as a transmitter, whilst still permitting the caller to listen at a reduced level. The insertion of the second penny operates the balance arm which operates spring assembly 2. This removes the short-circuit from the dial impulsing springs and permits dialling to proceed. Whilst the dial is off-normal, its N-springs short-circuit the telephone circuit, connect a 30-ohm shunt across the bell to avoid tinkling and connect a spark quench circuit ($2\mu F + 30$ ohms) across the dial impulsing springs.



When the called subscriber answers and announces his identity, the caller presses button A to deposit the fee. This causes spring assemblies 1 and 2 to restore, and the telephone circuit is restored to normal.

If the call is ineffective, the caller presses button B and the coins are diverted to the refund chute. The operation of button B releases spring assemblies 1 and 2, and operates spring-set B which disconnects the line. Spring-set B is held open by a mechanical escapement for about seven seconds, so that the connection is cleared down.

0-level or emergency calls may be made without the insertion of coins. A special cam is fitted to the dial so that when 0 or 9 (for 999 service) is dialled, the 0 springs operate to remove the short-circuit from the dial impulsing springs.

The arrangements made in the call-office installation to ensure that the full fee is paid on a multi-fee call consist of the separate coin chutes and gongs described earlier, by means of which each denomination of coin makes a distinctive sound which is transmitted to the controlling operator by the coinbox transmitter, so that the fee inserted can be checked before the operator requests the caller to press button A. In the exchange, arrangements are made so that coinbox subscribers can only gain access automatically to single-fee routes—usually by connecting coinbox lines to a separate group of first selectors which do not have access to multi-fee routes, so that the assistance of the operator has to be obtained for multi-fee calls. The circuits from the coinbox group of selectors to the manual board are provided with a distinctive lamp signal on the switchboard so that the operator is made aware that the call is from a coinbox and that a fee has to be collected.

Q. 8. *Explain the meaning of the terms, (a) traffic unit, and (b) availability. Quote practical examples.*

A group of 2nd selectors has levels 1 and 2 connected to two groups of final selectors, the other 8 levels being spare. It may be assumed that there is full availability on all groups. If it is found that the first choice final selector on level 1 carries one-third of the total traffic offered to it, and the first choice final selector on level 2 carries one-quarter of the traffic offered to it, calculate the total traffic passing through the 2nd selectors.

A. 8. (*a*) The traffic unit is the unit of traffic flow. The traffic flow in traffic units for a specified period is numerically equal to the average number of calls in progress simultaneously; it is also equal to the product of the number of calls originating in the specified period and the average holding time expressed in terms of the period. Assume, for example, that the number of calls handled by a group of switches is read at 6-minute intervals for an hour, and that each call lasts exactly 6 minutes. If the readings obtained are 5, 9, 8, 6, 3, 7, 6, 4, 8, 4, then the average number of calls in progress simultaneously

$$= \frac{5+9+8+6+3+7+6+4+8+4}{10} = 6$$

and the traffic handled is 6 traffic units.

Similarly the number of calls originating in the hour $= 5+9+8+6+3+7+6+4+8+4 = 60$

and the average holding time $= 6$ mins. $= 0{\cdot}1$ hour.

So that the traffic handled $= 60 \times 0{\cdot}1 = 6$ T.U.

The symbol A is usually used to denote the traffic in T.U. and, if C = number of calls per hour and T the average holding time in hours, then $A = C \times T$.

The traffic in traffic units is also equal to the average number of calls originated in the average holding time. This can be shown by again employing the figures given above.

Total number of calls in hour $= 60$.

Average holding time $= 0{\cdot}1$.

Average number originated in average holding time $= 60 \times 0{\cdot}1 = 6$.

Traffic handled $= 6$ T.U.

(*b*) Availability is the number of trunks to which a selector has access on any route. Thus, a 24-outlet uniselector has an availability of up to 24, and a 200-outlet two-motion group selector has an availability of up to 20 on any level.

If A is the traffic offered and a the traffic carried by the 1st trunk, then

$$a = \frac{A}{A+1}$$

and on level 1

$$\tfrac{1}{3}A = \frac{A}{A+1}$$

$$\tfrac{1}{3} = \frac{1}{A+1} \quad \therefore A = 2$$

and for level 2

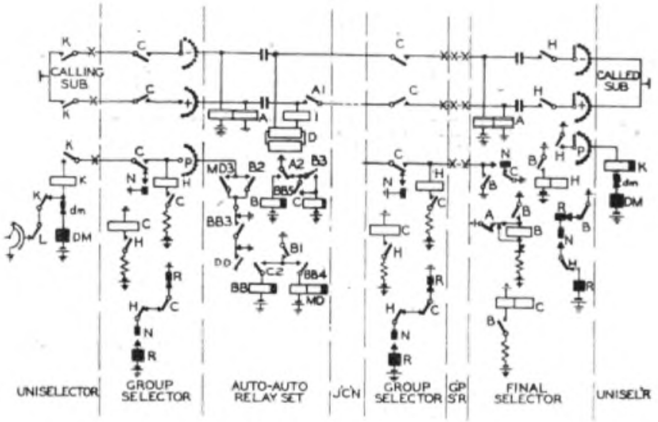
$$\tfrac{1}{4}A = \frac{A}{A+1}$$

$$\tfrac{1}{4} = \frac{1}{A+1} \quad \therefore A = 3$$

$\therefore$ Total traffic passing through second selectors $= 2+3 = \underline{5 \text{ T.U.}}$

Q. 9. *With the aid of diagrams of the circuit elements concerned, describe the sequence of events during the release of a call originated by a subscriber on an automatic exchange to a subscriber on a distant automatic exchange via an auto-auto relay-set. State the operate and release times of the relays involved in the release of the connection.*

A. 9. The circuit elements concerned with the sequence of events during the release of a call originated by a subscriber on an automatic exchange to a subscriber on a distant automatic exchange via an auto-auto relay set are shown in the sketch.



When the caller replaces his receiver, relay A in the auto-auto relay set releases. A1 disconnects the junction to open the loop to the distant exchange selectors, which commence to release. Relay A in the final selector releases, short-circuiting relay B which releases slowly. The release of relay B disconnects relay H and removes the holding earth from the final selector P-wire, releasing the H relays of the preceding group selectors at the distant exchange. In the final selector, when B and H restore the R magnet self-drive circuit is completed to restore the wipers. In the group selectors, the release of H disconnects relay C, which releases and completes the R magnet self-drive circuit to restore the wipers. During release an earth is connected to the P-wire of each selector to prevent the selector being seized whilst the wipers are off-normal.

As the P-wire is not extended over the junction, it is necessary to provide for this guarding earth on the junction P-wire at the outgoing end, to prevent the junction being seized before the associated 1st selector has restored. This is known as "long junction guard" and is provided in the auto-auto relay set in the following manner. When relay A releases and A1 opens the loop to the distant selectors,

TELEPHONE EXCHANGE SYSTEMS II, 1950 (*continued*)

A2 disconnects relay B, but, during the slow release of B, relay C operates via B3 and A2. C2 re-operates relay BB which, at BB4, operates MD. MD3 maintains an earth on the relay set P-wire to guard the junction. After the release lag of relay B, B1 disconnects BB and MD, and B3 disconnects relay C. The operation of MD, after the release of A, guards the junction for a period equal to the release lag of B plus the release lag of MD, and this is sufficient to allow the distant 1st selector to release.

At the originating exchange, the release of MD3 disconnects the earth from the P-wire, and the H relays of the group selectors and K relay of the caller's uniselector circuit restore. The release circuit of the group selectors and the homing circuit of the uniselector are thus completed.

The approximate operate and release times of the relays involved in the release of the connection are given below.

Originating Exchange.—A relay (A-A R.S.) release 3 mS, B relay (A-A R.S.) release 350 mS, C relay (A-A R.S.) operate 10 mS, BB relay (A-A R.S.) operate 10 mS, MD relay (A-A R.S.) release 350 mS, H relay (group selector) release 5 mS, C relay (group selector) release 10 mS, R magnet (group selector) self-drive up to 300 mS.

Distant Exchange.—A relay (final selector) release 3 mS, B relay (final selector) release 350 mS, H relay (group selector) release 5 mS, C relay (group selector) release 10 mS, R magnet (group selector) self-drive up to 300 mS.

Q. 10. *In the power distribution system of a certain telephone exchange, the overall voltage drop between the power board P and a point C, twenty yards away, must not exceed one volt. At a point A on this cable run, 5 yards from P, some automatic switch racks are fed with 150 amperes, and at another point B, 5 yards farther on from A, other racks are fed with 200 amperes. The current leaving point C is 50 amperes.*

Calculate the minimum volume, in cubic inches, of copper conductor that would be required between P and C under each of the following three conditions :—

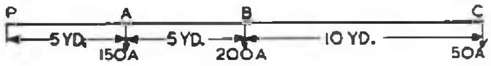
(*a*) *If the same size of cable were used throughout the run.*

(*b*) *If the voltage drop per foot run had to be the same throughout.*

(*c*) *If the current density were 800 amperes per square inch of cross-section of the conductors throughout.*

It should be assumed that the earth return conductors follow the same route and carry the same current as the corresponding battery feed, and that the resistance of 1,000 yards of copper conductor, one square inch in cross-section, is 0·025 ohm.

A. 10. The conditions are indicated in the sketch.



(*a*) If same size cable used throughout.

Let R = Resistance of both conductors P to C.

$$\text{Then voltage drop} = 400 \times \frac{R}{4} + 250 \times \frac{R}{4} + 50 \times \frac{R}{2}$$

$$= 187{\cdot}5\,R \text{ and this must not exceed 1 volt.}$$

$$\therefore R = \frac{1}{187{\cdot}5}$$

$$\text{Total length of conductor} = 20 \times 2 = 40\text{yd.}$$

$$\therefore \text{Cross-sectional area} = \frac{40 \times 0{\cdot}025/1{,}000}{1/187{\cdot}5}$$

$$= 0{\cdot}1875 \text{ sq. in.}$$

$$\therefore \text{Minimum volume in cu. in.} = 0{\cdot}1875 \times 36 \times 40$$

$$= \underline{270 \text{ cu. in.}}$$

(*b*) If voltage drop per foot run same throughout.

Then voltage drop PA = 0·25V

Then voltage drop AB = 0·25V

Then voltage drop BC = 0·5V.

$$\therefore \quad \text{Resistance PA} = \frac{0{\cdot}25}{400} = \frac{1}{1{,}600} \text{ ohm}$$

$$\text{Resistance AB} = \frac{0{\cdot}25}{250} = \frac{1}{1{,}000} \text{ ohm}$$

$$\text{Resistance BC} = \frac{0{\cdot}5}{50} = \frac{1}{100} \text{ ohm}$$

$$\therefore \text{Cross-sectional area PA} = \frac{1/4 \times 1{,}000}{1/1{,}600} = 0{\cdot}4 \text{ sq. in.}$$

$$\text{and volume PA} = 0{\cdot}4 \times 36 \times 10 = 144 \text{ cu. in.}$$

$$\text{volume AB} = \frac{1{,}000}{4 \times 1{,}000} \times 36 \times 10 = 90 \text{ sq. in.}$$

$$\text{volume BC} = \frac{100}{2 \times 1{,}000} \times 36 \times 20 = 36 \text{ sq. in.}$$

$$\text{Total volume PC} = \underline{270 \text{ cu. in.}}$$

(*c*) If current density 800 amp./sq. in.

$$\text{Cross-sectional area PA} = \frac{400}{800} = \frac{1}{2} \text{ sq. in.}$$

$$\text{Cross-sectional area AB} = \frac{250}{800} = \frac{5}{16} \text{ sq. in.}$$

$$\text{Cross-sectional area BC} = \frac{50}{800} = \frac{1}{16} \text{ sq. in.}$$

$$\text{Volume PA} = \frac{1}{2} \times 36 \times 10 = 180 \text{ cu. in.}$$

$$\text{Volume AB} = \frac{5}{16} \times 36 \times 10 = 112{\cdot}5 \text{ cu. in.}$$

$$\text{Volume BC} = \frac{1}{16} \times 36 \times 20 = 45 \text{ cu. in.}$$

$$\text{Total volume} = \underline{337{\cdot}5 \text{ cu. in.}}$$

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Q. 1. *A coil, which has an inductance of 0·1 henry, and a resistance of 50 ohms, is connected across one of two 100-ohm, non-reactive resistors, which are connected in series as in Fig. 1. The complete circuit is switched across a battery which has an e.m.f. of 4 volts and negligible internal resistance. Calculate the initial and final values of the currents in all branches of the circuit and the time constant of the circuit.*

Draw a graph to scale showing how the battery current varies with time.

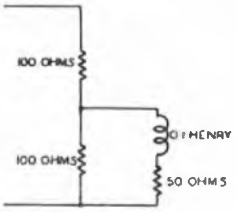
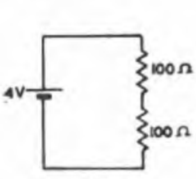


Fig. 1.

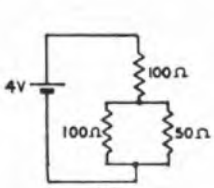
A. 1. At the instant of switching the circuit across the battery, no current will flow in the inductive resistance. Hence, the battery current and the current in the two 100-ohm resistors (sketch (*a*)) will be

$$\frac{4}{100 + 100} = \underline{20 \text{ milliamperes.}}$$

Finally, when the current in the inductive resistor has reached a steady value, there will be no back E.M.F. induced in the circuit, which can then be represented as in sketch (*b*). The combined resistance of the parallel branch is given by:—



(a)



(b)

$$\frac{1}{R} = \frac{1}{100} + \frac{1}{50} = \frac{3}{100} \qquad \therefore R = \frac{100}{3}$$

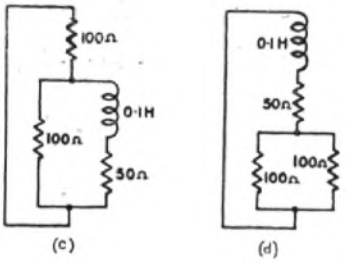
Thus the total resistance of the circuit is 100 + 100/3 = 400/3 ohms.

$$\text{The battery current} = \frac{4}{400/3}$$

$$= \underline{30 \text{ milliamperes.}}$$

The current through the shunted 100-ohm resistor will be 10 mA, and the current flowing in the inductive resistor will be 20 mA.

To determine the time constant of the circuit, the battery is replaced by a short circuit (sketch (*c*)), which can be rearranged as in sketch (*d*). Thus, the required time constant is



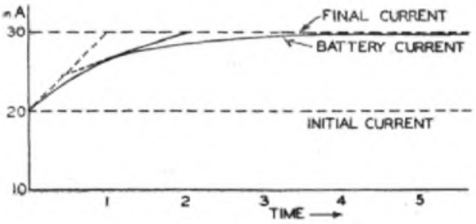
(c) (d)

$$\frac{0{\cdot}1}{50 + 100/2} = \frac{0{\cdot}1}{100} = 1 \text{ millisecond.}$$

At this time the battery current will be :—

$$20 + \frac{63{\cdot}2}{100}\left(10\right) = \underline{26{\cdot}32 \text{ mA.}}$$

The variation of battery current withtime (mS.) is given in sketch (*e*).



(*e*)

Q. 2. As indicated in Fig. 2 below, the primary winding of an air-cored mutual inductance is connected in series with a 50-ohm non-reactive resistor across a sinusoidal A.C. supply which has a frequency of 10 kilocycles/second. The secondary winding is connected to a variable capacitor and a non-reactive resistor of 100 ohms which are joined in series. When the capacitance is 0·1µF, the voltage across the 100-ohm resistor has a maximum value of 1 volt r.m.s. and the voltage across the 50-ohm resistor in the primary circuit is 2 volts r.m.s. Calculate the value of the mutual inductance between the windings, and the self-inductance of the secondary winding. The resistance of the secondary winding can be neglected.

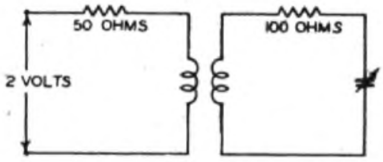


Fig. 2.

A. 2. Primary current, i_p, $= 2/50 = 40$ mA.
E.M.F. induced in secondary, $e_s = \omega M i_p$.
Secondary current, $i_s = 1/100 = 10$ mA.

Since the secondary is at resonance and as the resistance of the secondary winding can be neglected,

$$i_s = e_s/R = \omega M i_p/R$$

$$\therefore M = \frac{100 \times 10/1{,}000}{2\pi\ 10^4 \times 40/1{,}000} = \frac{10^{-2}}{8\pi}$$

$$= \underline{0{\cdot}398 \text{ mH.}}$$

$$\text{and } \omega l_s = \frac{1}{\omega C}$$

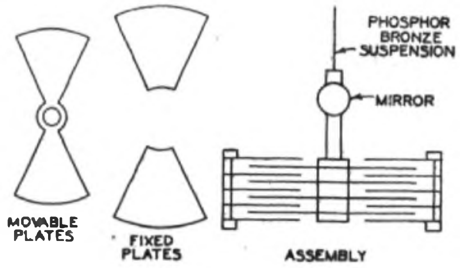
$$\text{or } l_s = \frac{1}{\omega^2 C} = \frac{10^6}{4\pi^2 \times 10^8 \times 0{\cdot}1}$$

$$= \underline{2{\cdot}5 \text{ mH.}}$$

Q. 3. Describe the construction and principle of operation of an electrostatic voltmeter.

Two similar electrostatic voltmeters, having a maximum scale reading of 500V and negligible leakance, are joined in parallel and then connected across a 200-V, D.C. supply. After disconnection from the supply the pointer of one instrument is moved to full-scale deflection by means of an insulated probe. Describe the resulting effect on the other instrument, giving reasons.

A. 3. An electrostatic voltmeter is, in effect, a variable air-spaced capacitor in which the movable plates are suspended or pivoted so that they can interleave freely with the fixed plates. The shape of the plates depends on the type of scale required. One type is shown in sketch (*a*). When the movable plates are suspended, a mirror is fixed to them, so that their movement can be detected by means of a lamp and scale. The controlling torque is applied by the suspension (phosphor-bronze). When the movable plates are pivoted, their movement is indicated by a light pointer which is fixed to them and moves over a graduated scale. In this case the controlling torque is applied by one or more phosphor-bronze "hair" springs, which also provide an electrical connection to the movable plates.



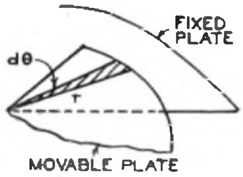
(*a*)

When the instrument is uncharged, the movable plates are not interleaved with the fixed plates.

Suppose a D.C. supply, of voltage V, is connected across the instrument with, say, the movable plates joined to the positive terminal and the fixed plates to the negative. Since the two sets of plates will thus have opposite electric charges a force of attraction will be exerted which, if large enough to overcome friction, will cause the movable plates to interleave with the fixed plates against the controlling torque and come to rest when,

$$\text{Deflecting Torque} = \text{Controlling Torque.}$$
$$\text{or } T = T_0 + K_1\theta$$

where T_0 is the frictional torque, K_1 is the stiffness of the suspension or control springs, and θ is the angle of deflection. During this motion, the capacitance of the instrument will have increased from C_0 farads, its initial value, to C farads. The precise manner in which this change takes place will depend on the way in which the area of overlap between the movable and fixed plates varies.



(*b*)

Now, referring to sketch (*b*), area of overlap $= \int \frac{1}{2} r^2 d\theta$.

If r is constant, we have area of overlap $= \frac{1}{2} r^2\theta = A$.

$$\therefore C = C_0 + \frac{nr^2\theta}{8\pi d} \times \frac{1}{9} \times 10^{-11} \text{ farads}$$

where d cms. is the thickness of a dielectric and n is the number of dielectrics.

Thus, $C = C_0 + K_2\theta$. But the energy stored in a charged capacitor $= \frac{1}{2} CV^2$ joules, and, since the electrostatic voltmeter will remain deflected, when the supply is removed, it follows that this amount of electrical energy must be equal to the mechanical energy stored in the control system and is given by $\int_0^\theta K_1\,\theta d\theta = \frac{1}{2} K_1\theta^2$ (discounting friction ($T_0 = 0$)). Hence, if the initial capacitance, C_0, can be neglected, we have :—

$$\frac{1}{2} K_2\theta V^2 = \frac{1}{2} K_1\theta^2, \text{ or } \theta = \frac{K_2}{K_1} V^2.$$

Thus, the instrument will have a square-law scale.

Suppose r is a function of θ, i.e., $r = F(\theta)$, then

$$A = \int \frac{1}{2} \left\{ F\ (\theta) \right\}^2 d\theta$$

and neglecting C_0, $$C = K_2 \int \left\{ F\ (\theta) \right\}^2 d\theta.$$

Thus, $\frac{1}{2} K_2\ V^2 \int \left\{ F\ (\theta) \right\}^2 d\theta = \frac{1}{2} K_1\ \theta^2$,

so that the scale of the instrument will depend on the shape of the movable plates.

It will be apparent that, if the connections between the D.C. supply and the electrostatic voltmeter are reversed, a force of attraction will still exist between the movable and fixed plates, so that the deflection will be in the same direction. It follows, therefore, that the instrument is satisfactory for measuring alternating voltages. The reading of an electrostatic voltmeter is proportional to the effective or root mean square value of the applied alternating voltage.

When the two electrostatic voltmeters are connected across the 200V D.C. supply, each will register this value and their registrations will be unaffected when they are subsequently disconnected from the supply. However, if then the pointer of one is moved to full-scale deflection, 500V, the capacitance of this instrument and, therefore, that of the whole system will be increased. But $C = Q/V$ or $V = Q/C$, and since Q, the total charge stored in the system, remains constant, it follows that the actual potential difference across the movable and fixed plates of each instrument will be reduced.

The instrument which is free to move will tend to indicate this lower value, but, in so doing, its capacitance and, therefore, that of the whole system will be reduced. Thus, the final reading of this second instrument will be less than 200V. The amount will depend on the manner in which the capacitance of the instruments vary with deflection.

Suppose that the initial capacitance, C_0, of each instrument can be neglected and that each has a square-law scale.

Let the capacitance of each, when indicating 200V, be C_1 farads.

Total charge stored in system, $Q = 2\ C_1\ 200 = 400\ C_1$ coulombs.

Also, $C_1 = K\ (200)^2$ or $K = \frac{C_1}{(200)^2}$

When the pointer of one instrument is moved to 500V, its capacitance will be :—

$$C_2 = K\ (500)^2 = C_1 \left(\frac{5}{2}\right)^2$$

If the final reading of the other instrument is V, the capacitance of this instrument will be :—

$$C_3 = KV^2 = C_1 \left(\frac{V}{200}\right)^2$$

The total capacitance of the system is

$$C_2 + C_3 = C_1 \left\{ \left(\frac{5}{2}\right)^2 + \left(\frac{V}{200}\right)^2 \right\}$$

$$\therefore\ V = \frac{Q}{C} = \frac{400\ C_1}{\frac{C_1}{4} \left\{ 5^2 + \left(\frac{V}{100}\right)^2 \right\}}$$

$$25V + \frac{V^3}{10^4} \approx 1{,}600.$$

i.e., $V^3 + 2{\cdot}5 \times 10^5\ V - 1{\cdot}6 \times 10^7 = 0$, from which it will be found that $V \simeq 64$ volts.

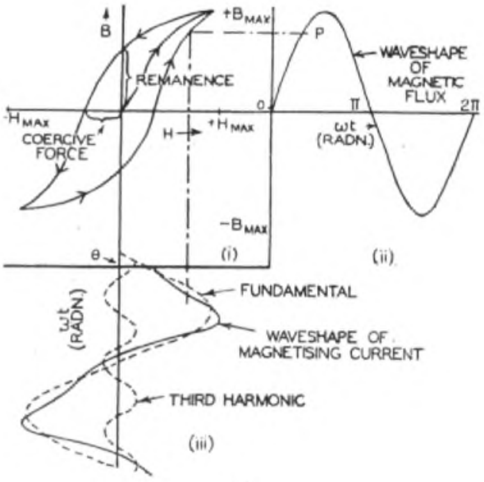
Q. 4. *Sketch the hysteresis loop for a sample of hard steel. If this were used for the closed, solid core of a transformer, deduce the approximate waveshape of the magnetizing current when the primary is connected across a sinusoidal A.C. supply the peak value of which causes the core to become magnetically saturated. Thence, point out some disadvantages from the use of this core material. Resistance of the winding and leakage may be neglected.*

What other difficulties arise from the use of a solid core in an alternating current transformer?

Describe how these defects are reduced in transformers for telecommunication purposes.

A. 4. The hysteresis loop for a sample of hard steel has been sketched in sketch (*a*) (*i*). It will be observed that the material is not readily magnetised. Again, the ratio of the coercive force to the remanence is high, indicating that it is not readily demagnetised, that is, it has a high retentivity.

The area contained by the loop is large, so that the energy required to carry the steel through a cycle of magnetisation is large, that is, the steel has a high hysteresis loss.



(*a*)

When the secondary winding of a transformer is open-circuited, the voltage applied to the primary winding must be equal and opposite to the vector sum of :—

(*a*) the voltage drop across the effective reactance of the primary winding, i.e., the back E.M.F. induced in the primary and given by

$$e = N \frac{d\Phi}{dt} \times 10^{-8} \text{ volts}$$

$$= NA \frac{dB}{dt} \times 10^{-8} \text{ volts.}$$

(*b*) the voltage drop across the leakage reactance of the primary,

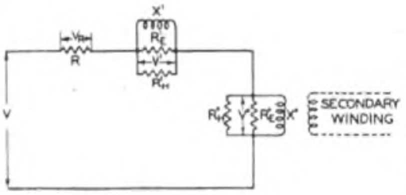
(*c*) the voltage drop across the effective resistance of the primary winding.

Although these three components are regarded as being in series with the primary current, it should be realised that actually (*c*) comprises :—

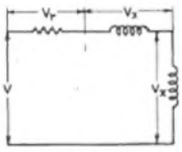
(i) the conductor resistance of the primary winding which is definitely in series with the primary current,

(ii) two sets each of two resistances in parallel, one set across (*a*) and the other across (*b*).

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



(*b*)



(*c*)

R'_H and R''_H are shunt resistances which will produce losses in power, $(V')^2/R'_H$ and $(V'')^2/R''_H$, equivalent to the hysteresis losses of the magnetic circuits of the reactances with which they are associated.

R'_E and R'_E give losses equivalent to those caused by the corresponding eddy currents.

The circuit of sketch (*b*) is equivalent to that shown in sketch (*c*) for any particular set of conditions.

If V_r and V_X can be neglected in comparison with V_x then,

$$V = V_X = -e = -NA \frac{dB}{dt} \times 10^{-8}.$$

or the applied voltage is proportional to the rate of change of flux density in the transformer core.

Hence, with the assumptions outlined above, the applied voltage is proportional to the rate of change of flux. If the applied voltage is sinusoidal, the rate of change of flux density is sinusoidal and the flux density must have a sinusoidal waveshape 90° out of phase with V. This has been shown in sketch (*a*) (ii) and, by projecting on to the hysteresis loop, the waveshape of the magnetising current can be determined, as in sketch (*a*) (iii). It will be observed that this comprises mainly a sinusoidal fundamental and a third harmonic.

The fundamental of the current wave is not in phase with the flux density but leads by the small angle θ. This means it has two components, one in phase with the applied voltage, which indicates a power loss due to hysteresis, and the other at right-angles to the former (and therefore 90° out of phase with the applied voltage) which produces the magnetic flux.

Thus, the disadvantages from using hard steel as the core of a transformer are :—

(*a*) large hysteresis loss,

(*b*) large third harmonic component in the magnetising current,

(*c*) larger number of turns or core cross-sectional area than with a material which will magnetise more readily, i.e., which has a greater permeability.

Other disadvantages are :—

(*d*) eddy current losses high,

(*e*) difficulties in manufacture, particularly in winding the core.

These difficulties can be overcome or reduced in transformers, for telecommunication purposes, if the core is built up from thin laminations of a high permeability magnetic material which has a high specific resistance. Alternatively, split cores of iron dust may be used. These are moulded from fine particles of a high permeability magnetic material, such as nickel iron, each separately insulated, and a suitable binder.

When winding difficulties are not important, toroidal iron dust cores are used, e.g., loading coils.

Q. 5. *An alternating voltage of sinusoidal waveshape is applied across the circuit shown in Fig. 3, which consists of :—*

$C = 2\mu F,$

$l = 0{\cdot}08H,$

$r = 300$ *ohms,*

and $R = 250$ *ohms.*

If the current in the inductive resistance is 10 *mA when the angular frequency of the supply,* $\omega = 5{,}000$ *rdn/sec., determine, by means of a vector diagram or otherwise,*

(*a*) *the current in R,*

(*b*) *the total current supplied,*

(*c*) *the total power dissipated in the circuit,*

(*d*) *the voltage applied across the circuit,*

(*e*) *the power-factor of the circuit*

under these conditions.

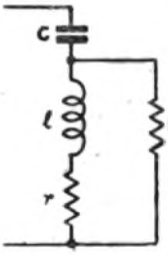
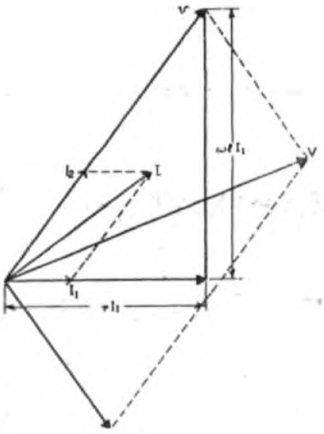


Fig. 3.

A. 5. At $\omega = 5{,}000$ rdn./sec.

$$\frac{1}{\omega C} = \frac{10^6}{2 \times 5{,}000} = 100 \text{ ohms.}$$

$$\omega l = 0{\cdot}08 \times 5{,}000 = 400 \text{ ohms.}$$



With reference to the vector diagram, the voltage, v, across the inductive resistance is the vector sum of 3 volts across r and 4 volts across l, namely, 5 volts.

Thus, the current, I_2, in the non-reactive resistance of 250 ohms is

$$I_2 = \frac{5}{250} = \underline{20 \text{ mA.}} \text{ in phase with } v.$$

Therefore, the current, I, supplied to the circuit is the vector sum of I_1 (= 10 mA) and I_2, which is in phase with the voltage across R.

$$I = \underline{27{\cdot}25 \text{ mA.}}$$

The voltage across the capacitance is 2·72 volts lagging 90° behind I.

Hence, the voltage, V, applied to the circuit is the vector sum of this 2·72 volts and v.

$$V = \underline{4{\cdot}93 \text{ volts.}}$$

The power, W, absorbed by the circuit, is :—

$$W = \left(\frac{20}{1{,}000}\right)^2 \times 250 + \left(\frac{10}{1{,}000}\right)^2 \times 300$$

$$= 0{\cdot}1 + 0{\cdot}03 = \underline{0{\cdot}13 \text{ watts.}}$$

But $VI = 4{\cdot}93 \times 27{\cdot}25/1{,}000 = 0{\cdot}1343.$

$$\therefore \quad \text{Power factor} = \frac{W}{VI} = \frac{0{\cdot}13}{0{\cdot}1343} = \underline{0{\cdot}9667.}$$

Q. 6. *Construct the vector diagram for an iron-cored transformer when a current of convenient magnitude flows in the inductive load which is connected across the secondary winding. Thence, or otherwise, show—*

(*a*) *the effect of the magnetising current on the total primary current,*

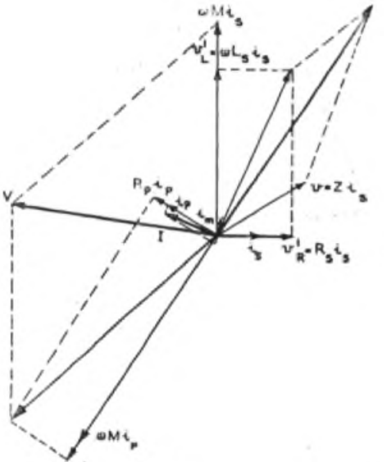
(*b*) *how the phase relationship between the primary and secondary currents can be determined,*

(*c*) *how the impedance measured across the primary winding is affected by the secondary load.*

What is understood by the term "ideal" when applied to transformers? A transformer, which can be assumed to be ideal, has two separate windings which have a turns ratio of three. Using this transformer and a 900-ohm resistor, show how at least four different values of resistance can be obtained.

A. 6. The vector diagram has been drawn in sketch (*a*) : i_s represents the sinusoidal current of convenient magnitude which flows in the load. $v = Zi_s$ represents the voltage across the inductive load and leads the load current. The voltages, due to i_s flowing in the resistance, R_s, and the inductance, L_s, of the secondary winding are added vectorially to v.

The total E.M.F. induced in the secondary winding must be equal and opposite to this combined vector and equals $j\omega Mi_p$, where M is the mutual inductance between the windings and i_p is the primary current. Hence, i_p, lagging 90° behind the secondary E.M.F., can be determined.

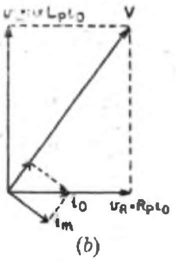


(*a*)

The voltages due to this current flowing through the effective resistance, R_p, and the effective inductance, L_p, of the primary have been drawn and added vectorially. Their resultant has been added vectorially to the vector $j\omega Mi_s$, which is the E.M.F. induced in the primary winding by the secondary current, i_s, to determine V, the applied voltage.

The effect of iron losses (hysteresis and eddy current losses) has been included in the foregoing by assuming that R_p and L_p are the effective resistance and inductance respectively of the primary winding. The magnetising current, i_m, of a transformer can be determined graphically from the no load primary current, i_0, and the applied voltage, V, (i_0 is the current flowing in the primary winding due to the applied voltage, V, when the secondary is open-circuited). A vector diagram, to a different scale, has been constructed in sketch (*b*) to obtain the voltage, V, which must be applied across the primary, when the secondary is open-circuited, to cause i_0 to flow through the effective resistance, R_p, and effective reactance, ωL_p, of the primary winding.

i_0 can be resolved into two components at right-angles, one in phase with V and the other lagging 90° behind V. The former multiplied by V gives the power absorbed by the transformer on no load, while the latter is known as the magnetising current, i_m.

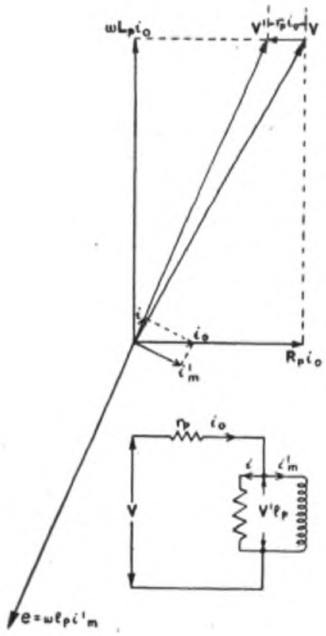


(*b*)

It should be pointed out, however, that the foregoing construction assumes that the conductor resistance of the primary winding, r_p, is negligible. When this is not so, a vector, $r_p\, i_0$, in phase with i_0 must be subtracted from the applied voltage, V, to obtain the voltage, V', which is equal and opposite to e, the back E.M.F. generated in the primary winding, due to the true magnetising current, i'_m, flowing through the actual self-inductance, l_p, of the primary winding. i'_m leads e and lags behind V' by 90°.

The component of i_0 at right-angles to i'_m and in phase with V', when multiplied by V', gives the core loss (hysteresis and eddy current losses in the iron core) at no load.

Even this construction, as shown in sketch (*c*), is not strictly correct, since it neglects the effects of primary leakage inductance and the power losses introduced by it. In addition, the effect of self-capacitance has been neglected.



(*c*)

In iron-cored transformers of good design the magnetising current can be assumed constant from no load to full load, and so can the iron losses. Hence, when a load is connected across the secondary winding, the primary current will have two components; namely, the no-load current, i_0, and a component which will provide an equal number of magnetising ampere-turns to counter-balance the demagnetising ampere-turns imposed on the core by the secondary current. The phase of this current will be determined by the characteristics of the load; thus, the primary current will be the vector sum of its two components. The smaller the no load current and, therefore, the smaller the magnetising current, the smaller will be the effect of the magnetising current on the total primary current.

The phase relationship between primary and secondary currents can be determined directly from the vector diagram of sketch (*a*). From the foregoing, it will be realised, however, that, if the no load primary current can be neglected, the primary current will be 180° out of phase with the secondary. Suppose I_p and I_s represent the primary and secondary currents under these conditions, and that N_p and N_s denote the number of turns on the primary and secondary windings respectively, then :—

Magnetising Ampere Turns = Demagnetising Ampere Turns

or $|I_p|\, N_p = |I_s|\, N_s$

The impedance which would be measured across the primary winding, when an inductive load is connected across the secondary, could be obtained from sketch (*a*) by finding the vector quotient of V and i_p.

Generally, power supplied to a transformer

$= (|I_p|)^2\, |Z_p| \cos \phi_p$

= Power supplied to secondary load + power losses in the transformer itself.

$= (|I_s|)^2\, |Z_s| \cos \phi_s + W_i + W_c$

where :—

W_c represents the copper losses in the transformer windings $= (|I_p|)^2\, r_p + (|I_s|)^2\, r_s$

W_i represents the core losses (hysteresis and eddy current losses in an iron core),

$|Z_s| \underline{/\phi_s}$ represents the impedance of the secondary load and $|Z_p| \underline{/\phi_p}$ is the resulting impedance measured across the primary winding.

Hence,

$$|Z_p| \cos \phi_p = \left(\frac{|I_s|}{|I_p|}\right)^2 |Z_s| \cos \phi_s + \frac{W_i + W_c}{(|I_p|)^2}$$

If iron and copper losses can be neglected,

$$|Z_p| \cos \phi_p = \left(\frac{|I_s|}{|I_p|}\right)^2 |Z_s| \cos \phi_s$$

$$= \left(\frac{N_p}{N_s}\right)^2 |Z_s| \cos \phi_s.$$

Thus,

$$\phi_p = \phi_s$$

$$\text{and } |Z_p| = \left(\frac{N_p}{N_s}\right)^2 |Z_s|$$

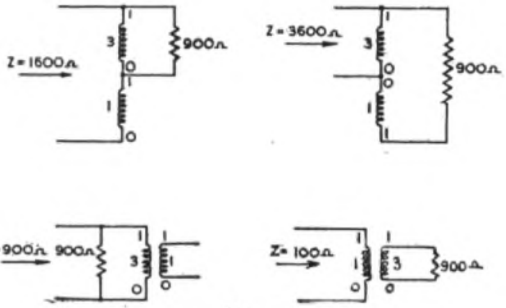
A transformer is said to be ideal when :—

(i) it has no losses, i.e., $W_i = W_c = 0$,

(ii) there is no magnetic leakage between primary and secondary windings, i.e., $M = \sqrt{L_p L_s}$,

(iii) it has no magnetising current. Thus, ωL_p and, therefore, ωL_s must be infinitely large.

From the four typical connections, shown in sketch (*d*), it will be seen how a transformer, which has a turns ratio of 3, and a 900-ohm resistor can be used to obtain different values of resistance. The transformer can be connected as an auto-transformer, with the windings series aiding, series opposing, or as two separate windings.



(*d*).

Other values of resistance obtainable by re-arrangement of connections are : 0 ; 56·25, 225, 506·25, 8,100 and 14,400 ohms.

(*To be continued*)

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