

SUPPLEMENT

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GUIDANCE FOR STUDENTS

Contents

CGLI: LINE PLANT PRACTICE B 1979	65
CGLI: LINE PLANT PRACTICE C 1979	68
CGLI: MATHEMATICS B 1980	71
CGLI: TELECOMMUNICATION PRINCIPLES B 1980	76
CGLI: TELEGRAPHY B 1980	79
CGLI: TELECOMMUNICATION PRINCIPLES C 1980	82
CGLI: TELEPHONY C 1980	85
CGLI: TELEGRAPHY C 1980	89
TEC: ELECTRICAL PRINCIPLES 2	94

CITY AND GUILDS OF LONDON INSTITUTE

Questions and Answers

Answers are occasionally omitted or reference is made to earlier Supplements in which questions of substantially the same form, together with the answers, have been published. Some answers contain more detail than would be expected from candidates under examination conditions.

LINE PLANT PRACTICE B 1979

Students were expected to answer any 6 questions

Q1 Describe, with the aid of sketches

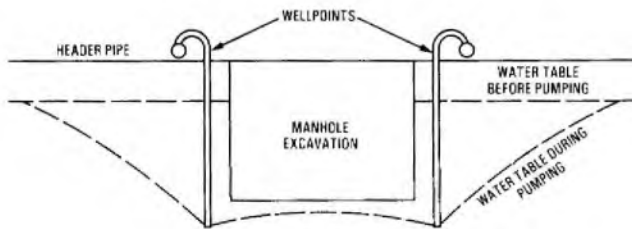
(a) how wellpoints are used to lower the water table of the ground in which a manhole is to be constructed, and

(b) the details of the valve system of a wellpoint.

A1 (a) To lower the water table of the ground before a manhole excavation is made, a number of wellpoints are sunk into the ground around the proposed site. The wellpoints are sunk by first removing the hard paving and foundation material where necessary to expose the soil, placing the tube vertically in the hole and pumping water down the tube under pressure.

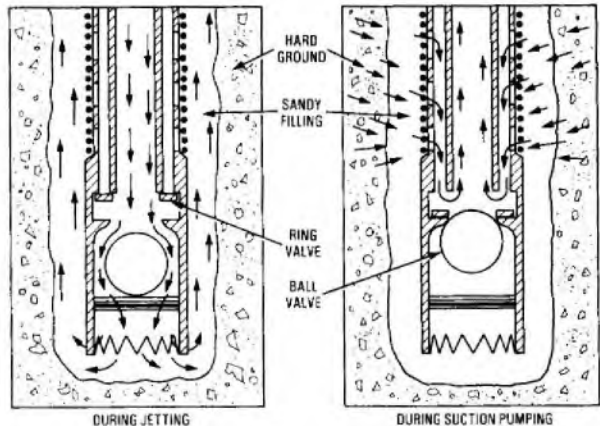
The jet of water erodes the soil below the tube, which normally sinks under its own weight. In difficult soils the jetting is assisted by rotating the serrated cutting edge. In cohesive soils it may be necessary to clear a space for the soil to be washed out by using a chain to enlarge the hole. The chain hook is disengaged by lifting the tube slightly and the chain can then be withdrawn on completion.

The space around the tube is filled with a granular soil to act as a coarse filter and the wellpoint can then be connected to the inlet of the pressure pump and used as a water source for sinking other well points. When all wellpoints are in position they are connected to a common header pipe and this in turn is connected to a suitable size suction pump. As pumping continues, the water table is lowered as shown in sketch (a) leaving the excavation site dry.



(a)

(b) Details of the valve system are shown in the sketches (b) and (c). During jetting the ring valve rises and closes-off the passage from the filters to the tube and directs water downwards past the ball valve which opens. When suction commences the ball valve is drawn up and seals off the water inlet through the base of the wellpoint. The ring valve falls and opens the route through the three filters which consist of a fine mesh sandwiched between two coarse filters. The water is then sucked away from the excavation and deposited elsewhere.



(b)

(c)

Q2 (a) Describe, with the aid of a diagram, the double-ended Varley test for locating a low insulation resistance fault on a length of cable.

(b) In a test on a cable pair 5 km long, the near-end and distant-end readings were 170Ω and 110Ω respectively. How far was the fault from the near end?

A2 (a) The equipment required to carry out a double-ended Varley test consists principally of two Wheatstone bridges, one connected at each end of the cable under test. The sketch shows the circuit arrangements and the test is made as follows.

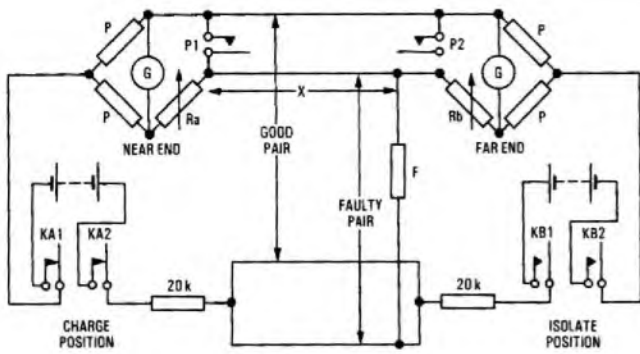
(i) The line is charged up from the near-end battery by putting key KA in the charge position. Key KB is left in the isolate position. The line is short-circuited at the far end by inserting plug P2. Plug P1 is not inserted at the near end.

(ii) The bridge resistor at the near end (R_a) is adjusted to give zero deflexion on the galvanometer. When the zero reading is constant the value of R_a is recorded.

(iii) A similar test is made at the far end by putting key KB in the charge position, and key KA at the near end in the isolate position. Plug P2 is removed and P1 inserted. The far-end bridge is balanced and the value of resistor R_b recorded.

These tests are repeated several times to obtain accurate mean values for R_a and R_b . The distance to the fault is calculated from the following formula:

LINE PLANT PRACTICE B 1979 (continued)



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

Where X = distance to fault from near end in kilometres,
 R_a = near-end Varley reading,
 R_b = far-end Varley reading, and
 L = length of cable in kilometres.

(b) Substituting the given values: $R_a = 170 \Omega$, $R_b = 110 \Omega$, $L = 5 \text{ km}$ gives

$$X = \frac{100 \times 5}{170 + 110} \text{ km} = 1.96 \text{ km.}$$

Thus, the fault is 1.96 km from the near end.

Q3 A 1.83 km loading section of audio cable has been laid.

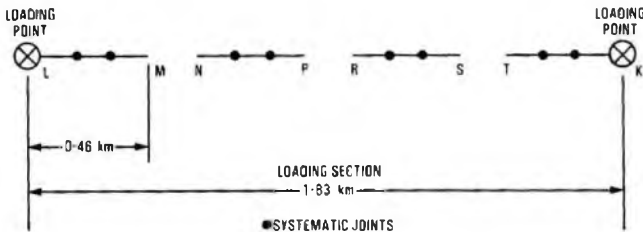
(a) Draw a diagram showing where the systematic and test-selected joints in the loading section of cable would be located.

(b) Describe how the final joints would be made in the cable section length.

(c) Compare the effects of systematic jointing with that of test selection.

(d) Draw up a typical systematic jointing schedule for a 14-pair quad cable.

A3 (a) The diagram is shown in the sketch.



(b) Referring to the diagram, test-selected joints will be made first at MN and ST and then the complete section will be connected together by making the final test-selected joint at PR.

(c) The use of systematic jointing is sufficient to compensate for the quad-to-quad unbalances throughout the loading section, while test selected jointing is used to eliminate within-quad unbalances. The object of test selection is to connect together quads in such a manner that the within-quad unbalances of adjacent sections cancel out.

(d) The table shows a typical systematic jointing schedule for a 14-pair quad cable.

	Up-side quad No.	Down-side quad No.
Centre	1	2
First Layer	2	4
	3	6
	4	1
	5	3
	6	5
	7	7

Q4 A 3 mm diameter steel suspension wire supporting an aerial cable is to be erected on a pole route. The stress on the wire must not exceed 500 MPa and the maximum dip allowed is 550 mm. The cable and wire together weigh 4.8 N/m. Calculate the maximum lengths of span that could be used along the route.

A4 If the diameter of wire is 3 mm then the tension (T) in the wire if limit of stress is 500 MPa becomes

$$T = 500 \times \pi \times 1.5^2 \text{ N},$$

$$= 3534.3 \text{ N.}$$

If span length is L the weight of the cable and wire is w and dip (d) is 0.550 m

$$T = \frac{w \times L^2}{8 \times d} \text{ N,}$$

$$= \frac{4.8 \times L^2}{8 \times 0.55} = 3534.3 \text{ N.}$$

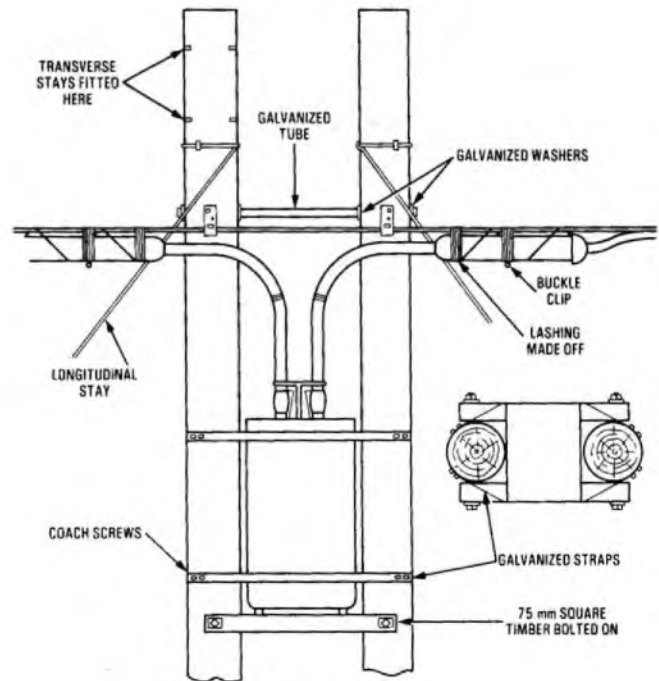
$$\text{Thus, } L^2 = \frac{3534.3 \times 8 \times 0.55}{4.8} = 3240.$$

$$\text{Limiting span} = \sqrt{3240} = 56.92 \text{ m.}$$

Q5 With the aid of sketches describe a method of loading an aerial cable using a loading case with twin stubs and an auxiliary pole mounting.

A5 The auxiliary pole is mounted close to the main pole and the loading pot is mounted on a platform between the two poles. The auxiliary pole should be of approximately the same diameter as the line pole to ensure that the arms forming the platform are parallel. The auxiliary pole can be mounted either in front of the line pole or alongside it depending on the layout of the route.

The sketch shows a detailed layout of a loading pot mounted between two poles in line with the route.



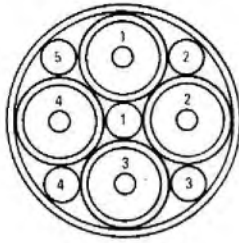
Q6 A cable consists of four 1.2/4.4 A coaxial pairs and five 0.63 mm pairs.

(a) Draw a cross-section of the cable showing layout and numbering of the pairs.

(b) Give a table of colour-code marking of the 0.63 mm pairs.

(c) Using a sketch describe the make up of ONE of the coaxial pairs.

A6 (a) A cross-section of the cable is shown in sketch (a).

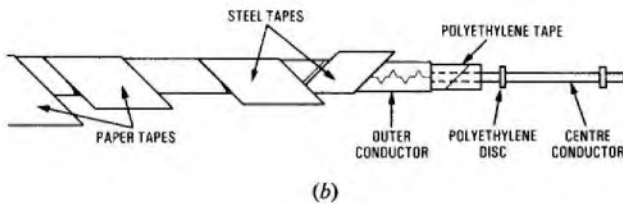


(a)

(b) The colour-code marking is shown in the table.

	Pair No.	Colour	Marking
Centre pair	1	Green	, .
	2	Orange	, .
Interstice pairs	3	Orange	, .
	4	Blue	, .
	5	Blue	, .

(c) A 1.2/4.4 mm coaxial pair consists of a solid copper central conductor of 1.2 mm diameter enclosed in an outer cylindrical conductor of 4.4 mm internal diameter. The outer conductor is supported concentrically with the central conductor by polyethylene discs equally spaced along the central conductor. Overall insulation between the inner and outer conductors is provided by a thin high density polyethylene tape wound over the discs. To provide adequate mechanical strength and electromagnetic screening, the pair is bound with two layers of mild steel tapes. To insulate and identify the coaxial pair, two thicknesses of insulating paper tape having an identifying number printed on it are used. The make-up of the pair is shown in sketch (b).

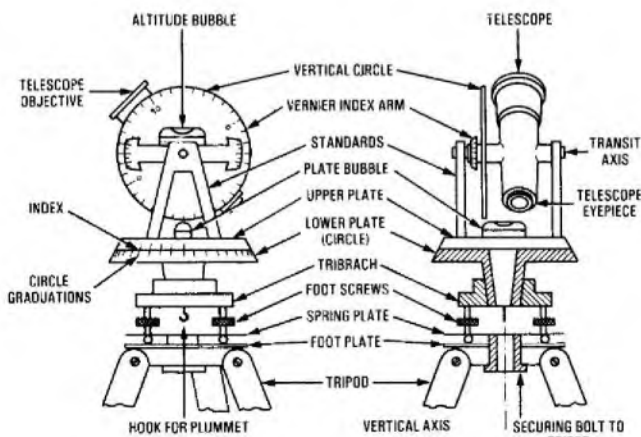


(b)

Q7 (a) Describe, with the aid of sketches, the basic construction of a theodolite.

(b) Describe how a theodolite would be used to measure the height of an aerial dish mounted on a mast.

A7 (a) The essential features of a theodolite are shown in the sketches.



The main parts of a theodolite are as follows:

- (i) telescope,
- (ii) levelling head,
- (iii) lower and upper plates,
- (iv) vertical measuring circle and standard,
- (v) bubble tubes,
- (vi) clamp and target screws, and
- (vii) supporting tripod.

(b) The theodolite is set up at a measured distance from the base of the mast and then the telescope is ranged on to the centre of the aerial dish. The angle of elevation is read from the vertical scale from whence the height can be calculated from

$$\text{height} = \text{base} \times \text{tangent of elevation angle.}$$

Q8 Describe FIVE methods by which trunk and junction circuits can be provided in a telecommunications system.

A8 (i) *Audio circuits.* For short distance transmission where the loss is low, 2-wire unamplified circuits are used. When the transmission loss of a line exceeds the maximum permitted for its particular use, amplifiers must be inserted in the circuit. Circuits up to 50 km in length can still be worked on a 2-wire basis, but when the length exceeds 50 km a 4-wire circuit must be used. A 4-wire circuit uses a separate pair of wires in the same cable for each direction of transmission.

(ii) *4-wire carrier.* Twenty-four channels are transmitted over each pair of a 24-pair PCQT cable, separate cables being used for each direction of transmission. It is possible to provide 576 circuits over the two 24-pair cables. Repeater stations are provided along the route with a maximum spacing of 25 km.

(iii) *Frequency-division multiplex (FDM).* FDM systems employ two commonly used coaxial cables of 1.2/4.4 and 2.6/9.5 size, separate pairs being used for each direction of transmission.

(iv) *Pulse-code modulation (PCM).* PCM systems are often used as an alternative to audio circuit provision. These systems enable 24 or 30 channels to operate over two pairs of wires. Cost comparison as to which system to use cannot be made due to various uncertainties for long term forecast and is left until a more accurate short term forecast can be made. Other digital systems are used on trunk circuits over coaxial cables.

(v) *Radio.* Circuits provided by a radio link can often be far cheaper and easier to maintain where intervening terrain is difficult. Where large numbers of circuits are required on a main route the possibility of using a line-of-sight microwave radio link can be considered. The route is covered by a number of hops, and dish aerials are mounted on towers spaced at about 50 km intervals and receive the signals which are retransmitted in the required direction by further aerials on the same tower. The mast or tower spacing is governed by the frequency used, and the projected beam must clear intervening obstacles. The towers and ancillary equipment are not cheap to construct and transmission problems can arise. These must be set against the disruption caused by extensive digging to lay ducts and build jointing chambers.

Q9 Describe in detail FOUR major factors which must be considered in the design of a foundation block for one of the masts supporting a rhombic aerial.

A9 This answer assumes that the foundation block is for a guyed mast, ball supported at its base.

(i) The design will be based on peak working conditions usually associated with a "once-in-fifty-years" worst wind condition, together with a factor of safety of about 2 for the soil stresses and 3 for the steel and concrete.

(ii) The pressure per square metre between the foundation block and the soil on which it rests must not exceed the allowable bearing pressure of the soil.

(iii) At no point beneath the foundation block must the pressure become negative. To achieve this the resulting centre of pressure at the block-to-soil interface must be located near to the centre of the block. In the case of a square or rectangular block this is within the middle third measured across the width of the block.

(iv) Due attention must be paid to the possibility of differential or unequal settlement which must be kept within limits.

(v) The depth of the foundation must be such that it is not affected by changes in the soil due to surface conditions such as frost, heat, rain or flooding, or excessively dry conditions. About 1 m is considered as the minimum.

(vi) The interface between mast base and block must be so designed that the permissible bearing pressure of the concrete is not exceeded.

LINE PLANT PRACTICE B 1979 (continued)

Q10 A 50 Hz power line runs close to an overhead telephone line as shown in Fig. 1. Fig. 2 shows the relation between mutual inductance and separating distance. To what value must the fault current be limited in the power line so that the induced longitudinal voltage in the telephone line shall not exceed 430 V?

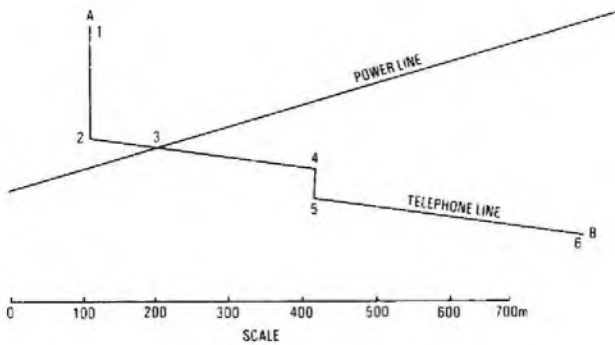


Fig. 1

A10 For the approach to this problem see A4, Line Plant Practice B 1976, Supplement, Vol. 70, p. 46, July 1977.

The telephone line in Fig. 1 has been divided into section 1-2, 2-3 etc. (not marked in the question). If S_1 metres is the separation at the start of each section, S_2 metres is the separation at the end of each section, M millihenrys/kilometre is the mutual inductance per unit length of each section, L kilometres is the length of each section, when projected onto the power line, the data given produces the following results:

Section	S_1 (m)	S_2 (m)	$\frac{S_1 + S_2}{2}$ (m)	M (mH/km)	L (km)	ML (mH)	
						+	-
1-2	200	28	114	0.53	0.06	—	0.032
2-3	28	0	14	0.90	0.06	0.054	—
3-4	0	94	47	0.70	0.23	0.162	—
4-5	94	140	117	0.52	0.02	—	0.010
5-6	140	280	210	0.42	0.34	0.142	—

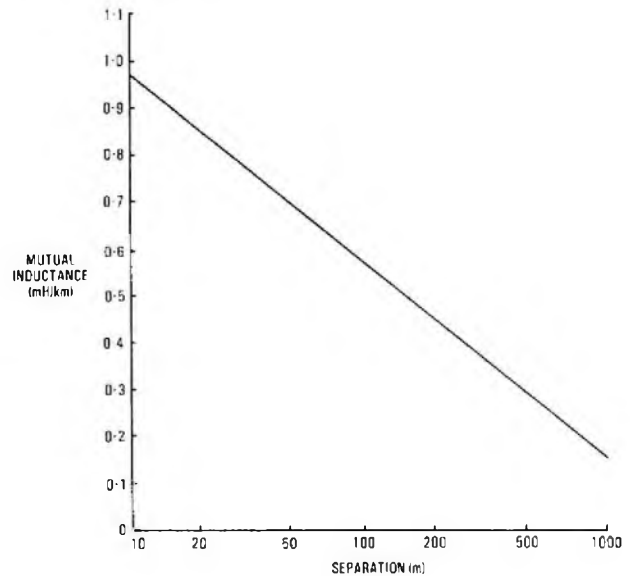


Fig. 2

$$\begin{aligned} \text{Total mutual inductance} &= +0.358 - 0.042 \\ &= +0.316 \text{ mH} \end{aligned}$$

The induced longitudinal voltage induced the telephone line, E volts, is given by

$$E = 2\pi fMI \text{ volts,}$$

where f is the frequency of the power supply (hertz), I is the fault current (amperes), and MI is in henrys,

$$\begin{aligned} \therefore I &= \frac{E}{2\pi fMI} \\ &= \frac{430}{2\pi \times 50 \times 0.316 \times 10^{-3}} \\ &= 4335 \text{ A.} \end{aligned}$$

LINE PLANT PRACTICE C 1979
Students were expected to answer any 6 questions

Q1 (a) Explain what is meant by non-electrolytic corrosion.
(b) Describe briefly FIVE of the forms of non-electrolytic corrosion that can occur on a lead-sheathed cable.

A1 (a) Non-electrolytic corrosion is defined as a form of electrochemical corrosion in which the anodic and cathodic areas are so close together that the flow of current between them is not measurable.

- (b) (i) Local-cell effects which are due to non-uniformity of the lead surface or to impurities embedded in the lead.
- (ii) Differential aeration effects in which corrosion occurs on those areas of lead sheath to which the access of oxygen is restricted.
- (iii) Drop corrosion, which is a variation of the differential-aeration principle.
- (iv) Crevice corrosion is another variation of differential aeration.
- (v) Scratch corrosion is where the oxide film is damaged and the exposed lead becomes anodic to the rest of the surface.

(vi) Phenol corrosion sometimes occurs on hessian-protected cables and is attributed to the denudation of bitumen from the lead sheath by pressure at points where the threads of the hessian tape cross each other. Microbiological action forms acids in the hessian tape which attack the lead at the bitumen-denuded points. The result is a large number of pits forming a distinct spiral pattern on the lead sheath.
(vii) Acid corrosion brought about by the electrochemical action of many acids which attack lead and form acid salts. Lead with acetic acid, in the presence of carbon dioxide, produces basic lead carbonate.

Q2 (a) Define the term Poisson's ratio.
(b) A steel bar is subjected to a pull of 11 kN. If the bar has a rectangular cross-section of 48 mm by 10 mm originally, and assuming $E = 200 \text{ kN/mm}^2$ and Poisson's ratio $m = 10/3$, calculate to five decimal places:

- (i) the decrease in the length of the sides of the cross-section of the bar, and
- (ii) the reduction in area, expressed as a percentage of the original cross-sectional area.

A2 (a) When a longitudinal stress is applied to a bar of elastic material, the resulting longitudinal strain is accompanied by a lateral strain causing a change in cross-section. The ratio of longitudinal strain to lateral strain is constant within the elastic range of the material, and is known as Poisson's ratio.

(b) (i) Longitudinal strain = T/EA , where T is the tension (in newtons) and A is the cross-sectional area of the bar (in metres²). Thus,

$$\begin{aligned} \text{strain} &= \frac{11 \times 10^3}{200 \times 10^9 \times 48 \times 10 \times 10^{-6}} \\ &= 0.0001146. \end{aligned}$$

$$\text{Lateral strain} = \frac{\text{longitudinal strain}}{\text{Poisson's ratio}}$$

$$= \frac{3 \times 0.0001146}{10} = 0.00003438.$$

Therefore, the decrease in the 48 mm side
 $= 48 \times 0.00003438 = 0.00165 \text{ mm}.$

The decrease in the 10 mm side
 $= 0.00034 \text{ mm}.$

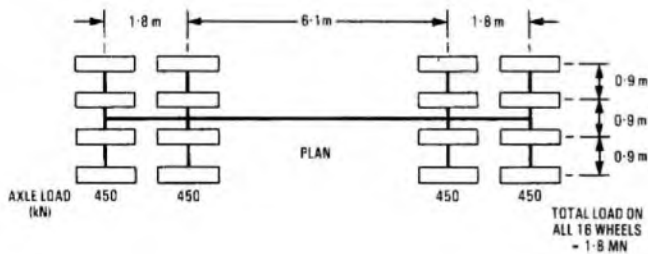
(ii) The new area of cross-section
 $= (48 - 0.00165)(10 - 0.00034),$
 $= 479.96718 \text{ mm}^2.$

The decrease as a percentage of the original
 $= \frac{480 - 479.96718}{480} \times 100\% = 0.00684\%.$

Q3 Write an account of the method of using standard traffic loadings for determining the maximum traffic loads which have to be considered in the design of underground jointing chambers.

A3 The maximum traffic loads that have to be taken into account in the design of jointing chambers are determined by using axle loads laid down by the British Standards Institute (BSI). There are two types of standard loading specified by the BSI: normal loading and abnormal loading. Each type of loading is derived from a consideration of the wheel loadings of hypothetical vehicles.

Normal loading approximately represents the effect of three vehicles, each of 220 kN and closely spaced, in each of two carriageway lanes, followed by 100 kN and 50 kN vehicles. The loading effect of these vehicles is interpreted either as a uniformly distributed load combined with a knife-edge load, or as individual wheel loads where small surface areas are involved. For normal highway loading, as in the former case, the uniformly distributed load is dependent upon the span length under consideration. Abnormal loading is a unit loading representing a single abnormally heavy vehicle. The plan and axle arrangements of the vehicle considered to represent abnormal loading in the UK is shown in the sketch.



In the application of standard loadings, normal loading is taken to occupy one carriageway lane and to be uniformly distributed over the full width of the lane. Two carriageway lanes are considered to be occupied by full normal loading and any other lanes are considered to be occupied by one third of the full lane loading.

The standard loading of the BSI specifies the following load requirements for bridges according to the class of road carried.

(a) Bridges carrying motorways and trunk roads shall be designed to carry normal loads and shall be checked for one lane carrying abnormal loading whilst all other lanes carry one-third of the normal loading.

(b) Bridges carrying Class-I and Class-II roads shall be designed for normal loading and shall be checked for one lane carrying five-sixths of abnormal loading with all other lanes carrying one-third of normal loading.

(c) Bridges carrying Class-III roads shall be designed for normal loading. No allowance is made for abnormal loading on Class-III roads.

Consideration of the specification for bridges enables structural members of all sizes to be designed. For large load-carrying members, the loadings approximate to uniform distribution and have been converted into standard loading curves but, for slabs which are supported on all four sides in such a way that the distance between supports in one direction is less than twice the corresponding distance in the other, the loading curves cannot be used and individual wheel loads must be considered. Where individual wheel loads are considered, the following conditions are specified:

- (i) two wheel loads, each of 112 kN, in line, transversely spaced at 0.9 m centres and having a contact area of 375 mm × 75 mm, the smaller dimension being in the direction of travel,
- (ii) dispersal under the wheel loads taken as 45°,

- (iii) 25% overstress permitted, and
- (iv) no allowance made for impact under the wheel loads.

Q4 (a) Describe, with the aid of a diagram, a bridge test which can be used to locate a fault which has lowered the dielectric strength of a coaxial pair in a cable.

(b) What safety precautions must be taken when carrying out this test?

A4 (a) and (b) See A8, Line Plant Practice C 1974, Supplement, Vol. 68, p. 81, Jan. 1976.

Safety precautions must be observed during the test because of the high voltages involved. Care must be taken to ensure that no one touches the equipment, the cable conductors or the connexions during the test, and that the terminal equipment and power supplies are disconnected at the conclusion. After the test, a neon tester should be used to ensure that the cable is fully discharged.

Q5 A pole route consists of 9 m poles set 1.5 m into the ground and spaced 70 m apart. An aerial cable is to be erected on the poles and supported in brackets mounted 0.75 m from the top of the poles. The safe moment of resistance of a medium pole is 15.5 kN m.

(a) What would be the maximum diameter of the aerial cable erected if the relation between wind pressure and diameter of cable is given by $P = 0.358d^2$, where P is in newtons and d in millimetres?

(b) Calculate the wind pressure on one span of cable.

A5 (a) The force acting on a pole is the wind pressure exerted on 35 m of aerial cable each side of the pole. Thus, the moment of resistance

$$= 70 \times 0.358d \times (9.0 - 1.5 - 0.75) \text{ N m}.$$

But the maximum moment of resistance of the pole is given as 15.5 kN m.

Thus, equating gives

$$15.5 \times 10^3 = 70 \times 0.358d \times 6.75.$$

Therefore, the maximum diameter of aerial cable is

$$\frac{15.5 \times 10^3}{70 \times 0.358 \times 6.75} = 91.63 \text{ mm}.$$

(b) Wind pressure

$$= 0.358 \times 91.63 \times 70 \text{ N} = 2.3 \text{ kN}.$$

Q6 Fig. 1 shows a network drawn up for the critical path analysis of a project. The time units are in days.

(a) From the network, draw up a table to show all the possible paths through the network and the total time for each path.

(b) Draw a network diagram with day numbers inserted for each activity, having applied the forward and reverse passes.

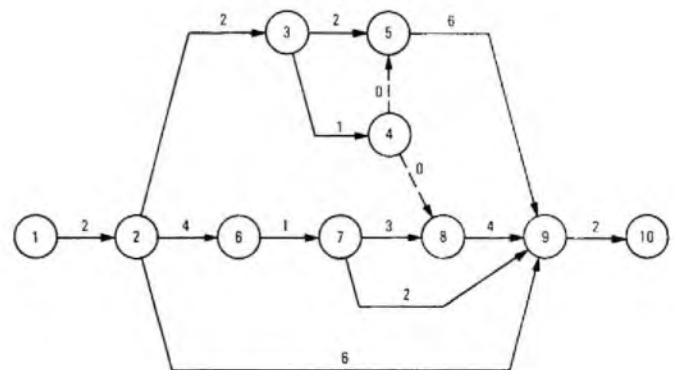


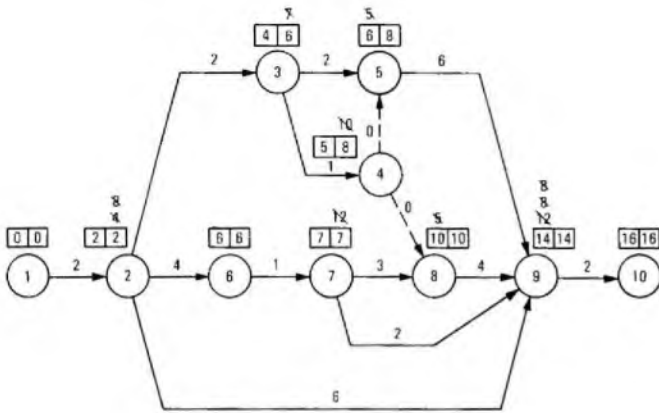
Fig. 1

A6 (a) The table shows the possible paths through the network and the total time for each path.

LINE PLANT PRACTICE C 1979 (continued)

Path	Duration
1, 2, 3, 4, 5, 9, 10	2 + 2 + 1 + 0 + 6 + 2 = 13
1, 2, 3, 4, 8, 9, 10	2 + 2 + 1 + 0 + 4 + 2 = 11
1, 2, 3, 5, 9, 10	2 + 2 + 2 + 6 + 2 = 14
1, 2, 6, 7, 8, 9, 10	2 + 4 + 1 + 3 + 4 + 2 = 16
1, 2, 6, 7, 9, 10	2 + 4 + 1 + 2 + 2 = 11
1, 2, 9, 10	2 + 6 + 2 = 10

(b) The network diagram in the sketch shows the day numbers for each activity, having applied the forward and reverse passes.



Q7 (a) Define the term economic percentage of steel in a reinforced concrete beam.

(b) A double reinforced concrete beam has dimensions and steel reinforcement as shown in Fig. 2. Calculate the maximum uniform load this beam will support across a 3 m span. The stress in the steel must not exceed 130 MPa and in the concrete not exceed 7 MPa.

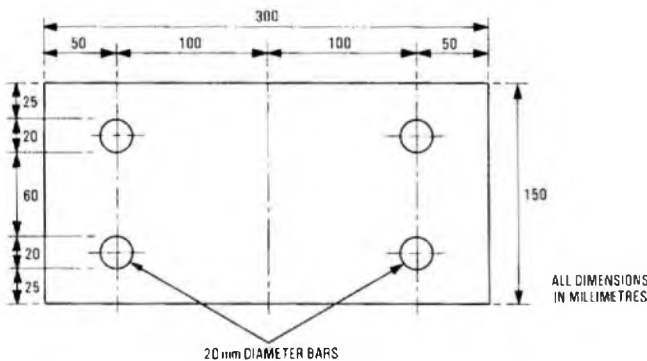


Fig. 2

A7 (a) In a reinforced concrete beam where the stresses in both the steel and concrete have reached their maximum allowable values, the steel used is called the *critical amount* or, expressed as a percentage of the cross-sectional area of the beam, the *economic percentage*.

(b) In a double reinforced beam, the concrete accepts no force at all; thus the neutral axis is equidistant from the top and bottom of the beam. The resisting moment offered by each flange is $f_s A_s x$, where f_s is the stress in steel, A_s is the cross-section area of steel in either flange, and x is the distance of the steel from the centre of the beam. Thus, the total resisting moment (M_r) = $f_s A_s 2x$. Substituting the given values,

$$M_r = \frac{130 \times A_s \times 2 \times 100}{10^3} \text{ N m,}$$

$$= \frac{130 \times \pi \times 10^2 \times 2 \times 2 \times 100}{10^3} = 16.336 \text{ kN m.}$$

Let the maximum uniform loading be w newtons/metre. If the span, L_s is 3 m, then the total load is $3w$ newtons. The maximum bending moment for uniform load is

$$\frac{wL^2}{8} = \frac{9w}{8}$$

but this must equal M_r . Therefore

$$w = \frac{16.336 \times 8}{9} = 14.52 \text{ kN/m.}$$

Q8 (a) Give details of various lubricants which could be used when pulling polyethylene-sheathed cables into ducts, and the effect they would have on the coefficients of static and dynamic friction in both PVC and glazed-earthenware ducts.

(b) What effect does the reduction of friction between cable and duct have on the economics of cable installation?

(c) Derive the relationship between the limiting pull (N) in newtons on a cable, the number of pairs (n) and the diameter (d) in millimetres of each conductor if the stress on the conductors must not exceed 30 MPa.

A8 (a) and (b) See A2, Line Plant Practice C 1973, Supplement, Vol. 67, p. 81, Jan. 1975.

(c) The cross-sectional area of the cable core

$$= \frac{\pi d^2 \times 2n \times 10^{-6}}{4} \text{ metres}^2.$$

The limiting stress on the cable, 30×10^6

$$= \frac{N}{\frac{\pi d^2 \times 2n}{4} \times 10^6} \text{ pascals.}$$

$$\therefore N = \frac{30 \times \pi d^2 \times 2n}{4} = 47d^2n \text{ newtons.}$$

Q9 (a) Describe a method of providing a telephone-exchange earth using deep-driven earth-rods.

(b) The resistance of a single earth-rod is 48Ω . By reference to Fig. 3, determine how many earth-rods will be needed to make the earth system 8Ω . Assume a spacing/rod ratio of 1.

(c) How can the life of earth-rods be increased from about 15 years to 50 years?

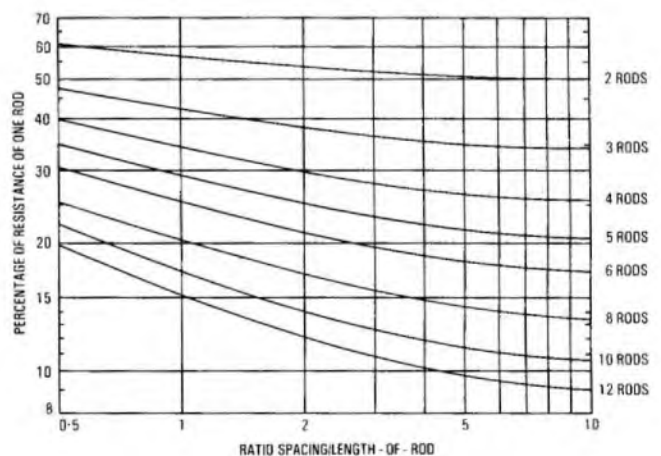


Fig. 3

A9 (a) See A10, Line Plant Practice C 1974, Supplement, Vol. 68, p. 82, Jan. 1976.

(b) For a single rod, the resistance is 48Ω , and the earth system is required to be 8Ω . Thus, 8Ω , as a percentage of the single-rod resistance

$$= \frac{8 \times 100}{48} = 16.7\%$$

Using Fig. 3 and a spacing/length-of-rod ratio of 1, the number of rods required is a minimum of 10.

(c) Coating steel earth rods with copper increases their life considerably.

Q10 (a) Describe, with the aid of a sketch, a concrete stay-anchor block suitable for use with a 100 m stayed mast.

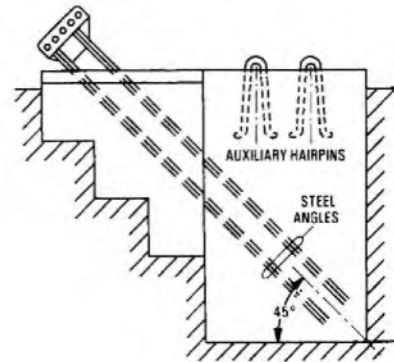
(b) A square-sided concrete block is used for one leg of a self-supporting tower foundation. The depth of the block must not exceed 3.85 m and the density of concrete is 2200 kg/m³. Calculate the size of the block which would be required to withstand an uplift of 985 kN if the factor of safety is to be 1.5.

A10 (a) The sketch shows a typical design for a concrete stay-anchor block for use with a 100 m stayed mast. A horizontal restraining force required to oppose the effect of wind and aerial loads on the mast is provided by the tension in the stay. Thus there are horizontal and vertical force components on the stay-block, the former tending to overturn the stay-block and the latter lifting the block out of the ground. The stay-block is designed so that the line of the stay will, if extended, pass below the centre of gravity of the block. Uplift is restricted by the weight of the concrete and of the overlying earth, and suction between the block face and the earth below. The horizontal shearing force is resisted by the internal friction of the soil and by its cohesion. For a sandy soil, resistance to shear is almost wholly produced by internal friction but, for a clay soil, resistance is mainly by cohesion. A mixture of both is expected for other soils.

(b) The volume of the block is 3.85S² metres³, where S is the length of the side of the block. Thus the weight of the block

$$= 3.85S^2 \times 2200 \times 9.81 \text{ newtons.}$$

For equilibrium, the weight of the block must equal the uplift



multiplied by the safety factor. Therefore

$$3.85S^2 \times 2200 \times 9.81 = 985 \times 10^3 \times 1.5.$$

$$\therefore S^2 = \frac{985 \times 10^3 \times 1.5}{3.85 \times 2200 \times 9.81} \text{ m}^2.$$

$$\therefore S = \underline{4.22 \text{ m.}}$$

MATHEMATICS B 1980

Students were expected to answer any 6 questions

Q1 The resistance, *R* ohms, of a circuit element varies with the temperature *t*°C. Three readings recorded were

<i>t</i>	0	100	450
<i>R</i>	300	325	470

Assuming a formula $R = R_0(1 + at + bt^2)$

- (a) give a meaning to the constant *R*₀, and its value in this instance,
- (b) calculate the constants *a* and *b* to 3 significant figures, and
- (c) estimate the temperature at which *R* = 400 Ω.

A1 (a) $R = R_0(1 + at + bt^2)$.

When *t* = 0, *at* and *bt*² are both zero and, hence, *R* = *R*₀. Therefore *R*₀ is the resistance of the circuit element when *t* = 0°C and, in this instance, its value is 300 Ω.

(b) When *t* = 100°C, $325 = 300(1 + 100a + 100^2b)$, (1)
and when *t* = 450°C, $470 = 300(1 + 450a + 450^2b)$ (2)

From equation (1),
 $1 + 100a + 10^4b = 325/300 = 1.08\bar{3}$, (3)

and, from equation (2),
 $1 + 450a + 20.25 \times 10^4b = 470/300 = 1.5\bar{6}$ (4)

Multiplying equation (3) by 4.5 gives:
 $4.5 + 450a + 4.5 \times 10^4b = 1.08\bar{3} \times 4.5$ (5)

Subtracting equation (5) from equation (4) gives:
 $-3.5 + 15.75 \times 10^4b = 1.5\bar{6} - 1.08\bar{3} \times 4.5$.
 $\therefore 15.75 \times 10^4b = 5.06 - 4.875$.

$$\therefore b = \frac{0.191\bar{6}}{15.75 \times 10^4}$$

$$= 1.212693 \times 10^{-6}.$$

Substituting for *b* in equation (3) gives:
 $1 + 100a + 10^4 \times 1.212693 \times 10^{-6} = 1.08\bar{3}$.
 $\therefore 100a = 0.08\bar{3} - 0.0121269$,
 $= 0.071164$.
 $\therefore a = 7.1164 \times 10^{-4}$.

Hence, to 3 significant figures
 $a = \underline{7.12 \times 10^{-4}}$ and $b = \underline{1.22 \times 10^{-6}}$.

(c) When *R* = 400 Ω,
 $400 = 300(1 + 7.1164 \times 10^{-4}t + 1.212693 \times 10^{-6}t^2)$.
 $\therefore 1.21269 \times 10^{-6}t^2 + 7.1164 \times 10^{-4}t + 1 = 1.3$.
 $\therefore 1.21269 \times 10^{-6}t^2 + 7.1164 \times 10^{-4}t - 0.3 = 0$.
 $\therefore t = \frac{-7.1164 \times 10^{-4} \pm \sqrt{(7.1164^2 \times 10^{-8} + 4 \times 1.21269 \times 10^{-6} \times 0.3)}}{2 \times 1.21269 \times 10^{-6}}$,
 $= \frac{-7.1164 \times 10^{-4} \pm \sqrt{(50.643 \times 10^{-8} + 1.6222 \times 10^{-6})}}{2.42538 \times 10^{-6}}$,
 $= \frac{-7.1164 \times 10^{-4} \pm \sqrt{(2.1289 \times 10^{-6})}}{2.42538 \times 10^{-6}}$,
 $= \frac{-7.1164 \times 10^{-4} \pm 1.4591 \times 10^{-3}}{2.42538 \times 10^{-6}}$,
 $= \frac{0.74746 \times 10^{-3}}{2.42538 \times 10^{-6}}$ (ignoring the negative value),
 $= \underline{307^\circ\text{C.}}$

Q2 The outer conductor of a coaxial cable is a hollow cylinder of internal radius *R*. The inner conductor is a solid of the same metal as the outer conductor. The radial separation between conductors is *s*.

- (a) Derive a formula for the thickness *t* of the outer conductor if it is to have the same DC resistance as the inner conductor.
- (b) Calculate *t* if *R* = 8 mm and *s* = 3 mm.

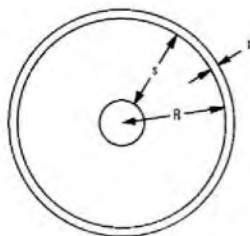
A2 (a) The DC resistance of a conductor is given by $\frac{\rho l}{A}$, where ρ is the resistivity of the material, *l* is the length of conductor and *A* is the cross-sectional area of the conductor. Since the same metal is used for both inner and outer conductors, ρ is the same for both and hence for the conductors to have the same resistance per unit length, the cross-sectional area of the inner conductor must equal the cross-sectional area of the outer conductor.

Therefore, if *A*_o is the area of the outer conductor and *A*_i is the area of the inner conductor, $A_o = A_i$.

Referring to the sketch,

$$A_o = \pi(R + t)^2 - \pi R^2,$$

and $A_i = \pi(R - s)^2$.



Hence, for A_0 and A_1 to be equal,
 $\pi(R+t)^2 - \pi R^2 = \pi(R-s)^2$
 $\therefore (R+t)^2 = (R-s)^2 + R^2$
 $\therefore R+t = \sqrt{(R-s)^2 + R^2}$
 $\therefore t = \sqrt{(2R^2 - 2Rs + s^2)} - R$

(b) When $R = 8$ mm and $s = 3$ mm,
 $t = \sqrt{(2 \times 64 - 2 \times 8 \times 3 + 9)} - 8$
 $= \sqrt{(128 - 48 + 9)} - 8$
 $= \sqrt{89} - 8 = 9.434 - 8$
 $= 1.434$ mm.

Q3 A building society report gives the number of its investors at 1 January as follows:

Year	1968	1970	1972	1974	1976	1978
No. of investors (y) (thousands)	190	234	301	411	538	710

- (a) Show graphically, that the formula $y = ka^x$ reasonably fits these figures at a date x years after 1 January 1968.
 (b) Obtain the constants a and k from the graph.
 (c) Find the approximate annual growth rate per cent.

A3 (a) $y = ka^x$

Taking logarithms,

$$\log_{10} y = \log_{10} k + x \log_{10} a$$

Since a and k are constants, this logarithmic form of the law is of the form

$$y = mx + c,$$

that is, a straight line law. Therefore, for the given data to obey the law, when plotted in logarithmic form, the points must form a straight line.

The graph may be plotted from the following table of values.

year	1968	1970	1972	1974	1976	1978
x	0	2	4	6	8	10
y	190	234	301	411	538	710
$\log_{10} y$	2.279	2.369	2.479	2.614	2.731	2.851

The graph is shown in the sketch.

It can be seen that it is possible to draw a straight line to pass reasonably close to all the plotted points and hence, the data given conforms approximately to the law $y = ka^x$.

(b) When $x = 0$, $\log_{10} k = \log_{10} y$ and hence the intercept on the $\log_{10} y$ axis gives the value of k . From the graph

$$\log_{10} y = 2.268 = \log_{10} k$$

$$\therefore k = 185.4$$

The gradient of the graph gives the value of $\log_{10} a$. From the graph (points A and B lying actually on the straight line),

$$\log_{10} a = \frac{2.840 - 2.268}{10 - 0} = 0.0572$$

$$\therefore a = 1.141$$

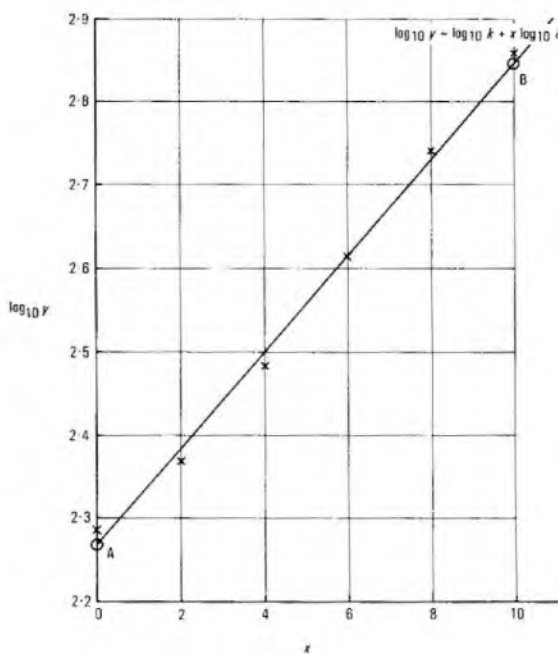
Hence, $a \approx 1.14$ and $k \approx 185$.

(c) Increase in the number of investors from 1968 to 1978
 $= 710\,000 - 190\,000 = 520\,000$

\therefore the annual growth rate over the 10-year period

$$= \frac{520\,000}{10 \times 190\,000} \times 100\%$$

$$= 27.37\%$$



Q4 (a) A current i milliamperes flows in a circuit t milliseconds after the operation of a switch, such that

$$i = 15(1 - e^{-0.4t})$$

- (i) Sketch the current/time graph for $t \geq 0$.
 (ii) Calculate the time taken for the current to attain 60% of its ultimate value.

(b) Given that $\log_{10} 3 = 0.4771$, calculate $\log_3 10$. Hence obtain $\log_3 2.7$ without using logarithm tables or a calculator.

A4 (a) (i) $i = 15(1 - e^{-0.4t})$

The curve of i plotted against t is drawn from the following values and is shown in the sketch.

t	0	0.5	1.0	1.5	2.0	2.5
$-0.4t$	0	-0.2	-0.4	-0.6	-0.8	-1.0
$e^{-0.4t}$	1	0.819	0.670	0.549	0.449	0.368
$1 - e^{-0.4t}$	0	0.181	0.330	0.451	0.551	0.632
$i = 15(1 - e^{-0.4t})$	0	2.715	4.950	6.765	8.265	9.480

t	3.0	4.0	5.0	6.0	10.0
$-0.4t$	-1.2	-1.6	-2.0	-2.4	-4.0
$e^{-0.4t}$	0.301	0.202	0.135	0.0907	0.0183
$1 - e^{-0.4t}$	0.699	0.798	0.865	0.9093	0.9817
$i = 15(1 - e^{-0.4t})$	10.485	11.97	12.975	13.640	14.726

Note: The sketch given here and the table of values from which it was plotted are more elaborate than would be expected from a student.

(ii) The ultimate value of i , when $t = \infty$, is 15 mA. Thus, when $i = 60\%$ of 15 mA,

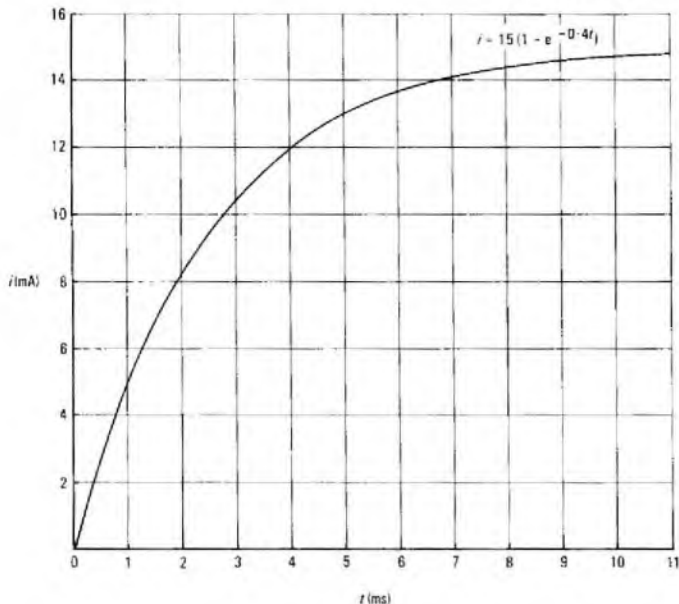
$$1 - e^{-0.4t} = 0.6$$

$$\therefore e^{-0.4t} = 0.4$$

$$\therefore -0.4t = \log_e 0.4 = -0.9163$$

$$\therefore t = \frac{0.9163}{0.4}$$

$$\approx 2.29 \text{ ms.}$$



(b) $\log_{10} 3 = 0.4771.$

But, $\log_3 10 = \frac{1}{\log_{10} 3},$
 $= \frac{1}{0.4771} = 2.096.$

$\log_3 2.7 = \log_3 \left(3 \times 3 \times \frac{3}{10} \right),$
 $= \log_3 3 + \log_3 3 + \log_3 3 - \log_3 10,$
 $= 3 - 2.096,$
 $= 0.904.$

Q5 (a) A vehicle costs £2400 new. Assuming a compound interest rate of depreciation of 12% per annum, calculate its value after 6 years' service.

(b) If, however, the value of money has depreciated by 8% per annum in the same period, calculate the cash value at the end of these 6 years.

A5 (a) The value of the vehicle after one year will be

$\pounds 2400 - 2400 \times \frac{12}{100},$
 $= \pounds 2400(1 - 0.12).$

After 2 years, the depreciated value at compound interest

$= \pounds 2400(1 - 0.12) - 2400(1 - 0.12) \times \frac{12}{100},$
 $= \pounds 2400(1 - 0.12)^2.$

In a similar way, it may be shown that, after x years, the depreciated value

$= \pounds 2400(1 - 0.12)^x.$

Hence, when $x = 6$, the depreciated value

$= \pounds 2400(0.88)^6,$
 $= \pounds 1114.6.$

(b) After one year, the depreciated value of the vehicle, in terms of the value of money in year 1

$= \pounds 2400 \times 0.88^1.$

However, since the value of money will have fallen by 8%, the cash value of the vehicle in terms of the value of money in year 2 will be

$\pounds 2400 \times 0.88 + 2400 \times 0.88 \times \frac{8}{100},$
 $= \pounds 2400 \times 0.88(1 + 0.08),$
 $= \pounds 2400 \times 0.88 \times 1.08.$

At the end of the second year this amount will be modified by the

two factors, the vehicle depreciation and the fall in the value of money and will therefore be

$\pounds 2400 \times 0.88^2 \times 1.08^2.$

Hence, after 6 years, the cash value in terms of the value of money in year 6 becomes

$\pounds 2400 \times 0.88^6 \times 1.08^6,$
 $= \pounds 1114.6 \times 1.08^6,$
 $= \pounds 1768.7.$

Q6 Using the expansions for $\sin(A + B)$ and $\cos(A + B)$:

(a) without using trigonometrical tables or a calculator

(i) evaluate $\cos 105^\circ$ to 3 significant figures, and

(ii) prove that $\operatorname{cosec} 15^\circ = (\sqrt{6} + \sqrt{2}).$

(b) express $\sin 3A$ in terms of powers of $\sin A$ only.

(c) express $\frac{\cot \alpha + \tan \beta}{\cot \alpha - \tan \beta}$ as the quotient of two cosines.

A6 $\sin(A + B) = \sin A \cos B + \cos A \sin B,$ and $\cos(A + B) = \cos A \cos B - \sin A \sin B.$

(a) (i) $\cos 105^\circ = \cos(60^\circ + 45^\circ),$
 $= \cos 60^\circ \cos 45^\circ - \sin 60^\circ \sin 45^\circ,$
 $= \frac{1}{2} \times \frac{1}{\sqrt{2}} - \frac{\sqrt{3}}{2} \times \frac{1}{\sqrt{2}},$
 $= \frac{1.41421}{4} (1 - 1.73205),$
 $= -0.35355 \times 0.73205,$
 $= -0.25882,$
 $= -0.259$ to 3 significant figures.

(ii) $\operatorname{cosec} 15^\circ = \frac{1}{\sin 15^\circ},$
 $= \frac{1}{\sin(45^\circ - 30^\circ)},$
 $= \frac{1}{\sin 45^\circ \cos(-30^\circ) + \cos 45^\circ \sin(-30^\circ)},$
 $= \frac{1}{\frac{1}{\sqrt{2}} \times \frac{\sqrt{3}}{2} - \frac{1}{\sqrt{2}} \times \frac{1}{2}},$
 $= \frac{2\sqrt{2}}{\sqrt{3} - 1},$
 $= \frac{2\sqrt{2}(\sqrt{3} + 1)}{(\sqrt{3} - 1)(\sqrt{3} + 1)},$
 $= \frac{2(\sqrt{6} + \sqrt{2})}{3 - 1},$
 $= \sqrt{6} + \sqrt{2}. \quad \text{QED}$

(b) $\sin 3A = \sin(2A + A),$
 $= \sin 2A \cos A + \cos 2A \sin A,$
 $= 2 \sin A \cos^2 A + \sin A (1 - 2 \sin^2 A),$
 $= 2 \sin A (1 - \sin^2 A) + \sin A - 2 \sin^3 A,$
 $= 2 \sin A - 2 \sin^3 A + \sin A - 2 \sin^3 A,$
 $= 3 \sin A - 4 \sin^3 A.$

(c) $\frac{\cot \alpha + \tan \beta}{\cot \alpha - \tan \beta} = \frac{\frac{\cos \alpha}{\sin \alpha} + \frac{\sin \beta}{\cos \beta}}{\frac{\cos \alpha}{\sin \alpha} - \frac{\sin \beta}{\cos \beta}},$
 $= \frac{\frac{\cos \alpha \cos \beta + \sin \alpha \sin \beta}{\sin \alpha \cos \beta}}{\frac{\cos \alpha \cos \beta - \sin \alpha \sin \beta}{\sin \alpha \cos \beta}},$
 $= \frac{\cos(\alpha - \beta)}{\cos(\alpha + \beta)}.$

Q7 For the function $y = 2x^3 - 18x$

(a) derive an expression for $\frac{dy}{dx}$ from first principles,

(b) find the turning values of this function and determine whether each is a maximum or a minimum, and

(c) sketch the graph of the function, including positive and negative values of x .

A7 $y = 2x^3 - 18x$.

Let x increase by a small amount δx and let the corresponding increase in y be δy .

$$\begin{aligned} \text{Then, } y + \delta y &= 2(x + \delta x)^3 - 18(x + \delta x), \\ &= 2(x^3 + 3x^2 \delta x + 3x \delta x^2 + \delta x^3) - 18x - 18\delta x. \\ \therefore \delta y &= 2x^3 + 6x^2 \delta x + 6x \delta x^2 + 2\delta x^3 - 18x - 18\delta x - 2x^3 + 18x, \\ &= 6x^2 \delta x + 6x \delta x^2 + 2\delta x^3 - 18\delta x. \end{aligned}$$

$$\therefore \frac{\delta y}{\delta x} = 6x^2 + 6x \delta x + 2\delta x^2 - 18.$$

$$\therefore \frac{dy}{dx} = \lim_{\delta x \rightarrow 0} \frac{\delta y}{\delta x}, \\ = \underline{6x^2 - 18}.$$

(b) The turning values occur when $\frac{dy}{dx} = 0$; that is,

$$6x^2 - 18 = 0,$$

which occurs when $x = \pm\sqrt{3}$.

But, $\frac{d^2y}{dx^2} = 12x$.

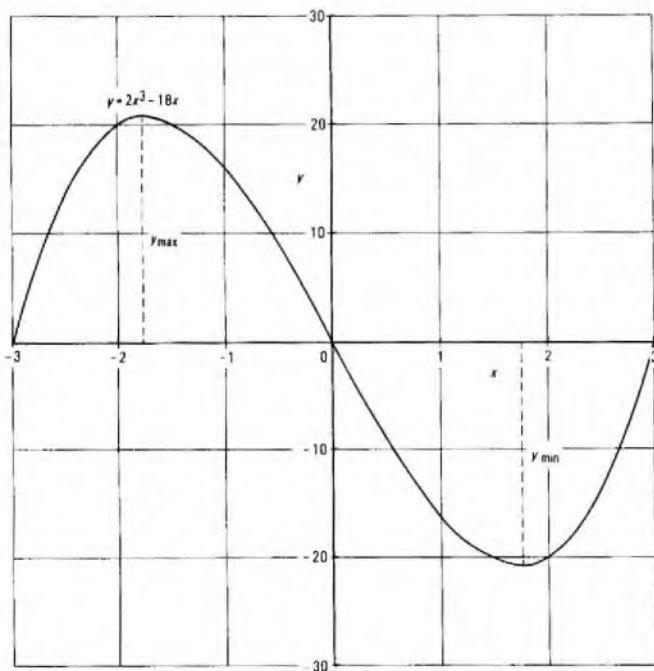
When $x = \sqrt{3}$, $\frac{d^2y}{dx^2}$ is positive, and hence a minimum value occurs.

When $x = -\sqrt{3}$, $\frac{d^2y}{dx^2}$ is negative and a maximum value must occur.

$$\begin{aligned} \therefore y_{\max} &= 2(-\sqrt{3})^3 - 18(-\sqrt{3}), \\ &= -6\sqrt{3} + 18\sqrt{3} = 12\sqrt{3}, \\ &= \underline{20.785 \text{ at } x = -\sqrt{3}}. \end{aligned}$$

$$\begin{aligned} y_{\min} &= 2(\sqrt{3})^3 - 18\sqrt{3}, \\ &= 6\sqrt{3} - 18\sqrt{3} = -12\sqrt{3}, \\ &= \underline{-20.785 \text{ at } x = \sqrt{3}}. \end{aligned}$$

(c) The graph is shown in the sketch from $x = -3$ to $x = +3$. Beyond these values the graph descends rapidly when x is negative and ascends rapidly when x is positive.



Q8 An alternating current flows through a resistor in series with a capacitor. The charge on the capacitor, q coulombs, at a time t seconds is

$$q = 4 \times 10^{-4} \cos 1600\pi t.$$

(a) Use the formula $v = \frac{q}{C} + R \frac{dq}{dt}$ to express the voltage v at time t , when $R = 50 \Omega$ and $C = 5 \times 10^{-6} \text{ F}$.

(b) Sketch the graph of v against t from $t = 0$ to $t = 1/800$.

(c) From the graph, or otherwise, find the peak value of this voltage.

A8 (a) $q = 4 \times 10^{-4} \cos 1600\pi t$.

$$\therefore \frac{dq}{dt} = -1600\pi \times 4 \times 10^{-4} \sin 1600\pi t, \\ = -0.64\pi \sin 1600\pi t.$$

$$\begin{aligned} \text{Hence, } v &= \frac{4 \times 10^{-4} \cos 1600\pi t}{5 \times 10^{-6}} + 50 \times -0.64\pi \sin 1600\pi t, \\ &= 80 \cos 1600\pi t - 32\pi \sin 1600\pi t, \\ &= \underline{80 \cos 1600\pi t - 100.53 \sin 1600\pi t}. \end{aligned}$$

(b) The curve, shown in the sketch, was drawn from the following table of values.

t	0	1/8000	1/4000	3/8000
$1600\pi t$ rad	0	$\pi/5$	$2\pi/5$	$3\pi/5$
$1600\pi t$ degrees	0	36	72	108
$\cos 1600\pi t$	1	0.8090	0.3090	-0.3090
$80 \cos 1600\pi t$	80	64.72	24.72	-24.72
$\sin 1600\pi t$	0	0.5878	0.9511	0.9511
$-100.53 \sin 1600\pi t$	0	-59.09	-95.61	-95.61
v	80	5.63	-70.89	-120.33

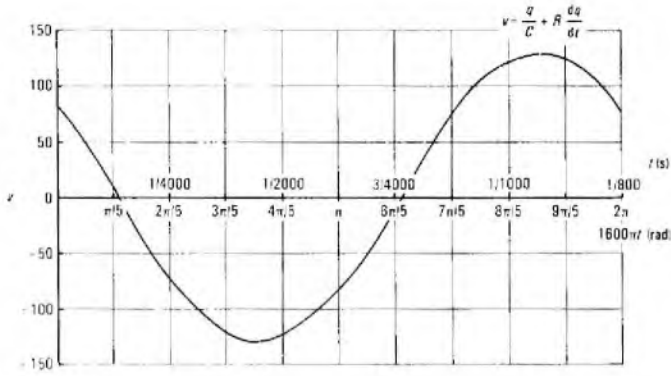
t	1/2000	5/8000	3/4000
$1600\pi t$ rad	$4\pi/5$	π	$6\pi/5$
$1600\pi t$ degrees	144	180	216
$\cos 1600\pi t$	-0.8090	-1	-0.8090
$80 \cos 1600\pi t$	-64.72	-80	-64.72
$\sin 1600\pi t$	0.5878	0	-0.5878
$-100.53 \sin 1600\pi t$	-59.09	0	59.09
v	-123.81	-80	-5.63

t	7/8000	1/1000	9/8000	1/800
$1600\pi t$ rad	$7\pi/5$	$8\pi/5$	$9\pi/5$	2π
$1600\pi t$ degrees	252	288	324	360
$\cos 1600\pi t$	-0.3090	0.3090	0.8090	1
$80 \cos 1600\pi t$	-24.72	24.72	64.72	80
$\sin 1600\pi t$	-0.9511	-0.9511	-0.5878	0
$-100.53 \sin 1600\pi t$	95.61	95.61	59.09	0
v	70.89	120.33	123.81	80

(c) The peak value of v may be determined from the graph, but not very accurately unless more points are plotted in the neighbourhood of $t = 1/1000$ s.

The peak value is determined accurately as follows:

$$\frac{dv}{dt} = -1600\pi \times 80 \sin 1600\pi t - 1600\pi \times 100.53 \cos 1600\pi t.$$



For a maximum or a minimum value, $\frac{dv}{dt} = 0$.

$$\therefore -1600\pi \times 80 \sin 1600\pi t = 1600\pi \times 100 \cdot 53 \cos 1600\pi t.$$

$$\therefore \tan 1600\pi t = -\frac{100 \cdot 53}{80},$$

$$= -1 \cdot 2566.$$

$$\therefore 1600\pi t = 180^\circ - 51^\circ 29' \text{ or } 360^\circ - 51^\circ 29',$$

$$= 3 \cdot 14159 - 0 \cdot 89862 \text{ or}$$

$$6 \cdot 28319 - 0 \cdot 89862,$$

$$= 2 \cdot 24297 \text{ rad or } 5 \cdot 38457 \text{ rad.}$$

It is clear from the sketch that a minimum value of v occurs at the lower value of $1600\pi t$ and that a maximum value occurs at the higher value.

Hence, $v_{\text{max}} = 80 \cos 5 \cdot 38457 \text{ rad} - 100 \cdot 53 \sin 5 \cdot 38457 \text{ rad},$
 $= 80 \times 0 \cdot 62268 + 100 \cdot 53 \times 0 \cdot 78248,$
 $= 49 \cdot 814 + 78 \cdot 663,$
 $= \underline{128 \cdot 477}.$

Q9 (a) Evaluate

(i) $\int_4^9 \sqrt{x} dx,$ and

(ii) $\int_1^3 (x^2 - 1)^2 dx.$

(b) Calculate the mean value of the function $y = 2x^2 - 5x + 2$ from $x = \frac{1}{2}$ to $x = 2$. Mark this mean value on a sketch graph of the function, shading-in the area involved in the integration process.

A9 (a) (i) $\int_4^9 \sqrt{x} dx = \int_4^9 x^{1/2} dx,$
 $= \frac{2}{3} \left[x^{3/2} \right]_4^9,$
 $= \frac{2}{3} (3^3 - 2^3),$
 $= \frac{2}{3} (27 - 8),$
 $= \underline{12 \cdot 6}.$

(ii) $\int_1^3 (x^2 - 1)^2 dx = \int_1^3 (x^4 - 2x^2 + 1) dx,$
 $= \left[\frac{x^5}{5} - \frac{2x^3}{3} + x \right]_1^3,$
 $= \frac{243}{5} - \frac{2}{3} \times 27 + 3 - \left(\frac{1}{5} - \frac{2}{3} + 1 \right),$
 $= \frac{242}{5} - 18 + 3 + \frac{2}{3} - 1,$
 $= \frac{736}{15} - 16,$
 $= 49 \cdot 0\bar{6} - 16,$
 $= \underline{33 \cdot 0\bar{6}}.$

(b) $y = 2x^2 - 5x + 2.$
 $y_{\text{mean}} = \frac{\int_{1/2}^2 (2x^2 - 5x + 2) dx}{2 - \frac{1}{2}},$
 $= \frac{2}{3} \left[\frac{2x^3}{3} - \frac{5x^2}{2} + 2x \right]_{1/2}^2,$

$$= \frac{2}{3} \left\{ \frac{2 \times 8}{3} + 10 + 4 - \left(\frac{2}{3} \times \frac{1}{8} - \frac{5}{8} + 1 \right) \right\},$$

$$= \frac{2}{3} \left(\frac{16}{3} - 6 - \frac{1}{12} + \frac{5}{8} - 1 \right),$$

$$= \frac{2}{3} \left(\frac{128 - 2 + 15}{24} - 7 \right),$$

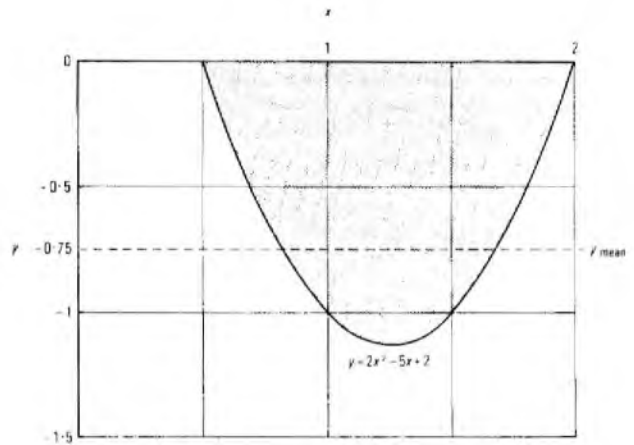
$$= \frac{2}{3} \times \left(-\frac{27}{24} \right),$$

$$= \underline{-0 \cdot 75}.$$

The graph is shown in the sketch, plotted from the following values.

x	$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	$1\frac{3}{4}$	2
$2x^2$	$\frac{1}{2}$	$1\frac{1}{8}$	2	$3\frac{1}{8}$	$4\frac{1}{2}$	$6\frac{1}{8}$	8
$-5x$	$-2\frac{1}{2}$	$-3\frac{3}{4}$	-5	$-6\frac{1}{4}$	$-7\frac{1}{2}$	$-8\frac{3}{4}$	-10
$+2$	2	2	2	2	2	2	2
y	0	$-\frac{5}{8}$	-1	$-1\frac{1}{8}$	-1	$-\frac{5}{8}$	0

The area obtained by integration, which is wholly negative between $x = \frac{1}{2}$ and $x = 2$, is shown shaded, together with the mean value of $y = -0 \cdot 75$.



Q10 (a) Display in a complex plane diagram the roots of the equation

$$5z^2 + 4z + 8 = 0.$$

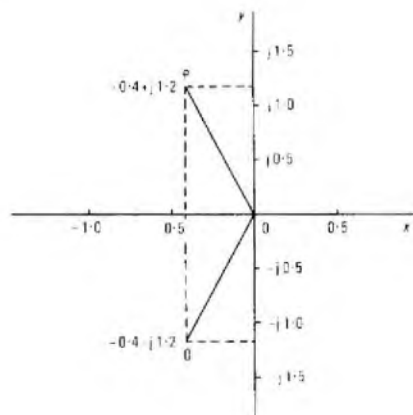
(b) If

$$\frac{1}{Z} = \frac{1}{R} + j\omega C$$

calculate Z in the form $a + jb$ when $R = 330$, $C = 0 \cdot 42 \times 10^{-6}$ and $\omega = 5000$.

A10 (a) $5z^2 + 4z + 8 = 0.$

$$\therefore z = \frac{-4 \pm \sqrt{4^2 - 4 \times 5 \times 8}}{10}$$



$$= -0.4 \pm \frac{1}{10} \sqrt{(-144)},$$

$$= -0.4 \pm j1.2.$$

The two complex roots of the equation are, hence,
 $z_1 = -0.4 + j1.2$ and $z_2 = -0.4 - j1.2$.

These are shown in the complex plane diagram as points P and Q respectively.

(b)
$$\frac{1}{Z} = \frac{1}{R} + j\omega C,$$

$$= \frac{1 + j\omega CR}{R}.$$

$$\therefore Z = \frac{R}{1 + j\omega CR},$$

$$= \frac{R(1 - j\omega CR)}{1 + \omega^2 C^2 R^2},$$

$$\therefore \omega CR = 5000 \times 0.42 \times 10^{-6} \times 330,$$

$$= 0.693.$$

$$\omega^2 C^2 R^2 = 0.480249.$$

$$\therefore Z = \frac{330(1 - j0.693)}{1.48025},$$

$$= \underline{222.9 - j154.5}.$$

TELECOMMUNICATION PRINCIPLES B 1980

Students were expected to answer 6 questions

Q1 Two impedances are connected in series and a $\frac{1}{\pi}$ mH inductor with an internal resistance of 2Ω is connected in parallel across the circuit, AB, as shown in Fig. 1. Calculate for a supply frequency of 1 kHz

- (a) the equivalent impedance between A and B,
- (b) the two series components that will produce the equivalent impedance at 1 kHz, and
- (c) the power factor of the circuit AB.

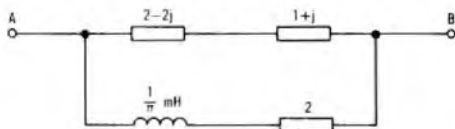


Fig. 1

A1 The circuit AB, of impedance Z , comprises two impedance, Z_1 and Z_2 , in parallel. Therefore, $\frac{1}{Z} = \frac{1}{Z_1} + \frac{1}{Z_2}$.

$$Z_1 = (2 - j2) + (1 + j) = (3 - j) \Omega,$$

$$Z_2 = (2 + jL2\pi f) = 2 + j \frac{10^{-3}}{\pi} \times 2\pi \times 10^3,$$

$$= (2 + j2) \Omega.$$

(a)
$$Z = \frac{Z_1 Z_2}{Z_1 + Z_2},$$

$$= \frac{(3 - j)(2 + j2)}{5 + j} = \frac{(8 + j4)}{5 + j},$$

$$= \frac{2(4 + j2)(5 - j)}{5^2 + 1^2} = \frac{22 + j6}{13},$$

$$= \underline{1.69 + j0.46 \Omega}.$$

(b) This impedance can comprise a series circuit of a resistor of value 1.69Ω and an inductance having a reactance of 0.46Ω .

If L henrys is the inductance at 1 kHz,

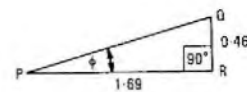
$$L \times 2\pi \times 10^3 = 0.46 \Omega.$$

$$\therefore L = 0.0732 \text{ mH at } 1 \text{ kHz}.$$

(c) The power factor of Z is $\cos \phi$, where ϕ is the angle between the current phasor and the voltage phasor on AB.

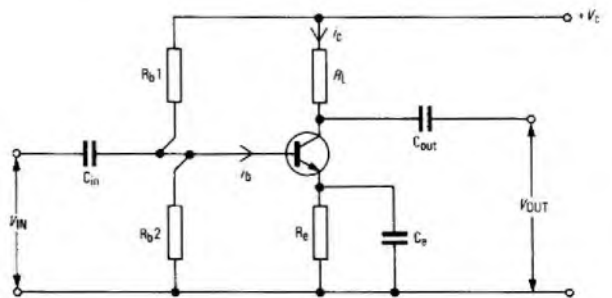
The phasor diagram is shown in the sketch. PR represents the resistance of 1.69Ω , and PQ is the inductive reactance leading PR by $\pi/2$ rad. Therefore, PQ represents the overall impedance and $\angle QPR$ is ϕ .

Hence,
$$\cos \phi = \frac{PR}{PQ} = \frac{1.69}{\sqrt{(1.69^2 + 0.46^2)}} = \underline{0.965}.$$



- Q2** (a) Sketch the circuit of a transistor common-emitter, single-stage amplifier, including bias stabilization.
- (b) Explain the principle of operation of the circuit.
- (c) Why is bias stabilization necessary?
- (d) Sketch typical V_{ce}/I_c characteristic curves.

A2 (a) A circuit diagram of a common-emitter, single-stage amplifier is shown in sketch (a).



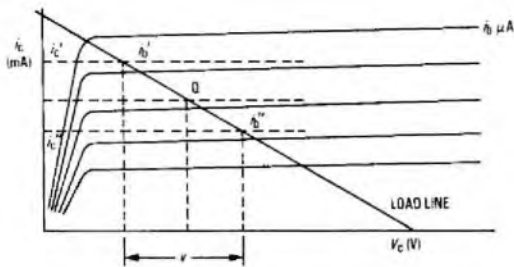
(a)

(b) Variations in the voltage between the base and emitter of the transistor cause variations in the base current, which create similar variations in the collector current, and therefore, the load resistor R_L . The circuit amplifies because the collector current, i_c , collector voltage, V_c , and base current, i_b , are related by the family of curves shown in sketch (b); the amplification can be deduced by drawing the load line corresponding to R_L across the curves. When the input signal causes the base current to vary between the peaks i_b' and i_b'' , the collector current will vary between i_c' and i_c'' . The change in voltage, v_c , across the load resistor R_L can therefore be large compared with the signal into the transistor.

The quiescent condition, Q, when the input signal is zero governs the magnitude (that is, the peak-to-peak value) of the signal that can be handled without appreciable distortion. This condition is determined by the bias in the base-emitter circuit, given by the potential divider resistors R_{b1} and R_{b2} operating across the collector DC supply, V_c . Variations in the voltage of the supply are reflected in the bias across R_{b2} by this arrangement, so giving some measure of stabilization. The emitter resistor, R_e , also improves stability of the bias voltage, especially against transistor characteristic changes that would move the bias point in sketch (b) and so reduce the magnitude of the signal swing for undistorted output. Capacitor C_e decouples R_e from AC, so avoiding negative feedback.

(c) It can be seen from part (b) that bias stabilization is needed to overcome the changes in gain and distortion level arising from alterations in collector supply voltage and transistor characteristics. In severe conditions damage to a transistor can be avoided by adequate bias stabilization.

(d) A family of typical V_c/I_c curves is shown in sketch (b). Note that the collector current, i_c , is given in milliamperes whereas the base current, i_b , is given in microamperes.



(b)

Q3 (a) State what is meant by

- (i) self-inductance, and
- (ii) mutual inductance.

(b) Show how transformer action depends on mutual inductance.

(c) A transformer has a primary winding of 180 turns and two identical secondary windings, each of 120 turns, that can be connected either in series or in parallel. The primary is connected to 100 V AC source. Find the EMF at the secondary terminals when the secondary terminals are connected in

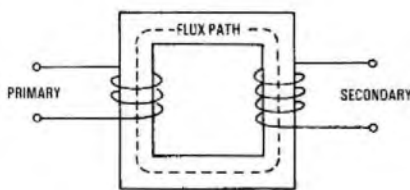
- (i) parallel aiding, and
- (ii) series aiding.

Ignore losses in the transformer.

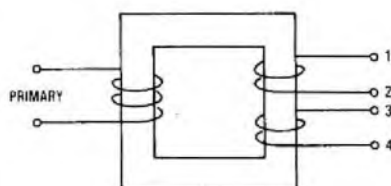
A3 (a) (i) The self inductance of a coil is the property that causes the coil to impede the passage of an alternating current in proportion to the frequency of the current. Self-inductance arises from the flux linkage between the turns of the coil due to the current flowing through the coil itself. A back EMF is induced.

(ii) Mutual inductance is a measure of the coupling between two coils. It arises from the flux caused by an alternating current in one coil linking with the second coil, thereby inducing an EMF in the second coil.

(b) Sketch (a) illustrates the operation of a simple transformer. An iron core in the shape of a continuous ring or rectangle has two windings, shown in the sketch as the primary and secondary windings wound on the limbs of the core. When an alternating current passes through either coil, the alternating flux created in the iron core links with the other coil; therefore an alternating EMF is induced in the second coil.



(a)



(b)

This effect is precisely that described in part (a) (ii). Mutual inductance is, in fact, responsible for the transfer of energy via the magnetic field from the primary to the secondary circuits.

(c) The transformer with two identical secondary windings is shown in sketch (b), in which the direction of each secondary winding is carefully indicated. Because the coils are identical, the induced alternating voltages across their terminals will be identical in magnitude and phase.

(i) When connected in parallel aiding (that is, terminal 1 connected to terminal 3 and terminal 2 to terminal 4) the RMS voltage will be that due to either coil. It is as if there were one secondary coil with wire of twice the cross-sectional area of one of the coils.

Thus, the RMS voltage will be $120 \times 100/180 = 66.7 \text{ V}$.

(ii) In series aiding (that is, terminal 2 and 3 connected together), the resulting secondary circuit is equivalent to a winding having twice the number of turns of either of the coils.

Thus, the RMS voltage = $66.7 + 66.7 = 133.4 \text{ V}$.

Q4 (a) Give TWO reasons why the field-effect transistor (FET) is proving a valuable device in telecommunications.

(b) Explain the principle of operation of an FET as a small signal amplifier. Include a circuit diagram with typical component values and operating voltages.

Q5 (a) What conditions must be satisfied for a series circuit to resonate? Use reactance-frequency curves to illustrate the answer and derive an expression for the frequency of resonance.

- (b) (i) Explain the effect of resistance in a resonant circuit.
- (ii) How is the Q-value of a resonant circuit defined?

(c) A $0.02 \mu\text{F}$ capacitor resonates in series with a 7.5 mH inductor to give a Q-value of 120. Find the loss resistance of the circuit.

A5 (a) When a circuit consists of positive and negative reactances (that is, inductance and capacitance), resonance will occur at the frequency at which the circuit reactance is zero; that is, the reactances are equal in magnitude but opposite in sign. The circuit therefore becomes purely resistive.

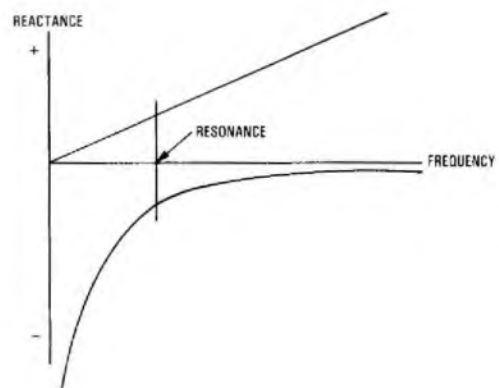
The sketch shows the reactance-frequency curves for an inductance and a capacitance. Since the reactance of an inductor of L henrys is $X_L = 2\pi fL$, where f is the frequency, the inductive reactance-frequency curve is a straight line. For a capacitance of C farads, the reactance $X_C = 1/2\pi fC$.

At resonance, $X_L = X_C$.

$$\text{Therefore, } 2\pi fL = \frac{1}{2\pi fC}$$

Hence, if f_0 is the frequency at resonance,

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \text{ hertz.}$$



(b) The resistance in a resonant circuit limits the current which will flow in the circuit. If the resistance were zero, the current would be infinite. The resistance also modifies the shape of the response curve; that is, total reactance plotted against frequency. The lower the resistance, the narrower and steeper is the response curve. This effect is given numeracy by a term called Q-factor, which is defined as $2\pi f_0 L/R$, where R ohms is the circuit resistance.

(c) The expression obtained in part (b) may be re-arranged. Thus,

$$R = \frac{1}{Q} \sqrt{\frac{L}{C}} \text{ ohms,}$$

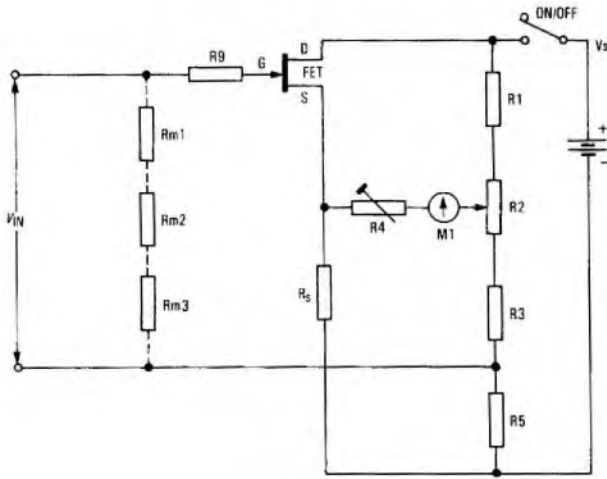
$$= \frac{1}{120\sqrt{(7.5 \times 10^{-3}) / (0.02 \times 10^{-6})}}$$

$$= 5.103 \Omega.$$

Q6 (a) Explain, with the aid of a circuit diagram, the principle of ONE type of electronic voltmeter used in telecommunications work.

(b) Describe and explain TWO features that make it specially useful in this branch of engineering.

A6 (a) The circuit diagram of an electronic voltmeter using a field-effect transistor (FET) is shown in the sketch. Basically the circuit behaves as a DC meter in the simple form shown. The FET is biased to near pinch-off and the source, S, is held at a negative potential with respect to the gate, G. This bias potential is obtained from the potential divider network R1, R2, R3 and R5. A sensitive centre-zero meter, M1, bridges the two parallel networks formed by the circuit and when this bridge is balanced the meter reads zero.



When a voltage is applied to the input (V_{in}), the gate of the FET will be forward biased so that a drain-source current will flow and unbalance the bridge. M1 will deflect in proportion to the value of V_{in} .

It is necessary to calibrate the instrument using R4. Firstly, with zero input, R2 is adjusted to give a balance on M1. A known potential, V_k , is then applied to the input and R4 adjusted to give full-scale deflexion. The voltmeter is thus calibrated for the range 0 V to V_k .

A range of voltages can be measured by using the range resistors, R_{m1} , R_{m2} , R_{m3} etc at the input.

This type of meter needs only a small operating voltage and therefore a safety resistor, R9, is wired in series with the gate of the FET.

(b) The most useful feature of the FET voltmeter is the very high input impedance it can present, so that the circuit being measured is unlikely to be disturbed by the application of the voltmeter.

A second feature is the sensitivity that can easily be obtained without additional complication. Power consumption is almost negligible and the unit is small and light in weight.

Current measurement can be made by connecting the input across a resistor of known value in series with the test circuit.

Q7 (a) Explain briefly the principle of the DC motor, showing how the torque is produced.

(b) How does the back EMF in the armature windings control the armature current according to the mechanical load on the motor shaft?

(c) The armature of a DC motor is a cylinder, diameter 5 cm and length 10 cm, wound with 10 coils each of 20 turns. It rotates between pole pieces that have a magnetic flux density of 0.50 T. Calculate the average torque developed when the average current in each coil throughout one revolution is 4 A.

A7 (a) See A8, Telecommunication Principles B 1976, Supplement, Vol. 70, p. 31, Apr. 1977.

(b) When the motor is running, direct current passes through the armature coils, which are themselves generating a back EMF because they are cutting the air-gap flux of the magnets. This EMF is, by Fleming's right-hand rule, proportional to the armature speed and is opposing the DC supplied to the armature by the source of electricity driving the motor. When the load on the shaft is increased, the motor

will run slower; the back EMF will then decrease and thus the net voltage across the armature will increase. The armature current will therefore increase and the torque developed will increase to meet the greater load.

(c) The magnetic force on each longitudinal conductor is given as an average around the whole circumference of the armature.

If b metres is the length of one conductor on one side, B teslas is the flux density and i amperes is the current,

$$\text{force per conductor} = biB \text{ newtons.}$$

This force acts tangentially to the armature, and therefore the total force around the whole circumference is $NbiB$ newtons, where N is the number of conductors.

$$\begin{aligned} \text{Torque developed} &= \text{total tangential force} \times \text{radius,} \\ &= NbiBr, \\ &= 400 \times 10 \times 10^{-2} \times 4 \times 0.50 \times 2.5 \times 10^{-2}, \\ &= 2.0 \text{ N m.} \end{aligned}$$

Q8 (a) (i) Describe, with the aid of a typical B-H loop, the magnetic hysteresis effect in iron.

(ii) Name FOUR properties of the iron that can be obtained from the diagram.

(b) Outline an experiment to obtain the information from which a hysteresis loop can be drawn. List the equipment needed and record the experimental procedure.

(c) How can the permeability be deduced from the results obtained in part (b).

Q9 (a) Explain, with the aid of sketches, the principle of operation of a cathode-ray tube.

(b) "A cathode-ray tube oscilloscope can be used to measure voltage or to display waveforms." Discuss this statement and with the aid of diagram show that it is true.

Q10 (a) The circuit of an inductance bridge is shown in Fig. 2. Derive formulae from which the values of L and r can be found. Why must R be adjustable?

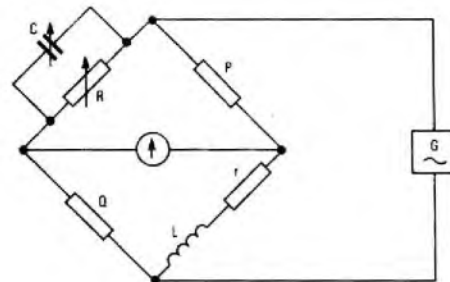


Fig. 2

(b) Describe briefly an experiment to find L and r , giving details of equipment for the source and the detector. If $C = 0.3 \mu\text{F}$, $R = 520 \Omega$, $P = 1000 \Omega$ and $Q = 250 \Omega$, calculate L and r .

A10 (a) Let the impedance of the combination of L and r be Z_1 , the impedance of Q be Z_2 , the impedance of P be Z_3 and the impedance of the combination of C and R be Z_4 . When the bridge is balanced, indicated by zero deflexion of the meter, the general relationship for the bridge is

$$Z_1 \times Z_4 = Z_2 \times Z_3$$

Using j notation, the arm impedances are

$$Z_1 = r + j\omega L \text{ ohms, } Z_2 = Q \text{ ohms, } Z_3 = P \text{ ohms and}$$

$$Z_4 = \frac{R}{1 + j\omega CR} \text{ ohms.}$$

Substituting these values in the balance equation gives

$$(r + j\omega L) \left(\frac{R}{1 + j\omega CR} \right) = QP.$$

$$\therefore Rr + j\omega LR = QP + j\omega CRQP.$$

Equating the real parts gives $r = \frac{QP}{R}$ ohms, and

equating the imaginary parts gives $j\omega LR = j\omega CRQP$.

Therefore, $r = \frac{QP}{R}$ ohms and $L = \frac{CQP}{R}$ henrys.

Resistor R must be adjustable to balance both the amplitude and phase of the voltage across the detector.

(b) The experimental report would be as follows.

Aim To find the inductance (*L* henrys) and the AC resistance (*r* ohms) of a given inductor.

Equipment The components Q, P, C and R; C and R are adjustable and calibrated.

An audio-frequency signal generator.

A sensitive amplifier-detector with ranges of level or, alternatively, low-impedance headphones for initial adjustment of the bridge and high-impedance headphones for final adjustment.

Method The circuit is arranged as shown in Fig. 2. Carefully screened connexions must be used throughout and components must be individually screened to avoid any unwanted coupling between them.

The input from the signal generator to the bridge should be via a

screened transformer which has an earthed interwinding screen. This eliminates stray longitudinal currents that can give disturbing readings and inaccurate values of C, L and r.

The signal generator is set up to the frequency at which L and R are to be measured. The low-impedance headphones are connected across the bridge and C and R adjusted alternately until a minimum signal is heard in the headphones. At this stage the high-impedance headphones are connected as the detector and adjustment of C and R continued until no signal is audible. The balance readings of C and R are noted.

Calculation From part (a),

$$L = CPQ = 0.3 \times 10^{-6} \times 1000 \times 250 = 75 \text{ mH.}$$

$$r = \frac{PQ}{R} = \frac{1000 \times 250}{520} = 480.8 \Omega.$$

TELEGRAPHY B 1980

Students were expected to answer any 6 questions

Q1 (a) For an electromagnetic teleprinter receiver line-termination, explain the reasons for providing

- (i) a resistor, and
- (ii) a capacitor.

For different values of capacitance, draw current/time graphs to illustrate the action of the combination, and give typical values.

(b) Why is an additional capacitor fitted in parallel with the receive magnet, and what is the effect on the capacitor in part (a)(ii)?

A1 (a) The receive line-termination for an electromagnetic teleprinter consists of a resistor and capacitor in parallel and is known as a signal-shaping network.

The value of the resistor is chosen such that, in conjunction with the value of the signalling voltage and the inductance, *L*, of the receive magnet, the current in the magnet reaches its maximum value as soon as possible. If the resistance, *R*, of the shaping network is much greater than the sum of the line resistance and the receiver resistance, the time for the current through the receive magnet to reach about two-thirds of its maximum value (i.e., the time-constant) is equal to the ratio of *L* to *R*. The normal value for *R*, when used with a signalling potential of 80 V and a receiver inductance of 6 H is about 4 kΩ. For these values, the time for the receive current to reach about two-thirds of its maximum value = $L/R = 6/4000 = 1.5 \text{ ms}$. This is illustrated by graph A in sketch (a).

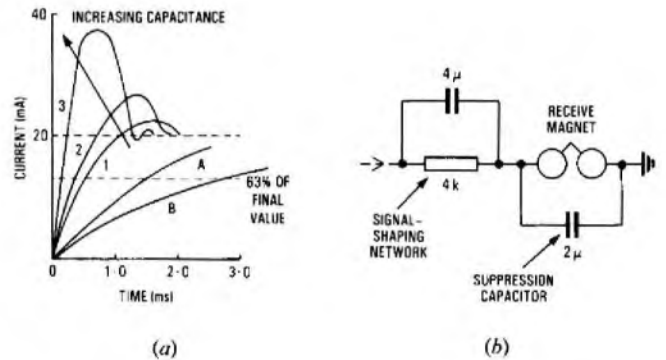
With a signalling potential of say 40 V, a resistance of 2 kΩ would be required to limit the receive magnet current to 20 mA. The time for the current to reach two-thirds of its maximum value = $6/2000 = 3 \text{ ms}$. This is illustrated by graph B in sketch (a).

The graphs show how the speed of operating the receive magnet, and hence the signalling speed, are improved by using a high signalling voltage and a high resistance in the signal-shaping network.

Graphs 1, 2 and 3 show the effect of connecting a capacitor in parallel with the resistor. A capacitor connected in this way acts as a path of negligible resistance whenever the signalling potential is reversed. Instantaneously, therefore, the capacitor acts as a short-circuit to the resistor and the signalling potential is applied directly to the receive magnet, causing the current to increase at a high rate and the magnet to operate quickly. As the capacitor charges, the flow of current through the capacitor decreases until the whole of the current flowing through the inductor is controlled by the resistor. The total current through the receiver is the sum of the currents through the capacitor and the resistor, and may rise to a value above the steady current through the receiver. The graphs show the effect of increasing the value of the capacitor: an increase in capacitance causes an increase in overshoot. Above a certain value of capacitance, the circuit may oscillate; this should be avoided since prolonged oscillation may interfere with the next operation of the relay.

Typical values for the capacitance are 1 μF, 2 μF and 4 μF for graphs 1, 2 and 3 respectively. The value of 2 μF (graph 2) gives the optimum signal shape.

(b) An additional capacitor is connected in parallel with the receive magnet to suppress the harmonics which may be generated by the movement of the magnet tongue in the magnetic field. The EMF generated would pass to line and could cause interference on telephonic circuits working in the same cable. The suppression capacitor, normally



2 μF, would tend to slow the operation of the magnet and, to compensate for this, the value of the shaping capacitor is increased to 4 μF. The complete receiver termination is shown in sketch (b).

Q2 (a) Explain the difference between a start-stop system and a synchronous system as a means of transmitting and receiving teleprinter signals.

(b) State the advantages and disadvantages of the TWO systems in (a).

(c) With the aid of sketches, describe the action of a teleprinter when receiving a START element and the first two character elements, one MARK and one SPACE, of a teleprinter signal.

A2 (a) Telegraph signals consist of positive or negative-polarity elements transmitted in a distinctive sequence to form a code representing numerical and alphabetical characters. The stream of elements may be continuous, as in a synchronous system where the receiver and transmitter start in phase and remain in step for the duration of the message. This system is fast in operation but requires expensive well-maintained equipment at both ends to ensure that both terminations remain in synchronism. For point-to-point systems carrying heavy traffic, such a system may be justified, but for scattered stations working on a switched network the simpler start-stop system is preferred.

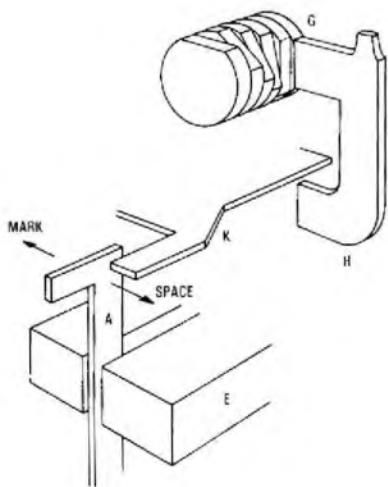
In the start-stop system, although the driving motors may be running continuously, the transmission and reception of the group of elements constituting a character is treated as a distinct self-contained cycle of operations. The transmitter prefixes each character by a START element to initiate a character cycle in the distant machine, which operates (for the duration of the character) in phase with the transmitter. During the cycle, the character elements are transmitted and received. A STOP element, transmitted for a minimum time at the end of each character, allows the transmitter and receiver to be brought to rest at the completion of each character cycle. In this way, any speed discrepancy between the receiver and transmitter is limited to the cumulative effect during one character, and provided the equipments are running close

to the nominal speed of the system, mutilation cannot occur and messages can be satisfactorily transmitted and received without costly synchronizing features.

(b) The advantages and disadvantages of the two systems are listed in the table.

Start-Stop	Synchronous
<p>Flexible Simple The machines are at rest until required, minimizing wear Slower in operation due to the addition of a START element and a STOP element to each character Any discrepancy in driving speed is limited to one character Propagation time over various circuits has no effect</p>	<p>Complicated Costly A synchronizing signal is required Continuous operation Speed discrepancy is cumulative over the whole message Propagation time over a range of circuits could affect reception Faster transmission as character elements only are transmitted: START and STOP elements can be omitted</p>

(c) The sketch shows the operation of a BPO Teleprinter No. 15 to incoming signals. The START signal causes electromagnet E to move armature A to the SPACE position, releasing the selector unit cam-sleeve G, which rotates in a clockwise direction. During the receive cycle, the five flats on cam G are presented in sequence to five sequential levers H which pivot inwards in turn. In sequence with the rotation of the cam, incoming MARK and SPACE signals are received by the magnet, moving armature A to the left and right respectively. If the incoming signal is a MARK, read lever K is allowed to move downward, engaging the lower arm of sequential lever H. The movement of a projection at the upper end of lever H causes a static MARK-code setting on a storage latch. If the incoming signal is a SPACE, read lever K is blocked and cannot move and will not affect sequential lever H; a SPACE-code setting will be registered. In this way, the five character elements will be registered on storage latches, and later in the cycle the combination is transferred to code-slats which select the correct type for printing.



Q3 (a) Describe, with the aid of sketches, how the perforations in paper tape are converted to telegraph signals by an automatic tape-transmitter.

(b) Describe the control and alarm facilities of the transmitter.

(c) What are the advantages and disadvantages of paper-tape transmission as compared with manual keyboard transmission?

Q4 (a) Draw current/time diagrams to illustrate a 50 baud teleprinter character affected by

- (i) 10% late bias distortion, and
- (ii) 15% early fortuitous distortion.

(b) Give THREE possible causes of EACH type of distortion in (a).

(c) Describe ONE other type of distortion which may be present in a telegraph circuit.

Q5 (a) The following items are provided at an automatic Telex exchange:

- (i) a dial speed-and-ratio tester, and
- (ii) a test final-selector.

State the facilities provided by these items and describe how they are used.

(b) Describe, with the aid of diagrams, how access may be gained to a subscriber's circuit other than through the test final-selector. What are the advantages and disadvantages of this method?

A5 (a) (i) The dial speed-and-ratio tester is designed to test the speed and ratio of a subscriber's dial, ensuring correct operation and identification of when repair may be necessary. The acceptable limits for the dial pulses are as follows:

$$\begin{aligned} \text{Speed: } & 9\text{--}11 \text{ pulses/s (Nominal rate: } 10 \text{ pulses/s)} \\ \text{Ratio: } & \left. \begin{array}{l} 65.5\% \text{--}54.5\% \text{ BREAK} \\ 34.5\% \text{--}45.5\% \text{ MAKE} \end{array} \right\} \text{Nominal ratio } 60:40 \end{aligned}$$

For the speed test, the tester measures the duration of alternate pulses by charging a capacitor and comparing the charge voltage with the voltage on a preset potentiometer. The resultant voltage is displayed on the test-desk voltmeter, with a deflexion to the left indicating out of limits and a deflexion to the right indicating within limits. A HIGH-LIMIT key on the tester presets the circuit to show zero at 11 pulses/s; any speed below this is indicated by a deflexion to the right and any speed above is indicated by a deflexion to the left. Similarly, the lower limit of 9 pulses/s is tested after operating the LOW-LIMIT key and receiving a train of pulses.

To test the ratio, the MAKE and BREAK elements each charge separate capacitors which are compared against each other and the result displayed on the voltmeter. The indications and use of the HIGH-LEVEL and LOW-LEVEL keys are as for the speed measurement.

For a description of a test final-selector, and a model answer to part (b) of the question, see A4, Telephony B 1977, Supplement, Vol. 71, p. 50, Oct. 1978.

Q6 A fully-equipped rack of 40 final selectors in an automatic Telex exchange carries 22 erlangs of traffic during the busy hour. The average currents drawn during a call are:

$$50 \text{ V: } 150 \text{ mA} \quad +80 \text{ V: } 3 \text{ mA} \quad -80 \text{ V: } 6 \text{ mA}$$

(a) Calculate:

- (i) the average current drawn from EACH supply in the busy hour,
- (ii) the ampere-hour consumption in the busy hour, and
- (iii) the maximum current which could be drawn from EACH supply at any instant.

(b) State the factors which govern the voltage at the selector as compared with the voltage at the battery, and quote the upper and lower voltage limits permissible.

A6 (a) (i) Average current:

$$\begin{aligned} \text{from } 50 \text{ V} &= 22 \times 150 \text{ mA} = 3.3 \text{ A,} \\ \text{from } +80 \text{ V} &= 22 \times 3 \text{ mA} = 66 \text{ mA,} \\ \text{and from } -80 \text{ V} &= 22 \times 6 \text{ mA} = 132 \text{ mA.} \end{aligned}$$

(ii) Ampere-hour consumption in the busy hour

$$= 3.3 + 0.066 + 0.132 = 3.498 \text{ A h.}$$

(iii) Maximum current:

$$\begin{aligned} \text{from } 50 \text{ V} &= 40 \times 150 \text{ mA} = 6 \text{ A,} \\ \text{from } +80 \text{ V} &= 40 \times 3 \text{ mA} = 120 \text{ mA,} \\ \text{and from } -80 \text{ V} &= 40 \times 6 \text{ mA} = 240 \text{ mA.} \end{aligned}$$

(b) The factors which govern the voltage at the selector as compared with the voltage at the battery are the load, the cross-sectional area of the power cables and the number of simultaneous calls. The difference in voltage is due to the potential difference generated across the feeder between the battery and the selector. The potential difference is calculated by multiplying the current by the resistance of the feeder cable. Typical permitted losses are 1 V for $\pm 80 \text{ V}$ supplies and 0.15 V for 50 V supplies. The load on a power supply from any selector will vary during a call, depending on the functions being performed at any instant during the call (e.g., vertical stepping). As the momentary surges of current are of short duration, it is more convenient to assume an average value for the load during a call. The number of selectors likely to be in use at any one time during the busiest part of the day is calculated, and the total normal load on any cable may be found by multiplication. The cross-sectional area of a cable also affects the voltage, as the resistance of the cable increases with a decrease in the cross-sectional area. The cost of distribution cables is high and, as the cost is inversely proportional to the voltage drop, the size of the conductor is normally calculated for the maximum permissible voltage drop.

The upper and lower permissible limits for voltage values at a selector are:

+80 V and -80 V: 75-85 V (the algebraic sum of positive and negative supplies must not total more than 4 V; i.e., there must be less than 4 V difference between the +80 V rail and the -80 V rail).

50 V: 46-52 V.

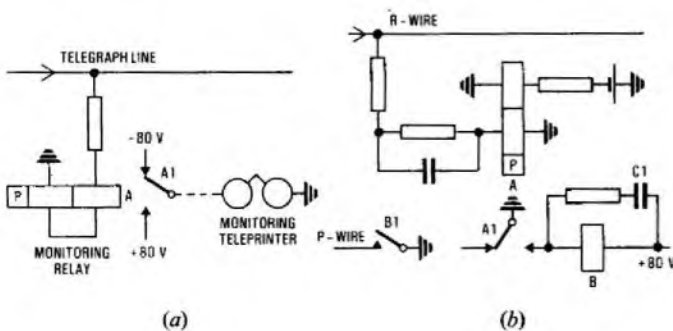
Q7 For an electromagnetic polarized relay:

(a) draw circuit diagrams to show how it may be used

- (i) as a monitoring relay, and
- (ii) as a supervisory relay, and

(b) describe TWO electrical tests which may be performed on a relay of this type to determine whether the relay is correctly adjusted.

A7 (a) (i) Sketch (a) shows the connexion of a monitoring relay to a telegraph line. The monitoring relay is a sensitive relay connected to the line through a high-value resistor and arranged to repeat the line signals to a monitoring teleprinter. The 2 coils of the relay are connected in series to give good sensitivity and the high series resistance ensures that a minimal amount of current is shunted from the line. The relay must repeat signals accurately and with the minimum of additional distortion. An alternative arrangement, using a high-impedance valve with a repeating relay in the anode circuit, is used for monitoring at test-desk positions.



(ii) Sketch (b) shows the circuit of a supervisory relay (relay A) in a Tecx final selector. Relay A is permanently connected to the R-wire and is used for repeating dial pulses during vertical and rotary stepping as well as acting as a supervisory relay during the progress of a call. The relay responds to teleprinter signals on the R-wire such that contact A1 is made during MARK signals (negative potential) and energizes relay B. Relay B remains held during SPACE signals (positive potential) by virtue of the energy stored in capacitor C1. Contact B1 applies earth potential to the P-wire to hold preceding selectors.

When the call is cleared, continuous positive potential is applied to the R-wire and contact A1 is broken. After a period of 325-475 ms, relay B releases and disconnects the earth potential from the P-wire to release the preceding equipment.

The supervisory relay is sensitive, and is connected to the R-wire through a high resistance to prevent impairment of the teleprinter signals. A bias winding ensures that the supervisory relay assumes the positive-potential (clearing) condition to release the selector if the line becomes disconnected during a call.

(b) *Vibrate Test for Neutrality (Bias)* An alternating EMF is applied to one of the OPERATE coils of the relay at a time, and a DC potential is applied to the contact, as shown in sketch (c).

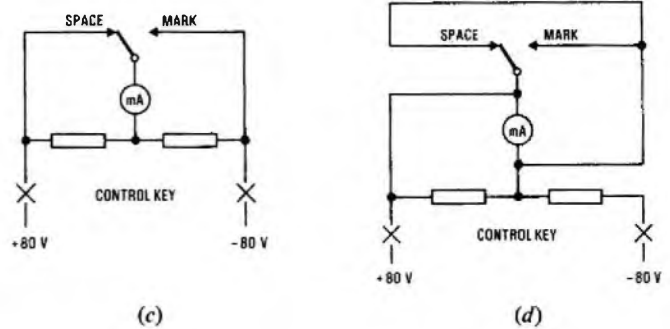
The meter will show a vibrating deflexion, the mean position of the vibrations indicating the bias of the relay. Thus, if the mean position of the meter is to the left of zero, the relay contacts are located too far to the left and a SPACING bias exists; if the mean position of the vibrations is to the right of zero, the contacts are too far to the right and a MARKING bias exists.

When the mean position of the meter coincides with zero, the relay is unbiased and the tongue of the relay is in contact with its MARK and SPACE contacts for equal periods.

A final adjustment of neutrality is made with the meter shunt disconnected, giving a large vibrating deflexion to allow more accurate neutral adjustment to be made.

When the test has been completed using one coil, the test is repeated for the remaining operate coils as a check.

Transit-Time Test The contact transit-time test is carried out while the relay is vibrating, as in the previous test. In this test, it is arranged to short-circuit the meter while the relay tongue is resting on either of the contacts, and current passes through the meter only while the tongue is in transit between the contacts. The circuit is shown in sketch (d).



The deflexion on the meter (which is to the left) is proportional to the transit time of the contact. The transit time in milliseconds can be calculated from the following formula:

$$\text{transit time} = \frac{1000D_3 \times 1.1}{2D_2fS} \text{ milliseconds}$$

where D_3 is the meter reading (with shunt disconnected) during the transit-time test, D_2 is the steady reading when the DC test is applied to the relay, 1.1 is an empirical factor correcting for inherent damping of the meter and electrical circuit, and f is the frequency of the EMF applied to the relay coil.

The duration of contact time can be calculated from the following formula:

$$\text{contact time} = \frac{1000(D_2 - D_3) \times 1.1}{2D_2fS} \text{ milliseconds.}$$

Q8 For a multi-circuit voice-frequency telegraph system,

(a) draw a labelled block diagram,

(b) explain the operation of this system, and

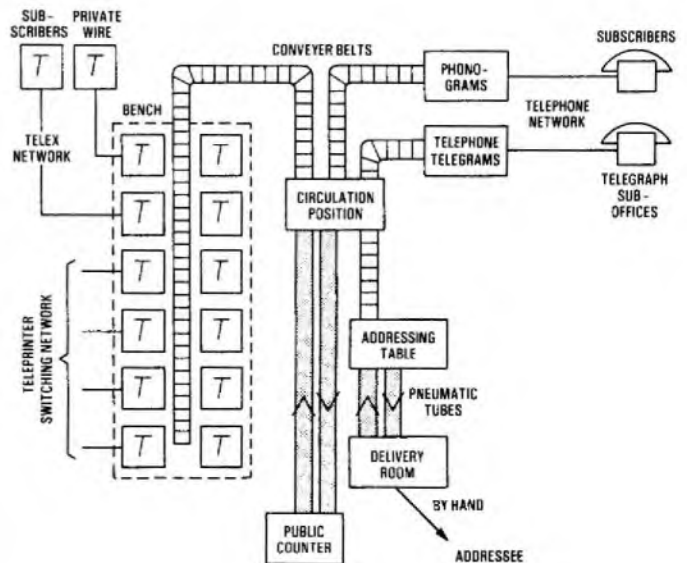
(c) indicate at various points on the diagram the waveform of the electrical signals present.

A8 Sec A3, Telegraphy B 1975, Supplement, Vol. 69, p. 45, July 1976.

Q9 (a) With the aid of a diagram showing the layout of equipment in a large telegraph centre, describe the reception, routing and transmission of the various types of telegram which may be handled.

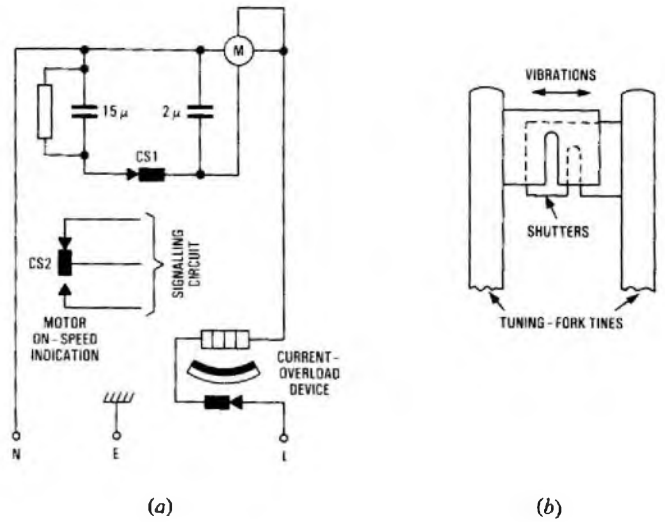
(b) Describe the circuit access, testing and protective facilities provided at such a centre.

A9 (a) The layout adopted for a teleprinter instrument room will depend to a large extent on the shape of the accommodation available and on the services to be included. The sketch shows a typical layout which could be used for an installation comprising up to 12 teleprinters and using bench-type tables. Bench-type tables are arranged in back-to-back suites and, if the traffic load justifies the use of band conveyors, they may be provided. The circulation positions and



addressing positions would be located centrally with respect to the teleprinter positions. The teleprinter positions are normally divided into suitable groups dealing with either outgoing or incoming traffic and, if a position is provided for night concentration of teleprinter traffic, this would be placed near to the circulation table. The Phonogram and telephone-telegram positions would preferably be situated in a separate but adjacent room away from the high noise level of the teleprinter machines.

(b) Cables for lines and miscellaneous signalling purposes are terminated on connexion strips at the end of each bench suite. The ± 80 V supplies used to drive the teleprinter motors and to provide line-signalling power are cabled from the battery via fuses to a distribution fuse-board at the end of each suite; protective resistor-bulbs are fitted in the signalling supplies. Separate earth wires are used for the signalling earth and for the protective earth of the teleprinter equipment. Line circuits are cabled from the intermediate distribution frame (IDF) via a jack field in order that any circuit may be picked up by the use of plugs and cords for connexion to a monitor-and-test set. This enables temporary cross-connexion between any machine and any line circuit; it also provides access for testing. The IDF is used for the permanent connexion between the incoming circuits and the teleprinter positions.



Q10 (a) With the aid of a diagram, explain the operation of a teleprinter motor circuit.

(b) What precautions are taken to prevent the motor becoming a fire hazard?

(c) Describe how the speed of the motor may be measured using

- (i) a stroboscope, and
- (ii) a telegraph distortion-measuring set (TDMS).

A10 (a) Sketch (a) shows the connexions of the synchronous motor circuit of a BPO Teleprinter No. 15. The synchronous motor is a capacitor-start, capacitor-run motor which rotates in synchronism with the mains frequency to ensure accuracy. The motor reaches speed within 1.5 s, and centrifugal contacts CS1 and CS2 operate when the motor has reached 75% of its synchronous speed. The motor consists basically of a rotor operating within two pairs of fixed stator coils, the latter consisting of one main pair and one secondary pair. If the current is supplied only to the main coils, the net torque when stationary is zero. The connexion of capacitance in series with the secondary coils produces a rotating field similar to that provided by 2-phase windings, and a starting torque is produced causing the rotor to rotate. When the motor has almost reached working speed, the centrifugal contact CS1 disconnects the heavy starting-torque capacitor (15 μ F) and the motor continues to run in the rotating field on the main coils and in the lighter (2 μ F) secondary-coil field.

(b) The motor and associated components are fitted in a metal cover which reduces radio interference and noise, and acts as a safeguard to the remainder of the machine if the motor runs hot. The cover is ventilated by a fan on the motor which cools the motor and exhausts hot air through louvres in the base tray. This prevents lubricants in the machine from drying out and avoids the accumulation of dust in the

mechanism. A manually reset circuit-breaker, which is a current-overload device, is incorporated in the mains wiring circuit, and disconnects the motor if a heavy current flows for an excessive period due, for example, to a stalled motor. Normal fuses also protect the wiring if a full short-circuit occurs.

(c) (i) The standard method of checking the speed of a teleprinter motor locally is to use a tuning-fork stroboscope to observe alternate black and white markings on the cover of the teleprinter-motor governor. At the correct speed, the motor rotates at 3000 revolutions/min; i.e., 50 revolutions/s. With six black and six white segments on the cover, a white or a black segment will be opposite any chosen spot 300 times each second. The tuning fork has a frequency of 150 Hz, which is an exact multiple of the rate of appearance of the segments on the governor cover. To check the speed of the motor, the stroboscope is set vibrating by striking it, and the segments are viewed through the stroboscope slits. If the segments appear stationary, the motor is running at the correct speed. Sketch (b) shows the action of the stroboscope shutters.

(ii) The speed of a teleprinter motor may be checked by monitoring the output of the teleprinter using a TDMS. The TDMS has an accurate time-base which can be adjusted by means of switches to match the speed of a teleprinter signal. To check the speed, the teleprinter is set to transmit a character continuously and the bright spots indicating the received signal are observed on the TDMS. If the speed of the teleprinter and TDMS do not match, the spots drift across the TDMS screen. To ascertain the speed of the teleprinter, the TDMS speed is adjusted until the spots are stationary, when the speed is read from the setting of the TDMS dials.

TELECOMMUNICATION PRINCIPLES C 1980

Students were expected to answer any 6 questions

Q1 (a) A coaxial cable of negligible loss has constants $L = 0.2 \mu\text{H/m}$ and $C = 80 \text{ pF/m}$. Calculate for this cable

- (i) the characteristic impedance,
- (ii) the velocity of propagation, and
- (iii) the wavelength at 25 MHz.

(b) A 7.5 m length of this cable has one end connected to a 25 MHz source of open-circuit voltage 4 V and internal impedance equal to the characteristic impedance. The other end of the cable is connected to a load impedance equal to the characteristic impedance. Calculate, for the cable length

- (i) the input voltage,
- (ii) the output voltage, and
- (iii) the phase difference between the input and output voltages.

A1 (a) A cable, of negligible loss, has a characteristic impedance, Z_0 , given by

$$Z_0 = \sqrt{\frac{L}{C}}, \dots \dots (1)$$

and a velocity of propagation, v_p , given by

$$v_p = \frac{1}{\sqrt{LC}}, \dots \dots (2)$$

$$\begin{aligned} (i) \quad Z_0 &= \sqrt{\left(\frac{0.2 \times 10^{-6}}{80 \times 10^{-12}}\right)} \\ &= \sqrt{\left(\frac{20}{80} \times 10^4\right)} \\ &= 50 \Omega. \end{aligned}$$

$$\begin{aligned} (ii) \quad v_p &= \frac{1}{\sqrt{(0.2 \times 10^{-6} \times 80 \times 10^{-12})}} \\ &= \frac{1}{\sqrt{(16 \times 10^{-18})}} \\ &= \frac{10^9}{4} = 2.5 \times 10^8 \text{ m/s.} \end{aligned}$$

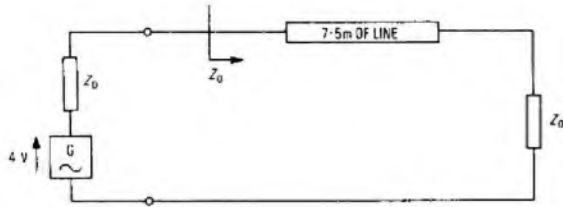
(iii) The wavelength, λ , is given by

$$\lambda = \frac{v_p}{f}, \text{ where } \lambda \text{ is the wavelength in metres and } f \text{ is}$$

the frequency in hertz.

$$\lambda = \frac{2.5 \times 10^8}{25 \times 10^6} = 10 \text{ m.}$$

(b) (i) The circuit arrangement is shown in the sketch. It can be seen that the input impedance of the line is Z_0 and, hence, the input voltage is half of the source voltage; that is, 2 V.



(ii) As the line has negligible loss, the output voltage is equal in magnitude to the input voltage; that is, 2 V.

(iii) At 25 MHz, 7.5 m of cable corresponds to threequarters of a wavelength. Thus the phase difference between the input and output voltages is $\frac{3}{4} \times 360^\circ = \underline{270^\circ}$.

Q2 (a) Explain what is meant by "frequency modulation" of a sinusoidal carrier.

(b) In a frequency modulator the carrier frequency is shifted by 1500 Hz per volt of modulating signal. The carrier is a 4 V peak, 500 kHz sinusoid and the signal, which is sinusoidal, has a peak value of 3 V at a frequency of 600 Hz. Write down an expression for the instantaneous frequency of the modulator output and calculate the peak frequency deviation and the modulation index. Hence, or otherwise, give an expression for the instantaneous voltage of the modulator output.

A2 (a) Frequency modulation of a sinusoidal carrier is the form of carrier modulation in which the carrier frequency is changed such that the deviation in frequency from the nominal carrier frequency is proportional to the amplitude of the modulating signal.

(b) The instantaneous frequency is given by

$$f_{\text{inst}} = 500 \times 10^3 + 3 \times 1.5 \times 10^3 \sin 2\pi 600t \text{ Hz.}$$

The peak frequency deviation is $1500 \times 3 \text{ Hz} = \underline{4.5 \text{ kHz}}$.

The modulation index is the ratio of the frequency deviation to the modulating frequency. For the conditions given,

$$\eta = \frac{4.5 \times 10^3}{600} = \underline{7.5.}$$

The instantaneous voltage of the modulator output is given by

$$v = V_c \sin(\omega_c t - \eta \cos \omega_m t),$$

where V_c is the peak carrier voltage, ω_c is the angular velocity of the carrier, t is time, η is the modulation index and ω_m is the angular velocity of the modulating signal.

Therefore, for the given conditions

$$v = \underline{4 \sin(2\pi \times 500 \times 10^3 t - 7.5 \cos 2\pi \times 600t)}.$$

Q3 (a) List FOUR important effects of negative feedback in amplifiers.

(b) A field-effect transistor with $g_m = 5 \text{ mA/V}$ and $r_d = 42 \text{ k}\Omega$ is used with a $3 \text{ k}\Omega$ load resistor in series with the drain in a common-source amplifier. Calculate the voltage gain and the output resistance.

(c) Additional components, which take negligible current, are added to the amplifier described in part (b) to provide 5% negative feedback in series with the input. Calculate the new values of voltage gain and output resistance.

A3 (a) When negative feedback is applied to an amplifier the following effects result.

(i) The gain of the amplifier is reduced.

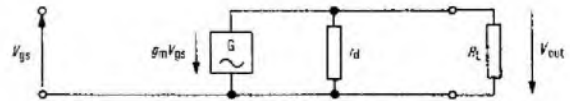
(ii) The gain of the amplifier is stabilized against component and temperature variations.

(iii) The input and output impedances are modified.

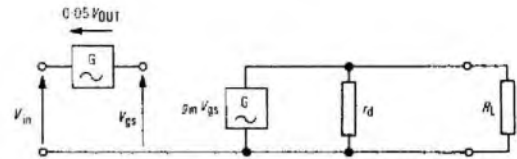
(iv) Non-linear distortion is reduced.

(b) The equivalent circuit of the amplifier is shown in sketch (a). The load resistance $R_L = 3 \text{ k}\Omega$ and $r_d = 42 \text{ k}\Omega$. Thus, the effective load, R_L and r_d in parallel, is $2.8 \text{ k}\Omega$. For a 1 V input signal, 5 mA flows in this effective load, which results in an output voltage of $5 \times 2.8 = 14 \text{ V}$. Thus the voltage gain is 14.

The output resistance is clearly r_d and has the value 42 kΩ.



(a)



(b)

(c) Sketch (b) shows the modified circuit.

The voltage gain is $\frac{V_{\text{out}}}{V_{\text{in}}}$,

$$V_{\text{out}} = g_m \times V_{gs} \times R$$

where V_{gs} is the gate-source voltage and R is the effective load.

$$V_{gs} = V_{\text{in}} - 0.05 V_{\text{out}}.$$

Thus, $V_{\text{out}} = g_m R (V_{\text{in}} - 0.05 V_{\text{out}})$.

$$\therefore \frac{V_{\text{out}}}{V_{\text{in}}} = \frac{g_m R}{1 + 0.05 g_m R}.$$

Therefore the gain, with feedback, is $\frac{5 \times 2.8}{1 + 0.05 \times 5 \times 2.8} = \frac{14}{1.7} = \underline{8.2}$.

The output resistance is calculated from the relationship

$$V_{\text{out}} = \frac{g_m R V_{\text{in}}}{1 + 0.05 g_m R}.$$

The open-circuit voltage is $\frac{g_m V_{\text{in}} r_d}{1 + 0.05 g_m r_d}$.

For $V_{\text{in}} = 1 \text{ V}$, the open circuit voltage is

$$\frac{5 \times 42}{1 + 0.05 \times 5 \times 42} = \frac{210}{11.5} = 18.3 \text{ V.}$$

The output resistance can be calculated from the value of R for which the output voltage is 9.15 V .

$$\text{Thus, } 9.15 = \frac{g_m R}{1 + 0.05 g_m R}.$$

$$\therefore 9.15 + 9.15 \times 0.05 g_m R = g_m R.$$

$$\therefore R = \frac{9.15}{g_m (1 - 9.15 \times 0.05)},$$

$$= 3.37 \text{ k}\Omega.$$

The output resistance, R_1 , is the value of resistance which in parallel with $40 \text{ k}\Omega$ results in a value of $3.37 \text{ k}\Omega$.

$$\therefore \frac{1}{R_1} + \frac{1}{40} = \frac{1}{3.37}.$$

$$\therefore \frac{1}{R_1} = 0.3 - 0.025.$$

$$\therefore R_1 = \underline{3.64 \text{ k}\Omega}.$$

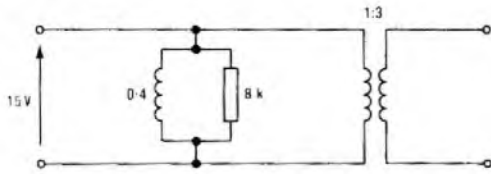
Q4 (a) An iron-cored transformer has a primary to secondary turns ratio of 1 to 3, and the winding resistances are negligible. With the secondary terminals open-circuited, the impedance between the primary terminals may be represented by 0.4 H in parallel with $8 \text{ k}\Omega$. A potential difference of 15 V with a frequency of 800 Hz is maintained across the primary terminals. Calculate

(i) the magnitude of the current through the primary terminals, and
(ii) the potential difference at the secondary terminals.

(b) A $9 \text{ k}\Omega$ resistor is then connected across the secondary. Determine the magnitude of the current through

(i) the primary terminals, and
(ii) the secondary terminals.

A4 (a) The equivalent circuit of the transformer is shown in the sketch.



(i) The current flowing into the primary terminals is the current in the parallel circuit of 0.4 H and 8 kΩ.

At 800 Hz, 0.4 H has an impedance of $2\pi \times 800 \times 0.4 = 2010.6 \Omega$.

The magnitude of the current is the modulus of the vector sum of the resistive current and the reactive current; that is,

$$15 \sqrt{\left(\frac{1}{8000^2} + \frac{1}{2010.6^2}\right)} = 7.69 \text{ mA.}$$

(ii) The potential across the secondary terminals is $3 \times 15 = 45 \text{ V}$.

(b) With 9 kΩ across the secondary terminals, the current through the secondary terminals is $\frac{45}{9} = 5 \text{ mA}$.

This current is equivalent to an extra 15 mA resistive current flowing in the primary terminals. Thus the primary current is 6.875 mA resistive + 7.46 mA reactive. Therefore, the total primary current is $\sqrt{(6.875^2 + 7.46^2)} = 10.1 \text{ mA}$.

Q5 (a) With the aid of a suitable circuit diagram, explain the operating principle of the Q-meter.

(b) Q-meter measurements on a coil give the following results

Frequency	2 MHz	2.5 MHz
Capacitor setting for resonance	153 pF	91 pF
Q-factor	200	203

Assuming that the stray capacitance is in parallel with the tuning capacitance, calculate

- (i) the stray capacitance,
- (ii) the inductance, and
- (iii) the series resistance at 2 MHz.

A5 (a) See Q2, Telecommunication Principles C 1979, Supplement, Vol. 72, p. 87, Jan. 1980.

(b) (i) The resonant condition is given in both cases by the expression

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

where f is the frequency, L is the inductance in H and C_T is the total capacitance, including the stray capacitance (C_s).

Thus, $2 \times 10^6 = \frac{10^6}{2\pi\sqrt{(C_s + 153)L}}$ (1)

and $2.5 \times 10^6 = \frac{10^6}{2\pi\sqrt{(C_s + 91)L}}$ (2)

Dividing equation (2) by equation (1) gives:

$$1.25 = \sqrt{\frac{C_s + 153}{C_s + 91}}$$

$$\therefore 1.5625 = \frac{C_s + 153}{C_s + 91}$$

$$\therefore C_s = \frac{153 - 142.1875}{0.5625} = 19.22 \text{ pF.}$$

(ii) From equation (1),

$$L = \frac{4 \times 10^6}{4\pi^2(19.22 + 153)} = 588.32 \mu\text{H.}$$

(iii) The Q-factor at resonance is given by $2\pi fL/r$, where r is the series resistance of the coil.

Thus, at 2 MHz, $r = \frac{2\pi \times 2 \times 10^6 \times 588.32 \times 10^{-6}}{200} = 36.96 \Omega$.

Q6 (a) State Thévenin's theorem.

(b) Determine an equivalent circuit at terminals A and B of the network shown in Fig. 1.

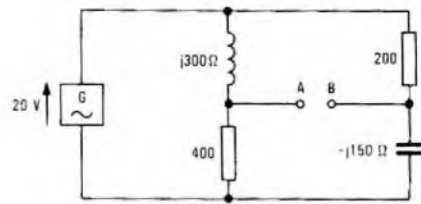


Fig. 1

A6 (a) Thévenin's theorem states that the current in any impedance connected to two terminals of a network is the same as if the impedance were connected to a simple generator, whose generated voltage is the open-circuit voltage at the terminals in question and whose impedance is the impedance seen when looking back into the network from the terminals with all generators replaced by their internal impedances.

(b) The generator voltage is the open-circuit voltage between terminals A and B. This can be calculated by determining the potential of both terminal A and terminal B with respect to the low potential side of the generator. There are then two potential divider circuits to consider and

$$(i) V_A = \frac{20 \times 400}{400 + j300} = \frac{20 \times 400 \times (400 - j300)}{400^2 + 300^2} \text{ V.}$$

$$(ii) V_B = \frac{20 \times -j150}{200 - j150} = \frac{20(-j150)(400 + j300)}{400^2 + 300^2} \text{ V.}$$

$$\begin{aligned} \therefore V_A - V_B &= \frac{20 \times 400 \times (400 - j300) + 40 \times j150 \times (400 + j300)}{400^2 + 300^2} \\ &= \frac{80(4 - j3) + j60(4 + j3)}{4^2 + 3^2} \\ &= \frac{320 - j240 + j240 - 180}{4^2 + 3^2} \\ &= \frac{140}{25} = 5.6 \text{ V.} \end{aligned}$$

The generator impedance is the impedance between terminals A and B when the 20 V generator is short-circuited.

The circuit then becomes Z_1 in series with Z_2 as shown in sketch (a).

$$\frac{1}{Z_1} = \frac{1}{j300} + \frac{1}{200}$$

$$\therefore Z_1 = \frac{j300 \times 200}{200 + j300}$$

Similarly,

$$Z_2 = \frac{-j150 \times 400}{400 - j150}$$

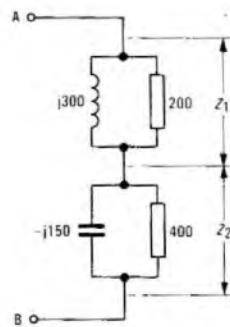
Thus,

$$Z_1 = \frac{j(300 \times 200)(200 - j300)}{200^2 + 300^2} = \frac{j6(200 - j300)}{13}$$

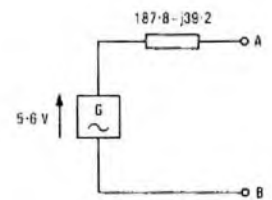
$$Z_2 = \frac{-j150 \times 400(400 + j150)}{400^2 + 150^2} = \frac{-j6(400 + j150)}{18.25}$$

$$\therefore Z_1 + Z_2 = j92.3 + 138.5 - j131.5 + 49.3 = 187.8 - j39.2$$

The equivalent circuit is shown in sketch (b).



(a)



(b)

Q7 The instantaneous voltage across the output of a transmitter is given by $V = 24 \sin(2\pi \times 10^6 t) + 4.5 \cos(2\pi \times 10^6 - 500)t - 4.5 \cos(2\pi \times 10^6 + 500)t$. Working from $e_m = E_c(1 + m \sin pt) \sin \omega t$, a general expression for an amplitude-modulated wave, show that the transmitter voltage is amplitude modulated and determine

- the carrier frequency,
- the frequency of the modulating signal,
- the modulation depth,
- the peak instantaneous voltage, and
- the RMS voltage.

A7 The expression $e_m = E_c(1 + m \sin pt) \sin \omega t$ can be written as

$$e_m = E_c \sin \omega t + \frac{mE_c}{2} \cos(\omega - p)t - \cos(\omega + p)t.$$

Comparing this expression with that for the transmitter output voltage, it can be seen that

- $E_c \sin \omega t = 24 \sin(2\pi \times 10^6 t)$, and
 - $\frac{mE_c}{2} \cos(\omega - p)t = 4.5 \cos(2\pi \times 10^6 - 500)t$.
- The carrier frequency is **1 MHz**.
 - The modulating signal frequency is **500 Hz**.
 - The modulation depth, m , is calculated from the expression

$$\frac{mE_c}{2} = 4.5.$$

Since $E_c = 24$, $m = \frac{9}{24} \times 100\% = 37.5\%$.

- The peak instantaneous voltage is $E_c(1 + m) = 24(1 + 0.375) = 33 \text{ V}$.
- The RMS voltage is given by $\sqrt{\left(\frac{24^2}{2} + \frac{4.5^2}{2} + \frac{4.5^2}{2}\right)}$, $= 17.56 \text{ V}$.

Q8 (a) Discuss the factors which cause power loss in capacitors connected to AC supplies.

(b) A potential difference of 6 V, having a frequency of 20 kHz is maintained across a 5000 pF capacitor. The capacitor is found to dissipate 8 μW. Determine for the capacitor

- the parallel loss-resistance,
- the power factor,
- the series loss-resistance, and
- the overall power factor with a 2 Ω resistor connected in series.

A8 (b) (i) Let R be the parallel loss-resistance. Then, the power loss

$$= \frac{V^2}{R} = \frac{36}{R}.$$

$$\therefore R = \frac{36}{8 \times 10^{-6}} = 4.5 \text{ M}\Omega.$$

- The power factor is approximately $\frac{1}{\omega CR}$, $= 1/(2\pi \times 20 \times 10^3 \times 5000 \times 10^{-12} \times 4.5 \times 10^6)$, $= 3.54 \times 10^{-4}$.

(iii) The series loss resistance is found by assuming that current in the resistance is $6\omega C$, since the series resistance is negligible compared with the impedance of the capacitor. Using this value of current to calculate the required resistance to dissipate 8 μW gives

$$\text{capacitor current} = 6 \times 2\pi \times 20 \times 10^3 \times 5000 \times 10^{-12},$$

$$= 3.77 \text{ mA}.$$

Power dissipated = $I^2 r = (3.77 \times 10^{-3})^2 r = 8 \times 10^{-6}$.

$$\therefore r = \frac{8}{3.77^2} = 0.56 \Omega.$$

- The overall power factor is given by $\omega C(0.56 + 2) = 2\pi \times 20 \times 10^3 \times 5000 \times 10^{-12} \times 2.56$, $= 1.6 \times 10^{-3}$.

Q9 (a) Explain the basic principles of time-division multiplexing.

(b) The basic timing of a particular TDM system produces a total of 2×10^5 samples per second. Given that for each signal the sampling frequency must be at least twice the highest frequency component in the signal, determine

- the greatest number of channels with a maximum frequency of 4 kHz, and
- the greatest number of 4 kHz channels if the system also carries two channels with a maximum signal frequency of 20 kHz.

A9 (a) See A4 (a) (ii), Telecommunication Principles C 1976, Supplement, Vol. 70, p. 54, Oct. 1977.

(b) (i) Assuming that a minimum number of samples of 8000/s per channel are taken, then the maximum number of channels is

$$\frac{2 \times 10^5}{8 \times 10^3} = 25.$$

(ii) The 4 kHz channels are sampled at 8 kHz and the 20 kHz channels at 40 kHz. Then, if n is the number of 8 kHz channels,

$$(n \times 8 \times 10^3) + 80 \times 10^{-3} = 2 \times 10^5.$$

$$\therefore n = \frac{1.2 \times 10^5}{8 \times 10^3} = 15.$$

Q10 (a) What are the essential features of a sinusoidal oscillator?

(b) Sketch the circuit of a practical oscillator and show how the features listed in part (a) are included.

TELEPHONY C 1980

Students were expected to answer any 6 questions

Q1 (a) With the aid of sketches, describe briefly THREE types of signalling system for transmitting dial pulses at 10 pps between two telephone exchanges.

(b) What factors influence the choice of system?

A1 (a) Three types of signalling system for transmitting dial pulses at 10 pulses/s are:

- Signalling System Direct Current (SSDC) No. 2,
- voice-frequency in-band signalling (SSAC9), and
- out-of-band signalling (SSAC8).

Each of the systems is described.

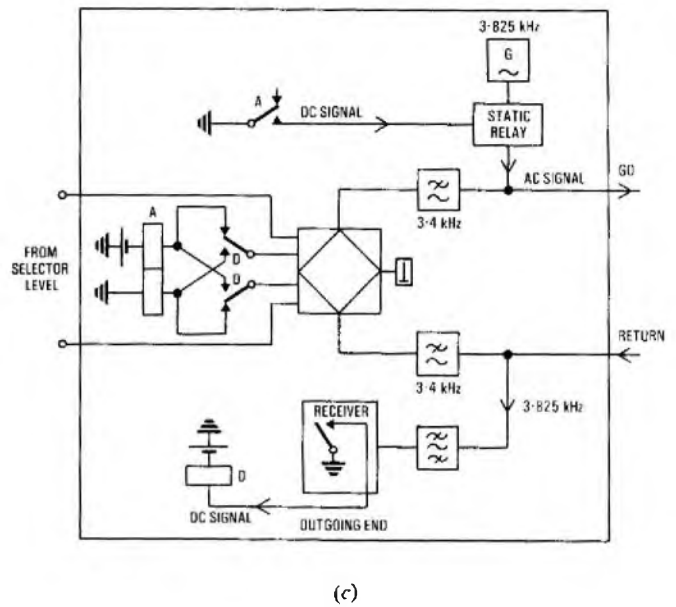
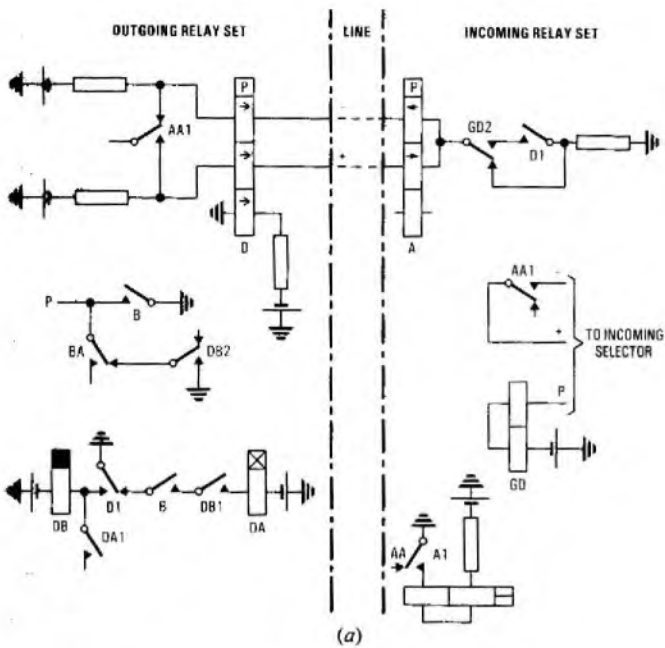
(i) Sketch (a) shows the principal elements of SSDC2, which is a uni-directional DC signalling system using double-current working. Relays A and D are Carpenter-type polarized relays and are side-stable; that is, they remain in the *make* or *break* position until a current flows through the coils in such a direction as to change the

condition of the relay. When the outgoing relay-set is seized, relay AA (not shown) in the outgoing relay-set operates and contact AA1 changes-over. Relay D remains in the normal position but, at the incoming relay-set, relay A operates, which operates relay AA via contact A1. Contact AA1 extends a loop forward to seize an incoming selector.

When pulsing takes place, contact AA1 in the outgoing relay-set moves to its normal position during the *break* period of the pulse and thus contact A1 in the incoming relay-set moves to its normal position. Contact A1 repeats the *break* pulses to relay AA which, in turn, repeats them to pulse the selector.

When the called subscriber answers, relay D (not shown) in the incoming relay-set operates and at contact D1 reconnects the earth to the winding of relay A. Relay A remains operated, while relay D in the outgoing relay-set is released to initiate the return of the appropriate supervisory signals.

(ii) Sketch (b) shows the principles of the 1VF in-band signalling



Q2 For a TXE2 exchange

(a) draw a trunking diagram showing the equipment required for setting up an own-exchange call,

(b) describe the principle of path selection used to connect the supervisory relay-set to the called line, and

(c) explain what limits the number of lines that can be served by the method described in part (a).

A2 (a) See A6 (a), Telephony C 1974, Supplement, Vol. 68, p. 66, Oct. 1975.

(b) and (c) See A10, Telephony C 1975, Supplement, Vol. 69, p. 75, Oct. 1976.

Q3 For a crossbar exchange

(a) describe, with the aid of sketches of the circuit elements, the arrangements necessary to enable a small group of exchange lines to serve a PBX identified by one directory number, and

(b) explain what limits the number of lines that can be served by the method described in part (a).

A3 See A5, Telephony C 1978, Supplement, Vol. 72, p. 25, Apr. 1979.

Q4 For a cordless automanual switchboard system

(a) draw a trunking diagram, and

(b) explain its operation when a coin-collecting-box subscriber dials 100 for assistance in completing an own-exchange call.

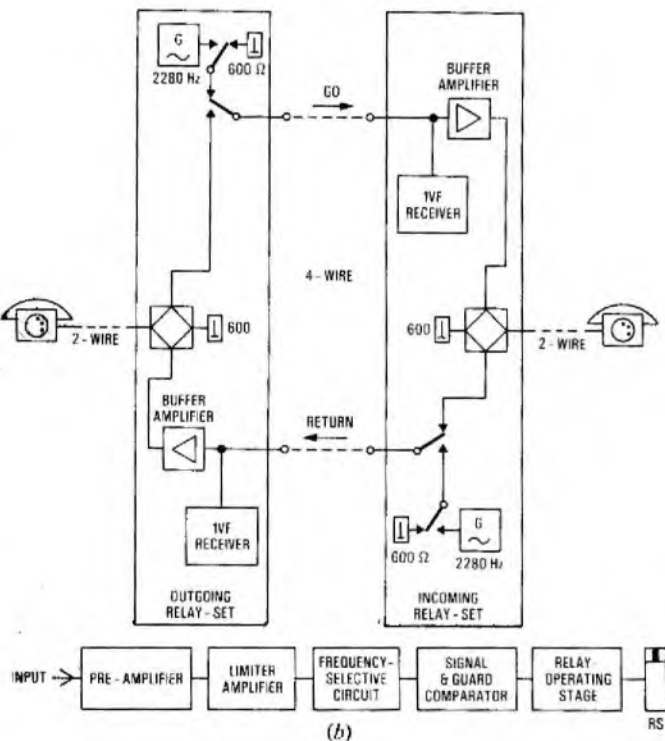
A4 (a) See A8, Telephony C 1975, Supplement, Vol. 69, p. 74, Oct. 1976.

(b) Operation of the cordless automanual switchboard system for non-coin-collecting-box subscribers is given in A8, Telephony C 1975, Supplement, Vol. 69, p. 74, Oct. 1976. When a call from a coin-collecting-box (CCB) subscriber is answered, the CB signal lamp will glow and the call timer will be automatically set for CCB conditions. The call will then be dealt with in a similar manner to a non-CCB call. On certain types of CCB call (for example, transfer charge) it may be necessary to reset the call timer for ordinary-call conditions. This is achieved by operating the ORD/CB key to ORD while the corresponding connecting-circuit key is thrown to the SPEAK position. The signal lamp on the display panel will also be changed from CB to ORD.

Q5 A fault disables (buses) all but two circuits of a full-availability junction route for 1 h 23 min 20 s. During this period 500 pure-chance calls of 1/2 min average duration are offered to the working circuits non-sequentially.

(a) Show by calculation whether more or less than half of these calls will be successful.

(b) How much traffic is carried by each of the two working circuits?



system. Signals in both directions are transmitted as pulses of 2280 Hz tone, which are converted to DC pulses by the voice-frequency receiver at each end of the circuit. The buffer amplifiers prevent near-end speech and noise interfering with reception of voice-frequency signals. Signals are interpreted by the terminal relay-sets by detecting their duration and their time relationship in the call sequence.

(iii) Sketch (c) shows the principles of out-band signalling. Filters are used to separate the speech and signalling paths. Low-pass filters are connected in the go and return paths of the 4-wire section of the network. The signalling frequency is 3.825 kHz and the band-pass filter in the return 2-wire section is designed to provide a low impedance at this frequency.

(b) SSDC2 can operate over 2 or 4-wire circuits up to a distance of approximately 160 km. AC signalling systems allow far greater signalling distances and are suitable for inclusion in carrier systems, whereby a large number of individual telephone channels can be transmitted over one system. SSAC9 is prone to voice simulation and signal spill-over, but is economical for use on long-distance circuits where signalling is not required during speech. SSAC8 is immune from voice simulation, permits signalling in both directions during speech and avoids signal spill-over.

A5 (a) As the traffic carried by the two circuits is normally calculated over a 1 h period, it is assumed that the 500 pure-chance calls are uniformly spread throughout the 1 h 23 min and 20 s period so that a proportional amount can be considered during 1 h.

The fault lasts for 1 h 23 min 20 s or

$$\frac{3600 + 60 \times 23 + 20}{3600} = \frac{5000}{3600} \text{ h.}$$

The number of calls offered during 1 h is

$$\frac{3600}{5000} \times 500 = 360 \text{ calls.}$$

The traffic offered to the two circuit groups is

$$\begin{aligned} &\text{number of calls} \times \text{average holding time,} \\ &= 360 \times \frac{30}{3600} = 3 \text{ erlangs.} \end{aligned}$$

The grade of service, B =

$$\frac{\frac{A^N}{N!}}{1 + A + \frac{A^2}{2!} + \frac{A^3}{3!} + \dots + \frac{A^N}{N!}}$$

where A is the traffic offered in erlangs and N is the number of circuits.

For the two-circuit group,

$$\begin{aligned} B &= \frac{\frac{3^2}{2}}{1 + 3 + \frac{3^2}{2!}} = \frac{\frac{9}{2}}{1 + 3 + \frac{9}{2}} = \frac{4.5}{8.5}, \\ &= 0.5294. \end{aligned}$$

As the grade of service is traffic-lost/traffic-offered, the traffic lost is more than half of the traffic offered and therefore less than half of the calls will be successful.

(b) Traffic carried by the first circuit =

$$\frac{A}{1 + A} = \frac{3}{1 + 3} = 0.75 \text{ erlang.}$$

Traffic lost by the second circuit =

$$B \times A = 0.5294 \times 3 = 1.5882 \text{ erlangs.}$$

Traffic carried by two-circuit group =

$$\begin{aligned} &\text{traffic offered} - \text{traffic lost,} \\ &= 3 - 1.5882 = 1.4118 \text{ erlangs.} \end{aligned}$$

Therefore, traffic carried by the second circuit =

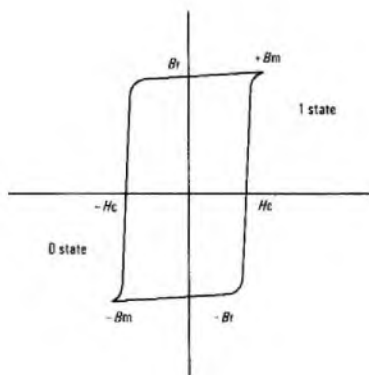
$$1.4118 - 0.75 = 0.6618 \text{ erlang.}$$

Q6 (a) Describe with the aid of sketches, the principle of operation of a ferrite core as a storage device.

(b) Explain how a matrix of ferrite cores can store a number of digits.

(c) How may the information be retrieved?

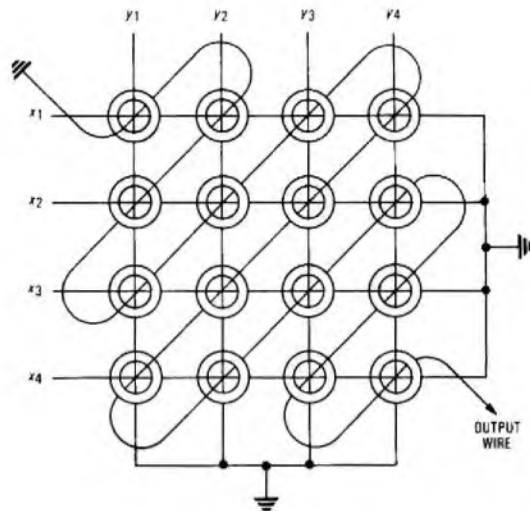
A6 (a) A typical hysteresis loop for a ferrite core used in a matrix store is shown in sketch (a).



(a)

A magnetized ferrite core has two saturated states caused by applying a magnetizing force of at least H_c in the appropriate direction to give a magnetic flux density of either $+B_m$ or $-B_m$. With the magnetizing force removed, the remanent flux, B_r , is almost equal to the maximum flux, and therefore the core stays in the state at which it is set.

If the hysteresis loop is nearly rectangular, there will be two distinct possible magnetic states, either near-positive saturation (state 1) or near-negative saturation (state 0). A change from one state to the other will occur only if the magnetizing force is greater than the critical value H_c ; thus, the core can be used as a storage device with two stable states.



(b)

(b) Sketch (b) shows sixteen ferrite cores arranged in a 4×4 matrix with READ and WRITE facilities.

Each core is threaded by a ROW wire (x) and a COLUMN wire (y). To change the state of a particular core, current pulses of half of the value required to switch the core are applied simultaneously to the appropriate ROW and COLUMN wires which intersect at the required core. At this point of intersection, the total magnetizing current will be sufficient to switch the core to the 1 state. Other cores in the row and column receive only half the value of magnetizing current required to change state and thus stay unchanged. Each core can be changed, if required, in turn so that the matrix can store up to 16 binary digits.

(c) To retrieve the information which has been stored, the COLUMN and row wires are pulsed by half-current pulses in the opposite sense to that used to write information into the store. If the core at the intersection of the two wires carrying coincident pulses is in the 1 state, it will change to the 0 state. This produces a large change in the magnetizing force which induces a large output signal in the common output wire. If the core is in the 0 state there will be only a small change in the magnetizing force, inducing a small signal in the output winding. Each core can be accessed in turn to give an output, thus reading out the 16 binary digits serially.

Q7 Multi-frequency signalling is used in a transit network.

(a) State the benefits derived from this form of signalling.

(b) Describe the signalling code and the sequence of signals during call set-up.

(c) What considerations lead to

- (i) the number of frequencies, and
- (ii) the choice of frequencies?

A7 (a) See A10 (b), Telephony C 1973, Supplement, Vol. 67, p. 74, Jan. 1975.

(b) For a description of the sequence of signals during call set-up see A10 (a), Telephony C 1973, Supplement, Vol. 67, p. 74, Jan. 1975.

The signalling code is based on two frequencies out of six for the forward direction and two frequencies out of five for the backward direction. The frequencies are within the speech band and spaced 120 Hz apart.

(c) (i) The number of frequencies used is determined by the number of possible signals which it is required to send. The number of codes

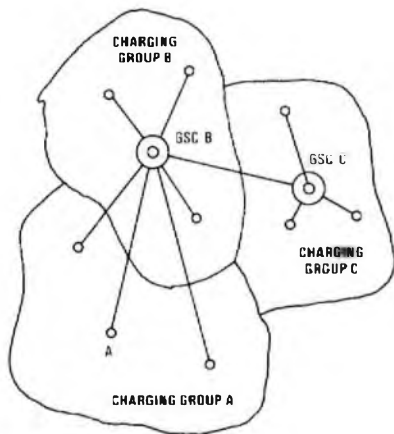
available in a two-out-of- n code is given by $\frac{n(n-1)}{2}$. Thus a two-out-of-six code will give 15 combinations and a two-out-of-five code will give 10 combinations.

- (ii) The choice of frequencies is determined by
 - (1) the need to keep the signal frequencies within the speech band,
 - (2) the need to keep the signal frequencies below the 2280 Hz line-signalling frequency to avoid mutual interference,
 - (3) the need to keep above 600 Hz as frequencies below this are more attenuated and prone to group delay, and
 - (4) the need to avoid harmonic simulation of the 2280 Hz frequency and intermodulation products with 2280 Hz or the channel frequencies of frequency-division multiplex systems.

Q8 (a) For a call from non-director exchange A, via its group switching centre (GSC) B, to a subscriber directly connected to GSC C, explain the circumstances in which the call would be

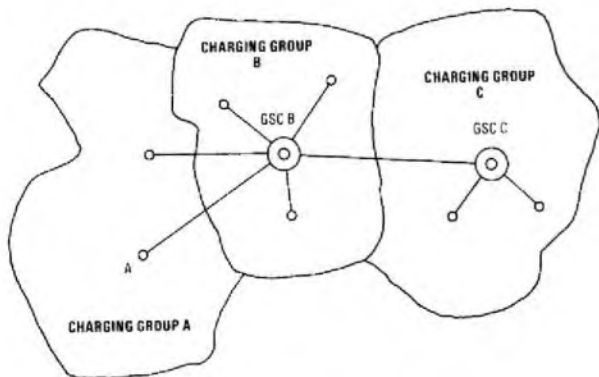
- (i) charged at local rate,
 - (ii) charged at trunk rate,
 - (iii) set up via level 9 (short code), and
 - (iv) set up via level 0 (National number dialled).
- Assume that A and C are in different charging groups, both adjacent to B.
- (b) State where the tariff equipment is located for local and STD calls.
- (c) Explain briefly how the meter pulses are conveyed to the subscriber's meter on an STD call.

A8 (a) (i) Sketch (a) shows the circumstances in which the call would be charged at local rate. Charging group A is adjacent to both charging group B and charging group C.



(a)

(ii) Sketch (b) shows the circumstances in which the call would be charged at trunk rate. Charging group A is not adjacent to charging group C. Sometimes calls between exchanges in adjacent charging groups are charged at trunk rate because, for example, a range of mountains separate adjacent charging groups requiring long and expensive circuits to link the exchanges.



(b)

- (iii) The call could be set-up via level 9 (short code dialling) in the situation shown in sketch (a); that is, routing between adjacent charge groups, with the call charged at local rate.
- (iv) The call would be set-up via level 0 (National number dialled) in the situation shown in sketch (b); that is, routing between non-adjacent charge groups. The call could be set-up via level 0 in the situation shown in sketch (a) as it is a long-term planning objective to eliminate short code dialling.

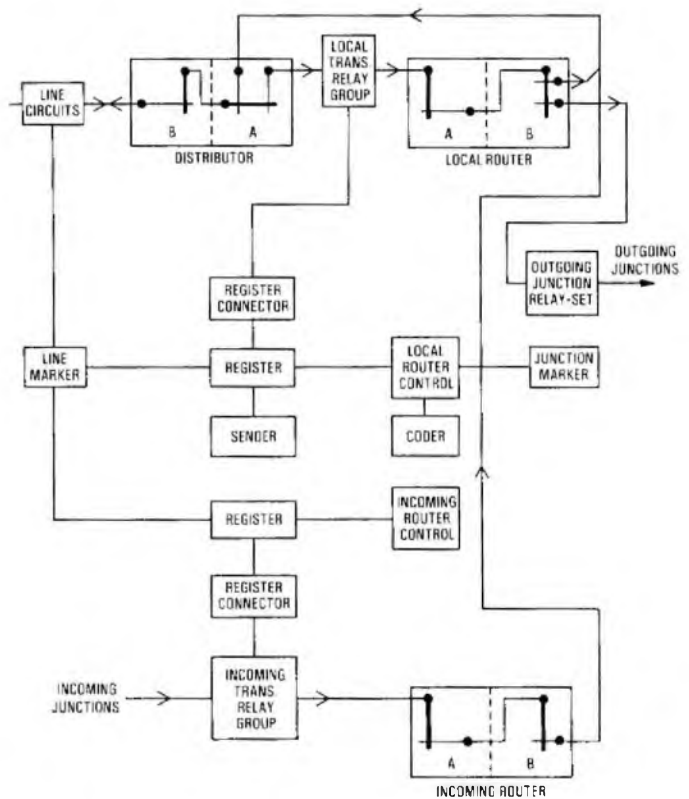
(b) For local calls, the tariff equipment is located in the originating local exchange. For STD calls, the tariff equipment is located in the originating GSC.

(c) See A8 (b), Telephony C 1978, Supplement, Vol. 72, p. 26, Apr. 1979.

Q9 Consider a 2000-line crossbar local exchange.

- (a) Sketch the trunking diagram.
- (b) Give typical quantities for the various items of equipment shown in the diagram.
- (c) Explain what is meant by the repeat-attempt facility and describe how it is performed.

A9 (a) The sketch shows a trunking diagram for a typical crossbar local exchange.



Note: Arrows denote direction of traffic flow

(b) (i) The distributor contains two ranks of crossbar switches: distributor switches A (DSAs) and distributor switches B (DSBs). Each DSB can cater for 25 line circuits and there are 20 DSBs in all, so that one distributor accommodates 500 subscribers' lines (20 x 25). An exchange of 2000 lines would require 4 distributors.

The number of DSAs within a distributor ranges from 6 to 16 depending on the traffic through the distributor. If the number exceeds 8, the extra switches are parallel to the existing switches in such a way as to give the same number of outlets but double the number of inlets; thus, if 16 DSAs are needed, there would be 16 x 10 = 160 inlets and 8 x 25 = 200 outlets.

(ii) The line marker is provided on a one-per-distributor basis.

(iii) The router contains route switches, up to 160 transmission relay groups, about 20 registers and two router controls. A route switch consists of two crossbar switch stages, RSAs and RSBs. There can be between 8 and 16 RSAs depending on the traffic, in a similar manner to the DSAs. There are 20 RSBs. Each router carries about 100 erlangs of traffic (originating and incoming-junction traffic). For a

2000-line exchange with an originating busy-hour calling rate of 0.04 erlang per line and 50% outgoing-junction traffic, two routers would be required.

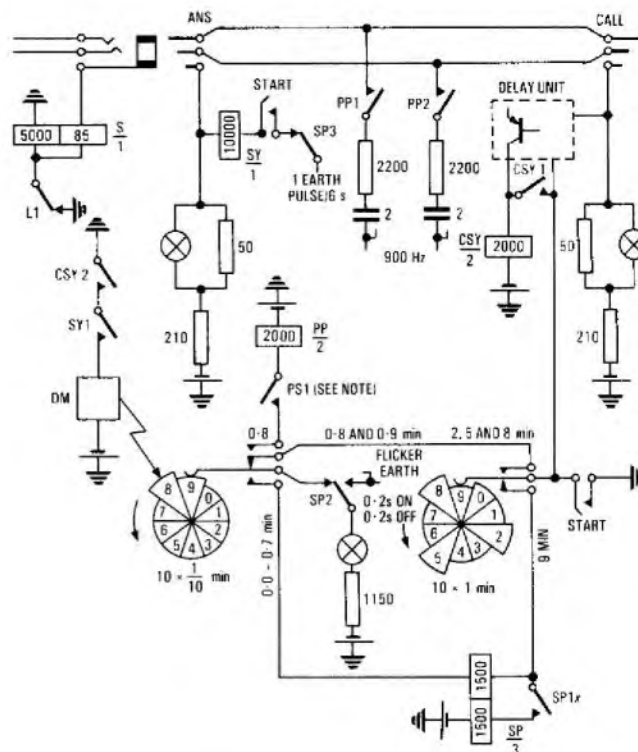
(c) During the setting up of a call in the crossbar exchange the router control is seized, which times each sequence of operations according to signals received from each stage. If a signal is not received at the appropriate time, the router control indicates the fault to the register and clears the call down. Before the router control releases, the equipment monitor is seized and all the information about the call and the type of fault is sent into this. The equipment monitor prints-out the information in coded form to be decoded by the maintenance officer. Meanwhile, the register, which has stored all the setting-up information, seizes the other router control and makes a second attempt to complete the call.

Q10 The circuit shown in Fig. 1 shows a chargeable time clock associated with a sleeve-control cord circuit.

- (a) Explain how the call is timed.
- (b) What purpose is served by the capacitors and resistors associated with contacts PP1 and PP2?

A10 (a) See A5 (a), Telephony C 1974, Supplement, Vol. 68, p. 65, Oct. 1975.

(b) The purpose of the capacitors is to provide a DC block; that is, to prevent any DC conditions associated with the 900 Hz tone supply being connected to the line. The purpose of the resistors is to limit the current flow from the 900 Hz tone supply. Each capacitor and resistor forms a particular impedance in series with the 900 Hz tone supply. As the tone supply is common to a number of cord circuits, the impedance provides a means of tone distribution.



Note: Contact PS1 closes 3 times every 6 s

Fig. 1

TELEGRAPHY C 1980

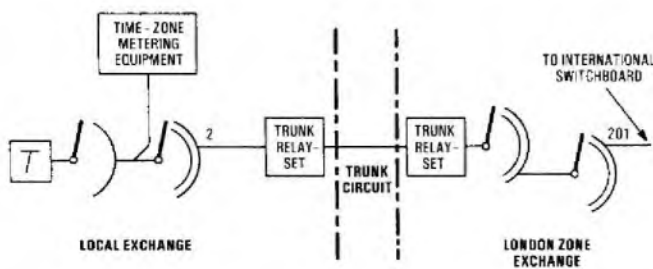
Students were expected to answer any 6 questions

Q1 (a) With the aid of trunking diagrams or equivalent explain how access may be gained to a manual international switchboard from a subscriber on a small local automatic Telex exchange.

(b) Draw a block diagram of a switchboard system and explain its operation when handling a call routed over an international cable circuit.

A1 (a) The sketch shows how access may be gained to manual international switchboard equipment from a small local automatic Telex exchange. The first selection digit dialled causes the first group selector in the exchange to step to level 2 and seize a free London trunk circuit. Digits 0 and 1 follow to position the London zone exchange selectors to seize a free switchboard circuit; the call waits in a queue until an operator is free to answer. The time-zone equipment at the local exchange also steps in response to the digits but, as the switchboard operator charges for the call by ticket procedure, metering pulses are not applied to the subscriber's meter during the call.

(b) See A6, Telegraphy C 1978, Supplement, Vol. 72, p. 45, July 1979.



Q2 A Telex station is connected to an automatic exchange by a short physical circuit.

(a) List, in order, the potentials and teleprinter signals on the receive wire and the send wire when

- (i) making a call to a subscriber's terminal which is not engaged,
- (ii) clearing the call, and
- (iii) making a call to a subscriber's terminal which is engaged.

(b) Explain the action of the circuit if the subscriber does not wish to receive calls and switches off the power.

A2 (a) (i) When the station is idle and no call is connected, +80 V potential is connected to the SEND (S) wire at the subscriber's station. This potential is looped at the exchange and connected to the RECEIVE (R) wire to the outstation.

When an outgoing call is to be made, the DIAL key on the subscriber's unit is operated, which connects -80 V potential to the S-wire. A rectifier in series with the circuit at the exchange prevents the connexion of the negative potential to the R-wire, which remains at zero potential until a free group selector and time-zone equipment are seized, at which time earth potential is connected to the R-wire. This is interrupted by the proceed-to-select signal, which consists of negative potential connected for 50-100 ms and which indicates to the calling station that dialling may begin.

When the outstation CALL lamp lights in response to the proceed-to-select signal, the dial may be operated. The selection signals from the dial, consisting of double-current (± 80 V) signals of nominal 60/40 positive/negative ratio at 10 pulses/s are transmitted on the S-wire. When the connexion has been established, negative potential is connected to the station R-wire by the exchange equipment. With the call established, either station may transmit double-current signals; when either station is idle, -80 V potential is connected to line by that station

(ii) To release the call, the station CLEAR key, which connects +80 V potential to the S-wire, is operated. If the key is operated for at least 325 ms, this is recognized as a clear signal by the exchange equipment and the switches are released. Earth potential is connected to the out-station R-wire so that current ceases to flow in that wire and the outstation control-unit releases. The release of the control-unit reconnects positive potential to the S-wire to provide the normal disengaged condition to the exchange.

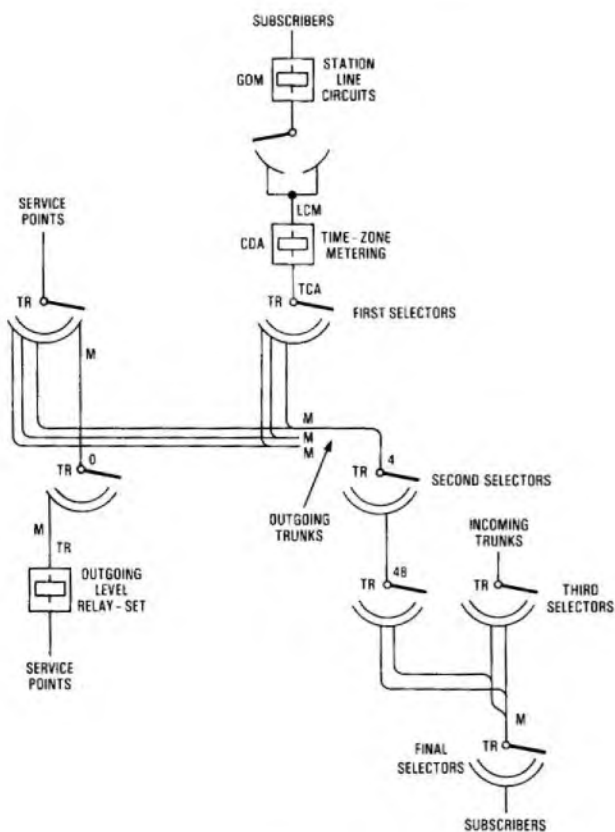
(iii) The potentials on the line are similar to those for a call to a disengaged subscriber in part (i) until the conclusion of the train of selection signals. If the called subscriber is engaged, no answer-back signal is transmitted from that terminal. The time-zone equipment waits for 1800 ms after transmitting the WRU signal and, when no answer-back signal is detected, transmits the service signal OCC to the calling subscriber. The OCC signal consists of 300 ms negative potential followed by the characters C/R L/F L/S O C C C/R L/F. A positive clearing signal follows to release the exchange equipment; earth potential connected to the R-wire clears the station as for a normal call.

(b) When it is required to close the station to incoming traffic (for example, when changing paper or because the subscriber wishes to prevent messages arriving at the station when it is unattended) the power supply to the station unit is switched off. With the disconnection of the positive potential on the S-wire, the subscriber's line equipment in the exchange hunts for a free group selector. This switch cannot hold, however, as negative potential is not present on the S-wire and in the subscriber's line circuit the 700 Ω negative potential connected to the PX-wire of the final-selector multiple is disconnected. When any call is routed to that subscriber, the final selector detects the absence of potential on the PX-wire and connects the service signal ABS to the calling subscriber. This is followed by positive potential to clear the call.

Q3 (a) With the aid of a trunking diagram or equivalent of a Telex area exchange, mark the location of

- (i) automatic traffic recorder recording points, and
- (ii) other totalling meters (except subscribers' meters) which record effective and ineffective calls.

(b) Explain the operation of the traffic recorder in an automatic Telex exchange.



TR: Automatic traffic recorder
 CDA: Call distribution analysis
 M: Overflow meter
 LCM: Late choice call and unit meters connected to last outlet of first selector grading
 TCA: Total call attempts meter
 GOM: Station line group overflow meter

A3 (a) The sketch shows the location of automatic traffic recorder recording points and other totalling meters in a Telex area exchange.

(b) See A10, Telegraphy C 1975, Supplement, Vol. 69, p. 70, Oct. 1976.

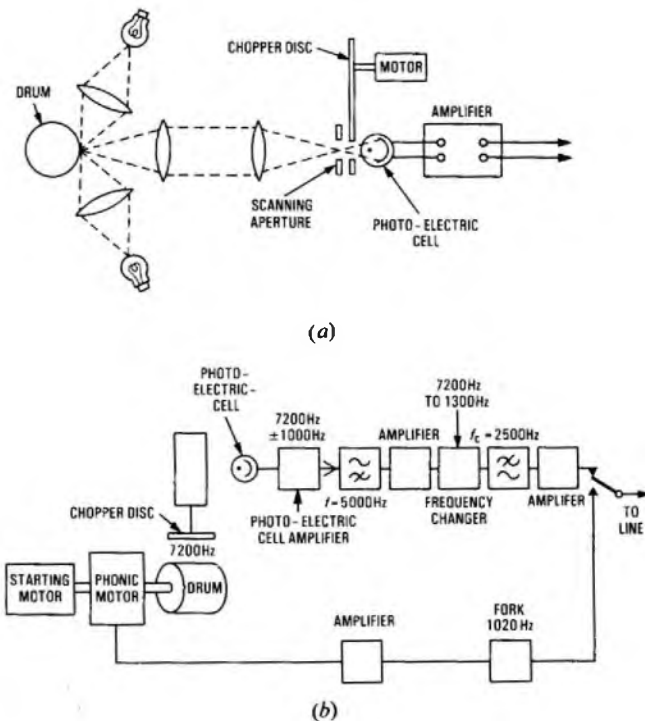
Q4 (a) Explain how a photo-electric cell is used to convert light signals to electrical signals in a phototelegraph facsimile system.

(b) With the aid of a block diagram describe the operation of equipment which contains a photo-electric cell and is used for transmitting pictures.

(c) What frequencies are used and what is the bandwidth required for the system?

A4 (a) A photo-electrical cell used for facsimile equipment consists of an evacuated or gas-filled envelope containing an anode and a cathode. The latter is covered with a very thin deposit of caesium-silver which reacts to the presence of light by emitting electrons at a rate proportional to the intensity of the light. The anode, which is at a positive potential with respect to the cathode, attracts the electrons, causing a current to flow in the external anode-cathode circuit. A load resistor in the external circuit is used as a source of voltage which is directly related to the intensity of the light incident upon the cathode. The polarizing voltage is of the order of 150 V but, as the cell produces a very low current (about 130 mA/lumen), it is necessary to amplify the signal, and the components of the circuit must be screened to prevent interference.

A device frequently used is a multiplier type of vacuum cell housing auxiliary electrodes, called *dynodes*, which are at progressively higher potentials from the cathode to the anode. As the emitted electrons from the preceding stage strike each dynode, a greater number of electrons are emitted to bombard the succeeding stage. This gives the required amplification within the cell. A 9-stage multiplier cell of this type has a sensitivity of about 10 A/lumen, with a maximum anode current of 1 mA.



(b) Sketches (a) and (b) show the arrangement of facsimile telegraph equipment suitable for the transmission of a picture. Sketch (a) shows the optical system employed at the transmitter. The picture is mounted on a drum which rotates and moves longitudinally so that the scanning beam of light covers each section of the picture consecutively in the form of a helix. Light is reflected from the picture on the drum and is detected by a photo-electric cell; the light is interrupted 7200 times each second by a chopper disc. The output from the cell depends on the intensity of the light reflected from the picture and can be used to reproduce a similar picture on photo-sensitive paper at the receive terminal.

Sketch (b) shows the electrical system at the transmitter. The cell current is amplified and passed through a high-pass filter with a cut-off

frequency of 5 kHz. The picture frequencies of 0-1 kHz are removed and a carrier of 7.2 kHz, modulated with the picture frequencies 0-1 kHz, remains. This signal is applied to a frequency changer with an oscillator frequency of 5.9 kHz; this delivers a carrier of 1.3 kHz modulated with the picture signal, which is selected by the low-pass filter. The 1.3 kHz modulated carrier is amplified before transmission to line.

Synchronization between transmitter and receiver is by means of the tuning fork and phonic motor method. The transmitter and receiver fork frequencies are synchronized by observation on a cathode-ray tube and one of the forks is adjusted to match the other. Phase synchronism is achieved by the use of magnetic clutches at both ends.

(c) See A9, Telegraphy C 1978, Supplement, Vol. 72, p. 46, July 1979.

Q5 For an automatic error-correcting (ARQ) multiplex system used on a high-frequency radio circuit

- (a) explain the reason for and describe the operation of
 - (i) signal alpha and signal beta,
 - (ii) a buffer store, and
 - (iii) character interleaving, and
- (b) if the system can accommodate four Telex circuits calculate the aggregate modulation rate of the system using a 7-unit code.

A5 (a) (i) Of the 35 combinations in the 7-unit error-detecting code, 32 are used for characters in the 5-unit code and the remaining 3 are used for the alpha, beta and RQ supervisory signals.

The alpha signal corresponds to a continuous space signal (or START polarity) and is the Telex clearing signal. This is continuously transmitted while a channel is idle between calls.

The beta signal corresponds to a continuous mark (or STOP polarity) and is the Telex calling signal. The beta signal is continuously transmitted during idle time while a call is in progress.

As the ARQ system is a synchronous time-division multiplex system, a signal must always be present on each channel to maintain the correct time relationship between each end. Should transmission conditions deteriorate while the alpha or beta signal is present, a correction cycle would be initiated.

(ii) An ARQ system is used for transmitting telegraph messages over high-frequency radio routes. The system converts each character of the transmitted message to a 7-unit code having a start-to-stop (space-to-mark) signal polarity ratio of 4 : 3. Mutilated characters can thus be detected and retransmitted on receipt of an RQ signal from the distant terminal. Two or three characters may have followed a faulty character before the RQ signal is received from the distant terminal, and the transmitting terminal therefore stores up to 4 characters to take account of the propagation time. As the store can become full when the radio route is incapable of carrying traffic (known as the cycling condition), incoming signals must either be controlled by the use of a pulsed automatic transmitter at the customer's premises, or, in the case of a Telex circuit where the use of release pulses for an automatic transmitter is not feasible, by a buffer store, which is provided to retain the Telex message until the radio circuit is again available. The store can hold 4000 characters or more, and may use paper tape, a magnetic drum or a core store. The traffic from the subscriber's teleprinter or tape reader is fed directly into the store and is extracted from it under the control of release pulses from the ARQ equipment when the route is clear. The characters held in the store are transmitted at a rate of 411/min compared with a maximum input rate of 400/min from a 50 baud Telex circuit. This ensures that the store can clear faster than it can fill after a period of cycling.

(iii) A high-frequency radio circuit has capacity for more than one circuit and, because the circuit is synchronous, time-division multiplex techniques must be used if more than one circuit is to be accommodated. In a 2-channel ARQ system, signals from two sources are interleaved. To maintain the original character clearance rate of the separate channels the duration of each signal element is halved, and this requires double the bandwidth. It would appear that no advantage is gained; but transmission on a time-division multiplex system allows one channel the exclusive use of the system for a short period, and during that time full power may be used to give a good signal-to-noise ratio. Character interleaving is preferred to element interleaving because a mutilated character may be detected earlier at the distant terminal and a request-to-retransmit (RQ) signal may be originated as quickly as possible.

(b) The modulation rate of a Telex circuit is 50 bauds, with a transmission time for each element of $1000 \div 50 = 20$ ms. Each character consists of five code elements (100 ms) with one START element (20 ms) and one STOP element (30 ms), a total character duration of 150 ms. If four Telex channels are to be interleaved, the ARQ circuit must be capable of transmitting 4 characters in 150 ms. Each ARQ character consists of 7 code elements. The ARQ circuit will therefore have to transmit $4 \times 7 = 28$ elements in 150 ms. One element will be transmitted in $150 \div 28$ ms giving

$$\begin{aligned} \text{modulation rate} &= 1000 \div \frac{150}{28} \\ &= 186\bar{3} \text{ bauds.} \end{aligned}$$

In order to ensure that all traffic is cleared from the system, even though a teleprinter motor is running fast or characters are held in the buffer store, the ARQ system has a character repetition cycle of 145 $\frac{1}{2}$ ms. In this case the aggregate modulation rate of a 4-channel system would be

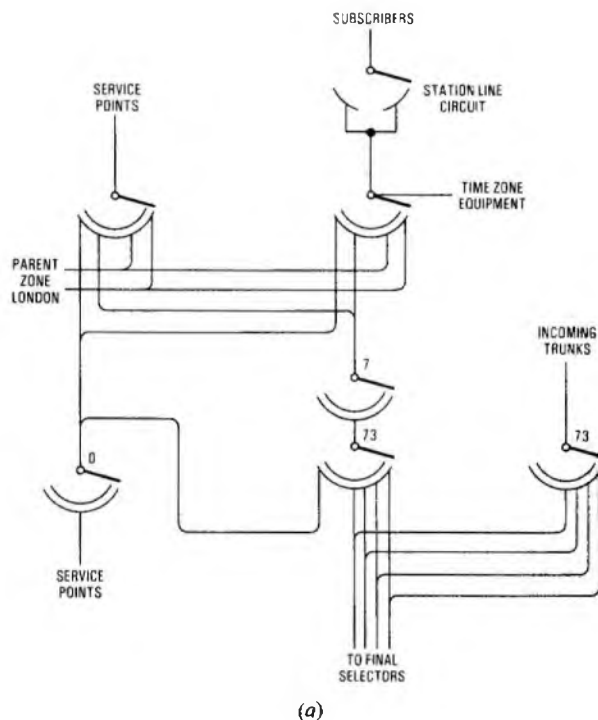
$$\begin{aligned} 1000 \div \frac{145\frac{1}{2}}{28} \\ = 192 \text{ bauds.} \end{aligned}$$

Q6 (a) With the aid of a trunking diagram or equivalent explain the progress of a local call through an automatic Telex exchange.

(b) With the aid of circuit or logic diagrams explain the operation of the equipment in response to the final two digits of the call

- (i) if the called circuit is free, and
- (ii) if the first line of a group of circuits to one subscriber is engaged but other lines are free.

A6 (a) The trunking diagram for a 500-line Telex area exchange is shown in sketch (a).



To originate a call, the DIAL key on the subscriber's control unit is operated, which connects a calling signal to the subscriber's line circuit. The unselector associated with the line circuit hunts for a free first group selector which is associated with a time-zone equipment. When a free first selector has been found, a proceed-to-select pulse, of negative polarity, is transmitted to the subscriber's station, causing the teleprinter motor to start and lighting a lamp to indicate that dialling may begin.

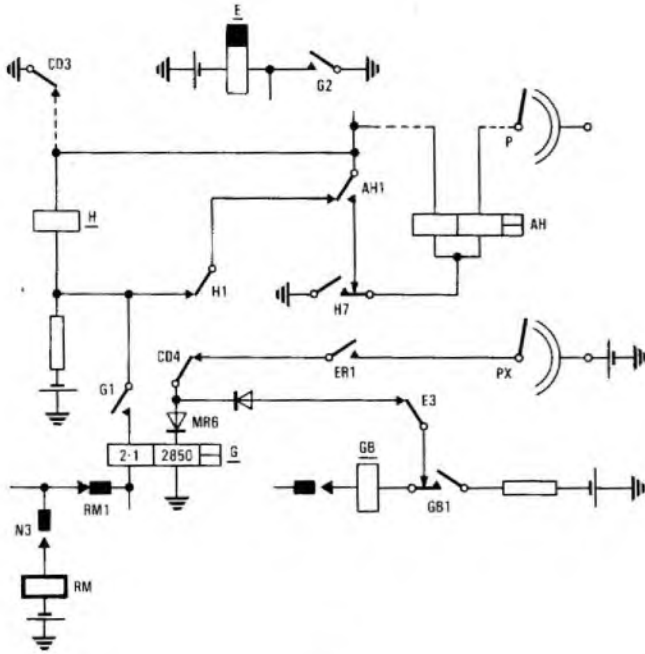
The time-zone equipment is permanently associated with a first selector and controls the operation of the subscriber's meter. The first train of dial pulses causes the group selector to step vertically and to hunt horizontally for a free second selector, which is stepped vertically by the second train of pulses. For a local call, in the exchange shown, the first two digits dialled will be 73. The time-zone equipment also operates to the first two digits, stepping a two-motion selector vertically and horizontally to select the correct meter-pulse connexion for a local call.

The third dial-pulse train energizes a group selector in a similar manner to the first and second selectors, and the final two pulse trains control the vertical and horizontal operation of a final selector to give connexion to the required subscriber. When the call-connected signal is received by the time-zone equipment, the who-are-you (WYU) signal is transmitted to the called subscriber and the answer-back signals are passed through the exchange to the calling station; the answer-back

signals are detected by the time-zone equipment and metering begins. When the call is finished either party may clear the connexion. Service signals are transmitted to the caller if the called subscriber is engaged (OCC), if the called subscriber's station is closed (ABS) or if a spare number has been selected (NP).

(b) (i) See A4, Telegraphy C 1975, Supplement, Vol. 69, p. 69, Oct. 1976.

(ii) The circuit arrangement is shown in sketch (b).



(b)

Lines forming part of an auxiliary group are marked by the connexion of positive potential to the PX-wire of all lines except the last one of the group; this line is marked with negative potential. If the first line is engaged, relay AH does not operate on the release of contact CD3. Relays E and ER are slow to release, and relay G operates to the positive potential on the PX-wire through contacts CD4 released and ERI operated. Contact G2 maintains relay E which, in turn, maintains relay ER; contact G1 connects earth potential from contacts CD3, AH1, H1 to the rotary magnet through the 2.1 Ω coil of relay G. The operation of the rotary magnet causes the switch to step to the next outlet and the rotary-magnet springs RM1 disconnect the circuit to the rotary-magnet coil. Relay G remains operated as the PX-wiper moves between outlets.

When a free line is found, relay AH operates and disconnects the rotary magnet circuit at AH1; the switch remains on this line. Contact AH1 also removes the short-circuit across relay H which operates and switches the circuit to the called subscriber. A contact of relay H also disconnects relay ER which releases relay G at contact ERI.

Q7 (a) What tests and modifications are required to be made on a telephone circuit which is to be used as a bearer circuit for a multi-channel voice frequency (MCVF) telegraph system?

(b) What factors govern the amount of power to be transmitted to line for each telegraph circuit?

(c) What tests and checks should be performed on a new MCVF system before it is brought into service?

A7 (a) and (c) See A3, Telegraphy C 1976, Supplement, Vol. 70, p. 65, Oct. 1977.

(b) The value of the current transmitted to line must be high enough to minimize crosstalk interference from neighbouring circuits and channels, and give a good signal-to-noise ratio, but it must not be so high as to cause interference in adjacent circuits. In addition, the current must not overload the line amplifiers, as this would cause distortion of the waveforms due to the production of harmonics. The power in each channel is adjusted to a value which ensures that the overall limit of the system is never exceeded.

If the maximum power permitted for a system of N channels is W watts, with a line of characteristic impedance Z ohms, the maximum voltage, E , is obtained from the formula $E = \sqrt{(WZ)}$.

The voltage is at a maximum when all the carrier frequencies reach

peak amplitude simultaneously. The maximum permissible voltage/channel, e , is given by

$$e = \frac{E}{N} = \frac{\sqrt{(WZ)}}{N} \text{ volts,}$$

and the maximum power/channel

$$= \frac{e^2}{Z} = \frac{WZ}{N^2 Z} = \frac{W}{N^2} \text{ watts.}$$

The maximum power for a multi-channel voice-frequency (MCVF) system has been standardized internationally at 5 mW. For an 18-channel system, the maximum power/channel

$$= \frac{5 \times 10^{-3}}{18^2} = 15 \mu\text{W.}$$

This enables telegraph systems to use telephone circuits with negligible interference to neighbouring circuits. A value of 10 μW/channel is used in practice, as it has been found that the slight decrease in signal-to-noise ratio is more than compensated for by the reduction in inter-channel interference due to cross-modulation.

Q8 A message-relay system is to be considered for a business with locations in different parts of the country.

(a) State what the advantages and disadvantages are of

(i) a single relay centre as compared with a network of several centres,

(ii) automatic centres as compared with manual centres, and

(iii) the use of a relay system as compared with the provision of Telex stations.

(b) State what precautions are taken against lost or mutilated messages in

(i) manual relay systems, and

(ii) automatic relay systems.

A8 (a) (i) The advantages and disadvantages of a single relay centre as compared with a network of several centres are:

Advantages	Disadvantages
Only one stage of transmission. No inter-centre circuits required.	Costly individual circuits to each station.
Central administration with only one operating force.	Concentration of all traffic in one office could lead to one breakdown affecting all services.
Easy control of broadcast.	

(ii) The advantages and disadvantages of automatic centres as compared with manual centres are:

Advantages	Disadvantages
No operators required. Fast working. Operates 24 hours per day. Simple broadcast procedure. Effective application of priority.	Costly technology and maintenance. Rigid formats required. Risk of breakdown affecting all lines. High peaks of traffic and overflow cannot be dealt with as easily as in a manual system.

(iii) The advantages and disadvantages of a relay system as compared with the provision of Telex stations:

Advantages	Disadvantages
Relay system offers easy broadcast, priority, fast transmission and a queuing facility, but gives no assurance that message has reached destination.	Telex costs are high and setting up is time consuming; lines may be engaged; broadcast facility not readily available. Telex gives assurance by answer-back or conversational mode that message has reached destination.

(b) (i) To deal with lost or mutilated messages in a manual system it is customary to number each message between centres. The numbers form part of the preamble to each message and are in sequence. The distant equipment, or operator, checks that the sequence is maintained, and lost or mutilated messages are retransmitted on request. Monitor teleprinters are connected to provide copies of incoming and outgoing messages for retransmission. The perforated tapes are also retained for several days, in case they are required. Further safeguards are provided by *paper-fail*, *motor-fail*, and *incoming-message* alarms.

(ii) Three features of an automatic relay system protect messages from irretrievable loss. The first is the use of incoming-channel sequential message-numbering equipment, which checks that the serial number carried as a prefix to each message is one integer greater than that of the previous message received on that channel. This enables missing messages to be identified and a request made to the originating station for the message to be retransmitted. Messages in transit through the system are safeguarded by measuring the delay time in storage, and by periodically checking the transmission paths through the system. Alarms are provided to indicate the faulty equipment, and any message in store is routed to the manual positions. The third safeguard is the provision of a monitor teleprinter for each outgoing circuit. Each outgoing message is recorded so that a lost or mutilated message can be retransmitted if requested.

Q9 (a) What are the advantages of routine testing equipment in an automatic Telex exchange?

(b) List the facilities provided by and describe the operation of a semi-automatic tester for any one main type of switching equipment.

(c) What are the merits or otherwise of providing a fully automatic routiner in place of the tester?

A9 (a) A semi-automatic routine tester normally consists of trolley-mounted equipment with plugs and cords for connexion to the equipment under test. With the appropriate connections made, and the equipment to be tested disengaged, the operation of the START key causes a series of tests to be applied automatically. The progress of the cycle of tests is indicated by a series of lamps, one of which lights during the progress of each test. In this way, one tester quickly applies tests which would otherwise have to be made, possibly one at a time, with the aid of box testers or calibrators. The semi-automatic tester normally only requires one connexion to be made to each item of main equipment, and a complete cycle of tests is completed in about one minute. The tester thus eases the work of the maintenance staff and improves the service by enabling more frequent and regular checks of main equipment to be made. The tester is used at frequent intervals to detect incipient faults and enables equipment to be repaired before it causes a break in service. This is particularly useful for common equipment where a faulty switch may affect a number of calls before the fault is noticed. Testers of this type are also used for acceptance testing new equipment when a new exchange is installed or when an existing one is extended.

(b) A typical tester for a group-selector checks that

(i) the selector is disengaged,

(ii) the potentials on the S-wire are correct,

(iii) the operation of relay A to minimum and maximum current value is satisfactory,

(iv) the release times of relays B and CD are within limits,

(v) the selector steps vertically to 50% and 80% break pulses at 12 pulses/s,

(vi) the selector switches to the HA choice on outlet 19 of level 9 and to the HB choice on outlet 20,

(vii) backward P-wire guarding is provided,

(viii) the time to reach outlet 20 on level 9 and the time to return to normal from this contact are within limits, and

(ix) the service signals are transmitted from the eleventh step.

The lamps on the tester indicate which test is in progress; if a fault is found, the tester stops and the appropriate lamp indicates the test which has failed. An additional lamp indicates that the cycle of tests has been successfully completed.

Plugs and cords are used to give the tester access to the equipment to be tested. One cord is connected to the group selector under test to give connexion to the test points within the selector. Further cords are connected to the rack for access to power supplies (-50 V and ± 80 V), service signals (OCC, NP, etc), phasing pulses and test lines. The latter are circuits connected to contacts 18, 19 and 20 of level 9 so that the tester may gain an indication that vertical stepping and switching has been satisfactory.

Connexions are also provided on the tester for a relay-timing tester so that the tester timing elements may be adjusted before use.

(c) A semi-automatic routine tester consists of trolley-mounted equipment which has to be placed in position near to the group selectors and plugged-in to rack supplies. The tester has also to be plugged-in to the group selector under test and started manually. If a

fault is detected, the tester stops until the operator has made a note of the fault and restarted the tester. The tester therefore requires constant attendance involving what is repetitive and uninteresting work. The tester does, however, provide the facility of repeating tests at leisure, and of testing the switch when the fault has been cleared; for an automatic routiner, this would require the operator to walk between the selector and the control panel.

The tester is relatively inexpensive to provide, does not require rack space nor space for access selectors, and may be stored in a room away from the apparatus floor; also, it does not require permanent wiring between the routiner and access and group-selector racks.

The advantages of a routiner are in operator economy, night and weekend testing, increased frequency of testing, testing before the exchange becomes busy, regular tests, tests of greater complexity and the facility of maintenance control by numbered and dated fault dockets. The routiner is more costly to design and purchase and occupies valuable floor space in an exchange. When all factors have been considered, it is normally a question of the number of group selectors an exchange will contain. Above a certain number, an automatic routiner is more economic and effective than a semi-automatic routine tester.

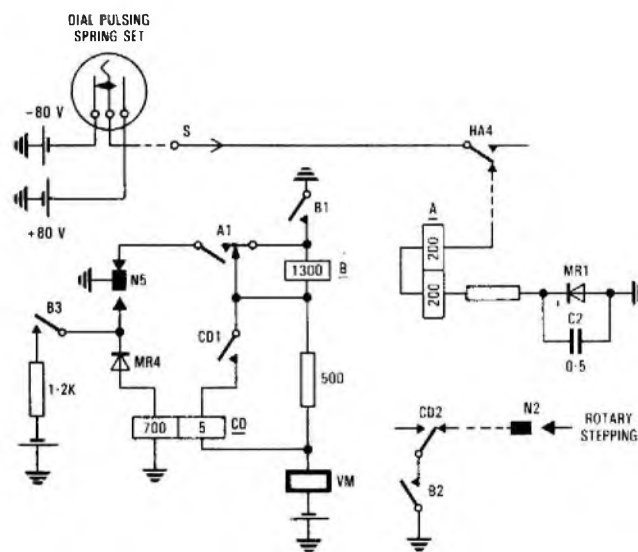
Q10 Selection signals are transmitted over telegraph circuits to establish connexion with a distant subscriber.

(a) With the aid of a circuit diagram explain how one train of dial pulses operates a 2-motion group selector.

(b) Describe how dial-pulse selection signals may be passed over a Telex circuit containing a regenerative repeater.

(c) What form do selection signals take on a radio circuit served by automatic error-correcting (ARQ) equipment and why?

(d) Describe the TWO uses of selection signals and the form which they take in an international exchange with automatic ticketing.



A10 (a) The sketch shows the operation of a 2-motion group selector, in response to a train of dial pulses. When the selector is seized, relay A operates to the -80 V potential from the dial; contact A1 operates relay B and contact B3 operates relay CD. When the dial is operated, dial pulses each nominally composed of a $+80$ V potential for 60 ms followed by -80 V potential for 40 ms are transmitted. Relay A releases to $+80$ V potential because of the action of rectifier MR1 and reoperates to -80 V potential. During the first pulse, relay A releases and contact A1 short-circuits relay B, making it slow to release with a lag of 150–225 ms, and operates the vertical magnet VM via the 5 Ω coil of relay CD. The vertical magnet causes the selector wipers to take one vertical step, operating the off-normal springs N. Contact N5 changes over, leaving relay B dependent on the earth at contact B1 and short-circuits the 700 Ω coil of relay CD, thus making it slow to release.

Relay A reoperates at the end of the first -80 V, or BREAK, pulse and contact A1 disconnects the short circuit on relay B. The current in the VM coil and the 5 Ω coil of relay CD is reduced to such a value by the resistance of relay B that VM releases and relay CD is dependent on its slow-to-release feature. The removal of the short-circuit re-energizes relay B.

Relay A, and consequently VM, release and reoperate in accord with the $+80$ V and -80 V pulses appropriate to the dialled digit and the wipers are stepped to the selected level. Relay CD receives pulses of

current in the $5\ \Omega$ coil during the 60 ms BREAK pulses and these, in conjunction with the slow to release feature imparted by the $700\ \Omega$ coil, are sufficient to hold the relay operated during the pulsing.

Relay A remains operated to the negative potential at the end of the pulse train. Relay CD releases at the end of its lag period and at contact CD1 disconnects the vertical magnet circuit. The circuit is now prepared for rotary hunting for a free outlet.

(b) A regenerative repeater in a telegraph circuit is designed to accept distorted teleprinter signals and re-transmit them as perfect signals with a duration of 150 ms. A dial pulse has a nominal duration of 100 ms (60 ms SPACE, 40 ms MARK) and so cannot be regenerated and repeated by this type of equipment. To accommodate dial pulses the regenerative repeater is switched out of circuit while dial pulses pass and is restored to the circuit when negative potential (MARK) has persisted for 125 ± 25 ms. When the clearing signal (positive potential) is passed over the Telex circuit for at least 360 ms the repeater is switched out of circuit to await the next call.

(c) A circuit served by an automatic error-correcting (ARQ) system is normally a radio circuit operating in a synchronous mode. The error

detection depends upon the correct number and formation of MARK and SPACE elements to form teleprinter characters, and thus cannot deal with dial pulses. To overcome this, the selection signals consist of numerical teleprinter characters which are normally transmitted from the keyboard of the operator controlling the circuit.

(d) When a calling subscriber is connected to automatic ticketing equipment in an international exchange, the signal KEY + is transmitted to the subscriber to indicate that selection must be sent from the teleprinter keyboard and not from the dial. The selection signals are used for the following purposes:

(i) As part of the automatic ticketing process; the selection signals are passed from the control relay-set via the 1-5 wire converter to the 5-wire tape punch machine where they form part of the head and tail sequence of perforated tapes which are used for call-charging.

(ii) As keyboard selection signals, stored in the register and transferred to the translator; the selection is translated and after the outgoing first and second group selector stages have seized an outgoing route, the appropriate selection transmit unit X, Y or Z transmits the selection digits in the form appropriate to the chosen route.

TECHNICIAN EDUCATION COUNCIL

Certificate Programme in Telecommunications

Sets of model questions and answers for TEC units are given below. They have been designed following analysis of assessment test papers actually set during the 1978-79 session by a number of colleges all over the country. The model questions and answers reflect the types and standard of question set and answer expected, and include the styles of both in-course and end-of-unit assessments.

The model questions and answers therefore illustrate the assessment procedures that students will encounter, and are useful as practice material for the skills learned during the course.

The use of calculators is permitted except where otherwise indicated.

Representative time limits or proportion of marks are shown for each question (or group of questions), and care has been taken to give model answers that reflect these limits. Where additional text is given for educational purposes, it is shown within square brackets [] to distinguish it from the information expected of students under examination conditions.

We would like to emphasize that, because the model questions are based on work at a number of colleges, they are not representative of questions set by any particular college.

As a general rule, questions are given in italic type and answers in upright type. Answers are sometimes shown in bold upright type; this is because, for some objective questions, it is convenient to place the questions and answers side by side, and bold type enhances the distinction in such cases. Where possible, answers have been positioned such that they may be covered up if desired.

ELECTRICAL PRINCIPLES 2 1979-80

Students are advised to read the notes above

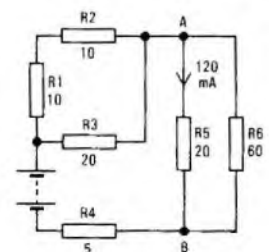
Q1 Say whether each of the following statements is true or false. (2 min)

- (a) The SI unit of energy is the watt.
- (b) Like charges repel.
- (c) A capacitor is not capable of storing energy.
- (d) Charge on a capacitor is proportional to applied voltage.
- (e) Relative permeability has the units henrys/metre.
- (f) A ferromagnetic material tends to concentrate magnetic flux.
- (g) Series resonance occurs when voltage and current are in antiphase.
- (h) A half-wave rectifier converts alternating voltages to unidirectional form.

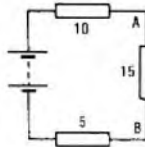
- False
- True
- False
- True
- False
- True
- False
- True

Q2 For the circuit shown, state:

- (a) the total resistance,
- (b) the supply voltage. (5 min)



A2 (a) [The two 10 Ω resistors (R1 and R2) in series form a 20 Ω resistor in parallel with R3, giving a total resistance for the combination of 10 Ω. R5 and R6 in parallel have a total resistance of $20 \times 60 / (20 + 60) = 15 \Omega$, giving the equivalent circuit shown.]



The total resistance is therefore $10 + 15 + 5$,
 $= 30 \Omega$.

(b) If the current in R5 is 120 mA, the voltage across points A and B is $120 \times 10^{-3} \times 20 = 2.4 \text{ V}$. As the total resistance between A and B is 15 Ω, the current between A and B is $2.4 / 15 \text{ A} = 160 \text{ mA}$. As this current is returned to the battery (via R4), it represents the total current in the circuit. Thus, the battery voltage is

$$160 \times 10^{-3} \times 30 = 4.8 \text{ V.}$$

Q3 (3 min)

- (a) Express 5000 μA in milliamperes.
- (b) State the SI unit of electric field strength.
- (c) Does the magnetic field set up by an induced current oppose or aid the action producing the current?
- (d) A transformer has an input (primary) voltage of 240 V and an output of 24 V. State the secondary-to-primary turns ratio of the transformer.
- (e) What is the average power dissipated in a purely capacitive circuit containing a 5 μF capacitor?
- (f) Is capacitive reactance determined by the expression $X_c = 2\pi fC$ or by $X_c = 1/2\pi fC$?

5 mA
V/m

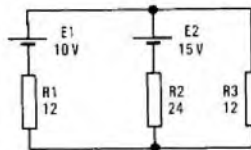
Oppose

1 : 10

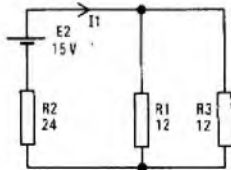
Zero

$1/2\pi fC$

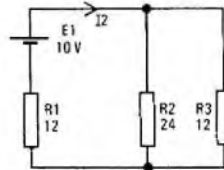
Q4 Use the superposition theorem to find the current in R3. (10 min)



A4 If E1 is considered short-circuited, the circuit in sketch (a) is obtained. The equivalent resistance of R1 and R3 in parallel is 6 Ω. The total current, I_1 , is $15 / (6 + 24) \text{ A} = 500 \text{ mA}$. The proportion of I_1 flowing in R3 is $500 \times 12 / 24 = 250 \text{ mA}$.



(a)



(b)

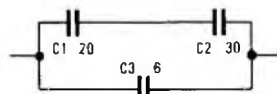
If E2 is short-circuited, the circuit in sketch (b) is obtained. The equivalent resistance of R2 and R3 in parallel is 8 Ω. Current $I_2 = 10 / (8 + 12) \text{ A} = 500 \text{ mA}$, and the proportion of I_2 flowing in R3 is $500 \times 24 / 36 = 333 \text{ mA}$.

Hence the total current in R3

$$= 250 + 333 = 583 \text{ mA.}$$

[Note that I_1 and I_2 flow in the same direction, so that their components in R3 are additive.]

Q5 State the total capacitance of the combination shown. (3 min)



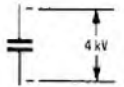
A5 C1 and C2 in series have a capacitance of $20 \times 30 / (20 + 30) = 12 \mu\text{F}$.

In parallel with C3, this gives a total capacitance of $12 + 6 = 18 \mu\text{F}$.

Q6 The charge on the capacitor shown is 2 C. Calculate

- (a) the capacitance,
- (b) the energy stored.

(4 min)



A6 (a) From $Q = CV$, $C = Q/V = 2/4 \times 10^3 \text{ F} = 500 \mu\text{F}$.

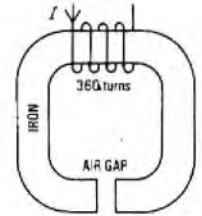
(b) $E = \frac{1}{2}CV^2 = 0.5 \times 500 \times 10^{-6} \times 4^2 \times 10^6 \text{ J} = 4 \text{ kJ}$.

Q7 For the magnetic circuit shown, determine

- (a) the total reluctance, S_T ,
- (b) the total magnetomotive force (MMF), and

(c) the current, I , required if the flux, Φ , in the air gap is to be $60 \mu\text{Wb}$. The reluctance of the iron is $3 \times 10^6 \text{ A/Wb}$ and that of the air gap is $9 \times 10^6 \text{ A/Wb}$.

(4 min)

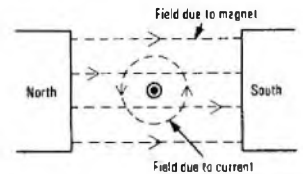


A7 (a) $S_T = S_{\text{iron}} + S_{\text{air}} = (3 + 9) \times 10^6 = 12 \times 10^6 \text{ A/Wb}$.

(b) $\text{MMF} = \Phi S_T = 60 \times 10^{-6} \times 12 \times 10^6 = 720 \text{ A}$.

(c) $I = \text{MMF}/N$ (where N is the number of turns on the coil) $= 720/360 = 2 \text{ A}$.

Q8 The sketch shows a conductor carrying a current in a magnetic field. Current flows towards the observer. (2 min)



(a) Is the field above the conductor strengthened or weakened?

Weakened

(b) Is the field below the conductor strengthened or weakened?

Strengthened

(c) Does the conductor tend to move up or down?

Up

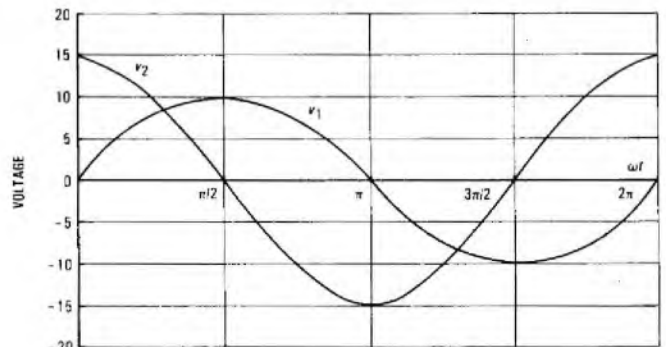
(d) State the name given to the principle illustrated.

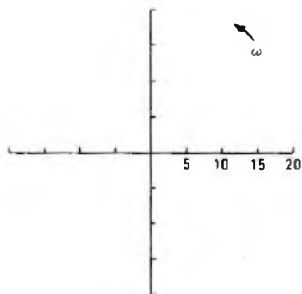
Motor principle

Q9 A voltage wave is described by the expression $v = 12 \sin 800\pi t$. State:

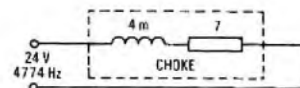
- (a) the peak voltage 12 V
- (b) the RMS voltage $0.707 \times 12 = 8.5 \text{ V}$
- (c) the frequency (1 min) $2\pi ft = 800\pi t$, whence $f = 400 \text{ Hz}$

Q10 (a) The sketch shows two voltage waves, v_1 and v_2 . Considering wave v_1 as the reference phasor, draw in (on the Argand diagram given) phasors representing the two waves.





Q12 Find the reactance of the choke shown. (2 min)



A12 $X_L = 2\pi fL = 2\pi \times 4774 \times 4 \times 10^{-3} = 120 \Omega$.

Q13 Find the impedance of a circuit having a capacitor in series with a 10 Ω resistor. The capacitor has a reactance of 7 Ω. (2 min)

A13 $Z = \sqrt{(X_c^2 + R^2)} = \sqrt{(7^2 + 10^2)} = 12.21 \Omega$.

Q14 Find the current taken by an impedance of 21 Ω connected across a 94.5 mV supply

- (a) if the impedance is an L-R series circuit
- (b) if the impedance is a C-R series circuit.

(2 min)

A14 (a) $I = V/X = 94.5 \times 10^{-3} / 21 \text{ A} = 4.5 \text{ mA}$.

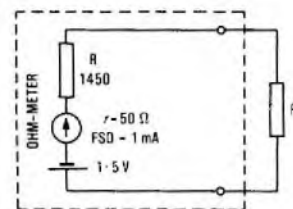
(b) [The type of reactance does not affect the magnitude of the current.] As in part (a), $I = 4.5 \text{ mA}$.

Q15 A circuit consists of a 4 μF capacitor, a 50 mH inductor and a 47 kΩ resistor in series. The current in the circuit is 3 mA and the frequency of operation is 3.4 kHz. Calculate the power dissipated in the circuit. (2 min)

A15 [Power is dissipated only in the resistance.]

$P = I^2 R = 3^2 \times 10^{-6} \times 47 \times 10^3 \text{ W} = 423 \text{ mW}$.

Q16 The sketch illustrates an unknown resistor, R_x , being measured by an ohm-meter. The meter shows a deflection of three-tenths of its scale. What is the value of the unknown resistor? (5 min)



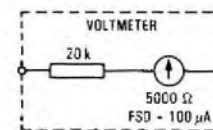
A16 If the meter has a full-scale-deflection (FSD) current of 1 mA, the meter current, I , at three-tenths FSD is 300 μA. By Ohm's law,

$$r + R + R_x = V/I$$

$$\therefore 50 + 1450 + R_x = 1.5 / 300 \times 10^{-6} = 5000$$

$$\therefore R_x = 5000 - 1500 \Omega = 3.5 \text{ k}\Omega$$

Q17 The voltmeter shown is required to measure a maximum (full-scale) voltage of 10 V. Can it be used as it stands, or will it need a shunt or multiplier: state which? What value of shunt or multiplier (if any) will be needed? (8 min)



A17 To give full-scale deflection (FSD) for the circuit as shown, there must be a voltage across the voltmeter of

$100 \times 10^{-6} \times (20\,000 + 5000) = 2.5 \text{ V}$.

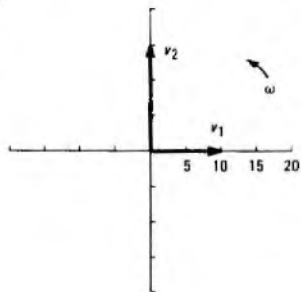
Hence, the meter is unsuitable, as it stands, for measuring voltages of up to 10 V.

To record 10 V at FSD, it will be necessary to drop 7.5 V across a series external resistor. Such a resistor is called a multiplier.

The multiplier must carry the FSD meter current and must therefore have a value of

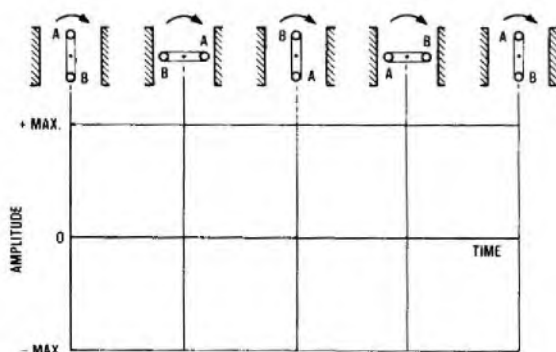
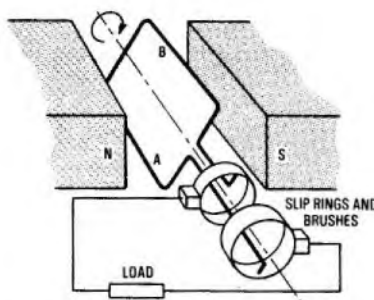
$7.5 / 100 \times 10^{-6} \Omega = 75 \text{ k}\Omega$.

A10 (a)



(b) $v_2 = 15 \sin(2\pi 600t + \pi/2)$
 $= 15 \sin(3770t + \pi/2)$ volts.

Q11 The sketch to the right illustrates a coil rotating in a magnetic field. Below is a series of sketches of five consecutive quarter-turns of the coil. Assuming the direction of current induced when coil side B is rising to be positive, mark on the given axes the amplitude of the current in the load for each of the positions illustrated, at the corresponding point on the time axis. Join your points to illustrate the form of the generated wave. (5 min)



A11

