SUPPLEMENT

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CITY AND GUILDS OF LONDON INSTITUTE EXAMINATIONS 1977

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.

TELEGRAPHY B 1977

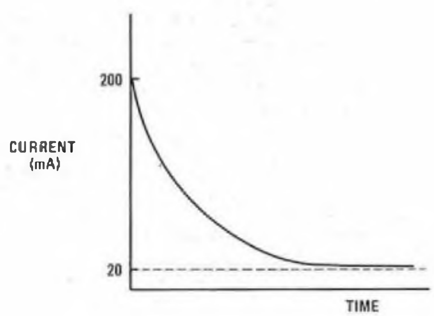
Students were expected to answer any 6 questions
The use of an electronic pocket calculator was permitted where appropriate

Q1 (*a*) *For a DC teleprinter signal, sketch waveforms to show the effect of*

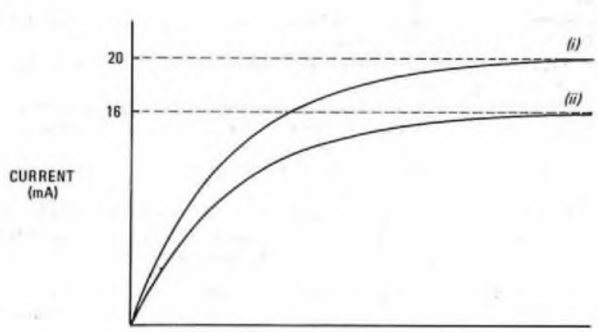
(*i*) *line capacitance on the transmitter current,*
(*ii*) *line resistance on the receiver current, and*
(*iii*) *receiver inductance on the receiver current.*

(*b*) *What type of equipment would be used to ensure satisfactory signalling over a circuit of length*

(*i*) *100 km, and*
(*ii*) *500 km?*



(*a*)

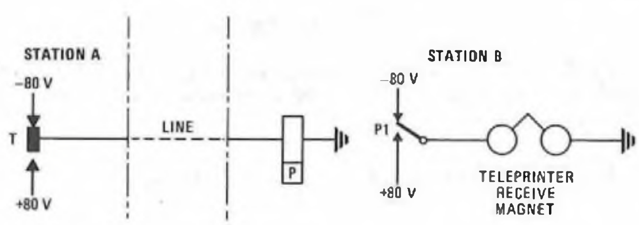


(*b*)

A1 (*a*) (*i*) Sketch (*a*) shows the effect of line capacitance on the transmitter current. Initially, the line capacitance acts as a short-circuit to earth, but, as the charge on the line increases, the current reduces exponentially to its steady state.

(*ii*) and (*iii*) Sketch (*b*) shows the effect of receiver inductance on the receiver current. With a normal 4 kΩ termination and a transmitter supply of 80 V the current rises exponentially to the steady value of 20 mA (curve (*i*)). If the line resistance is increased by say 1 kΩ, the current rises to a steady value of 16 mA as shown by curve (*ii*).

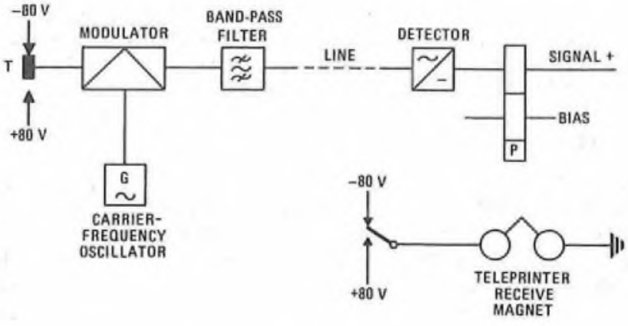
(*b*) (*i*) Telegraph signals transmitted over a physical circuit exceeding about 100 km in length would be severely attenuated and distorted due to the effects of line resistance, capacitance and inductance. The line capacitance would delay the rise of the current constituting the received signal and the resistance would reduce the final value of the current. For a line 100 km in length, the current might not rise to a value sufficient to operate the receive magnet, and the signals would be mutilated. To overcome this, a sensitive relay is installed at the receiving end of the circuit to repeat the signals to the receiver. The relay responds more faithfully to the incoming signals than the receive magnet, but does not correct any time distortion present in the received signals. Sketch (*c*) shows the connexions of the relay.



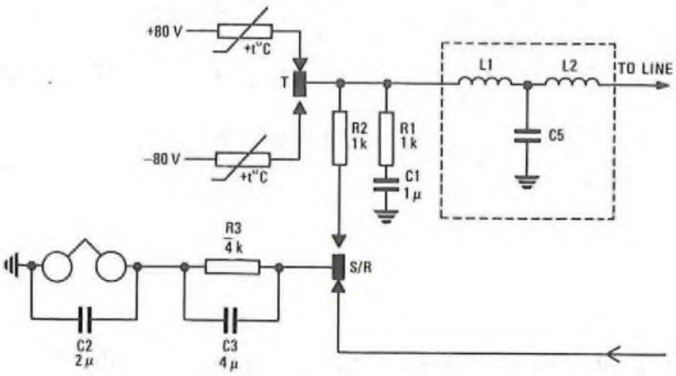
(*c*)

(*ii*) Satisfactory transmission of telegraph signals over a circuit 500 km in length could be ensured by the use of heavy-gauge conductors, high signalling voltages and the use of repeating relays. This arrangement is expensive and requires special telegraph cables; a more economical solution is to utilize the telephone network by converting the DC telegraph signals to voice-frequency tones before their transmission to line. At the distant terminal the AC signals are converted to DC signals to operate the receiver. Sketch (*d*) shows the main elements of a single-channel voice-frequency system.

The DC teleprinter signals are connected to the modulator (or static relay), so that changes in the polarity of the DC signal modify the output of the constant-frequency oscillator. The DC signals cause the modulator to vary the carrier frequency depending on the polarity of the DC signal.



(*d*)



The band-pass filter is designed to reduce the number of frequencies present at the output of the modulator so that only the side frequencies caused by the fundamental DC signalling frequency are transmitted to line at a significant power level. The filter severely attenuates signals outside the desired band.

At the receiver, the detector rectifies the voice-frequency signals and connects DC signals to actuate a polarized relay which transmits signals to operate the teleprinter receive magnet.

One voice-frequency circuit working at 50 bauds would not utilize efficiently the bandwidth available in a normal telephone circuit. It is customary to provide a multi-circuit voice-frequency (MCVF) system between central points, and connect the telegraph circuits to each centre using physical circuits with direct-current signals.

Q2 (*a*) *A Telex message consists of 200 words. Calculate the minimum time to transmit the message.*

(*b*) *The message is transmitted over a 2-channel synchronous time-division system in conjunction with a second Telex message. If the start and stop elements of each character are suppressed, what is the aggregate modulation rate of the system?*

(*c*) *If both sets of signals were converted to a 7-unit code before connexion to the system, what would then be the aggregate modulation rate?*

A2 (*a*) The Telex network operates at 50 bauds using $7\frac{1}{2}$-unit signals. The duration of each signal element is 1/50 s or 20 ms and the duration of each character is $7\frac{1}{2} \times 20 = 150$ ms.

One average word consists of 6 characters and has 900 ms duration. Hence, the minimum time to transmit a message of 200 words is 200×900 ms $= 180$ s $=$ 3 min.

(*b*) If the START and STOP elements of each character are suppressed, then each character consists of 5 elements. If 2 messages are transmitted simultaneously over one channel, then 2 characters must be sent in the time one character is received; that is, $2 \times 5 = 10$ elements must be transmitted in 150 ms, or one element in 15 ms.

The modulation rate is the number of elements which can be transmitted in 1 s, and is equal to

$$\frac{1000}{15} = 66{\cdot}7 \text{ bauds.}$$

(*c*) If both sets of signals were converted to a 7-unit code, 14 elements would be required to be transmitted in 150 ms, or one element in $\frac{150}{14}$ ms.

$$\therefore \text{ the modulation rate} = 1000 \div \frac{150}{14} = 93{\cdot}3 \text{ bauds.}$$

Q3 (*a*) *A simplex (half-duplex) teleprinter circuit with local record is provided over a local line. Draw a circuit diagram of the termination and explain the function of the main components.*

(*b*) *What modifications to this circuit would be required if the teleprinter were connected to a conference unit?*

A3 (*a*) The sketch shows a simplex teleprinter circuit with local record. The main components of the circuit are:

(*i*) *The teleprinter transmitter* (*T*). This consists of a change-over contact supplying positive (SPACE) or negative (MARK) potential to line depending on the element being transmitted. A resistor bulb is provided in each 80 V supply to protect the contacts and the line from excess current under fault conditions. The bulbs have a positive temperature coefficient which causes the resistance to increase when an increase in current heats the bulb filament. The fault current is limited to about 70 mA.

(*ii*) *The spark quench* (*R1, C1*). This combination absorbs the back EMF from the distant inductive receive magnet and prevents sparking at the transmitter contacts. The resistor prevents a heavy rush of charging current when the transmitter contacts change from MARK to SPACE.

(*iii*) *The low-pass filter* (*L1, L2, C5*). The teleprinter signal is a square wave signal and contains all the odd harmonics of the fundamental frequency up to infinity. If the teleprinter signal is transmitted over a circuit in an underground telephone cable, induced signals, consisting of clicks, may be heard on the telephone circuits. The filter allows only the fundamental, third and fifth harmonics of a 50 baud teleprinter signal to pass and attenuates all frequencies above about 140 Hz. As the telephone has a range of 300 Hz upwards, there is no interference in the adjacent circuits.

(*iv*) *The signal shaping network* (*C3, R3*). This network is provided to re-constitute the square-wave signal as transmitted. The resistor limits the steady current to about 20 mA, which is ample for the receive magnet, and at each change of polarity, the capacitor discharges to aid the change and give a surge of current to improve the shape of the received signal.

(*v*) *The send-receive switch* (*S/R*). This switch is part of the teleprinter and operates when a character is being transmitted. In this way, a leak circuit through resistor R2 is provided to give a local record of the characters transmitted to line.

(*vi*) Capacitor C2 prevents inductive surges caused by the movement of the receiver tongue in the field of the receive magnet from being transmitted to line and causing interference in a telephone cable.

(*b*) If the teleprinter was connected to a conference network, the local record would be received from the distant conference relay over the receive wire. As this signal would be delayed compared with the local record received through the send-receive switch, mutilation could occur if the 2 signals met at the receiver. To prevent this, the local record via the send-receive switch is disconnected when the termination is part of a conference network.

Q4 (*a*) *What testing facilities are available when using a test final-selector in an electromechanical automatic Telex exchange?*

(*b*) *How is access gained to this selector from the test-desk?*

(*c*) (*i*) *Describe, with a circuit diagram, one other method of gaining test access to a subscriber's circuit.*

(*ii*) *What additional facilities are offered by this method of access as compared with access from a test final-selector?*

A4 (*a*) The following testing facilities are available from the test desk when using a test final-selector.

(*i*) Measurement of line currents and voltages from the subscriber's station: one milliammeter on the test desk monitors the S-wire and a second meter the R-wire.

(*ii*) Measurement of signal distortion and modulation rate using the test-desk distortion-measuring set.

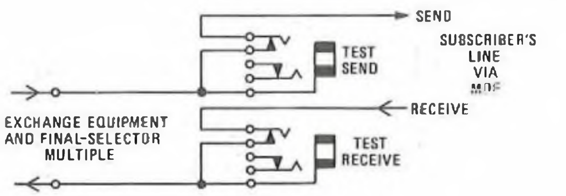
(*iii*) Measuring the margin of the teleprinter by transmitting distorted test messages from the test desk.

(*iv*) Using the test-desk voltmeter to test line conductor resistance and insulation resistance and to check for stray voltages present on the line.

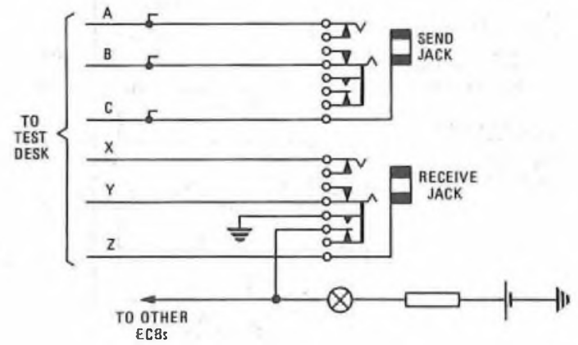
(*v*) Check and measurement of the speed and ratio of dial pulses received from the station equipment.

(*vi*) Calling and clearing the outstation, transmitting a hold-relay test signal and generating a PROCEED-TO-SELECT signal to give a functional test of the Telex control unit at the outstation.

(*b*) A test final-selector gives access to a group of subscribers' lines via the final-selector multiple. One test final-selector is provided for each 200-outlet final-selector multiple. Access to each test selector is from 2 jacks on the test position. If any particular selector is in use, an engaged lamp glows on each test position. The test selector is positioned to select the required subscriber's line under the control of



(*a*)



(*b*)

the dial on the test desk: only the last 2 digits of the subscriber's number are necessary to operate the vertical and rotary mechanisms. If the line is engaged, an OCC lamp on the test desk glows; the lamp is extinguished when the call is cleared. The test final-selector gives access to the subscriber's line and machine only; access to the subscriber's exchange equipment is not available.

(*c*) (*i*) The sketches show the method of connecting a subscriber's line to a test desk through the engineering control board (ECB). Each subscriber's line is connected to the exchange through 2 station line circuit interception jacks as shown in sketch (*a*). Test trunks are provided from the ECB to the test desk as shown in sketch (*b*); the test trunks may be multipled over several ECBs, and an engaged lamp is provided to warn when a trunk is in use. To test a station line, a double-ended cord is first inserted in one of the test-trunk jacks then the other end is inserted in the corresponding subscriber's interception jack. The jacks are wired so that, if the plugs are inserted in the correct order, the continuity of the circuit is maintained. When a subscriber's line has been intercepted in this way, tests can be made either of the subscriber's line and machine or of the subscriber's exchange equipment.

(*ii*) The ECB gives access to both subscribers' equipment and exchange equipment for each Telex circuit. By this means, exchange calling and clearing circuits may be tested in addition to the outstation equipment.

Q5 (*a*) *With the aid of a diagram, explain the operation of a single-battery float system for telegraph power supplies.*

(*b*) *What factors govern the size of the conductors for power distribution in an automatic Telex exchange?*

(*c*) *A distribution cable 20 m long is required to carry a current of 100 A. The maximum permissible voltage-drop in this section is 0·5 V. A specimen of the conductor material 300 mm² in cross-section and 1000 m in length has a resistance of 0·055 Ω. Calculate the most economical cross-sectional area for the conductor.*

A5 (*a*) See A9, Telegraphy B 1971, *Supplement*, Vol. 65, p. 6, Apr. 1972.

(*b*) The size of conductors used for power distribution in a Telex exchange is governed by the voltage drop allowed between the battery and the equipment and on the current rating of the cable. Typical values of voltage drop between various stages of the power distribution are as follows:

mains distribution to motors or rectifiers	0·5 V,
rectifier to power switchboard	0·5 V,
battery to power switchboard	0·25 V,
switchboard to apparatus rooms (80 V supply)	1 V, and
switchboard to apparatus room (50 V supply)	0·15 V.

Each value is for the maximum load current. The cost of distribution conductors is high and, as the cost is inversely proportional to the voltage drop, the size of the conductor is calculated for the maximum permissible voltage drop. When the optimum size of the cable has been calculated, a suitable choice is made from the standard sizes of cable. The cable chosen is then checked for current rating, to ensure that the cable is capable of carrying fault current, up to the maximum value allowed by the fuse, without overheating.

(*c*) The resistance of a conductor is calculated from the formula

$$R = \rho\frac{l}{a},$$

where R is the resistance in ohms, l is the length of conductor in metres, a is the area of cross-section of conductor in square metres, and ρ is a constant which represents the resistivity of the material.

For the sample given, $0{\cdot}055 = \rho\dfrac{1000}{300 \times 10^{-6}}$.

$$\therefore \rho = \frac{0{\cdot}055 \times 300 \times 10^{-6}}{1000}\ \Omega/\text{m}.$$

For the cable, $R = \dfrac{V}{I} = \dfrac{0{\cdot}5}{100} = \rho\dfrac{l}{a}$,

where V is the permissible voltage drop and I is the current.

$$\therefore \frac{0{\cdot}5}{100} = \frac{0{\cdot}055 \times 300 \times 10^{-6}}{1000} \times \frac{20}{a}.$$

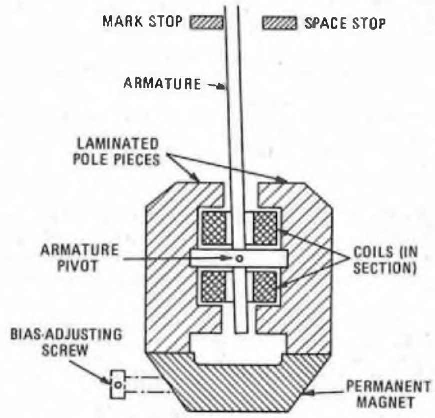
$$\therefore a = \frac{0{\cdot}055 \times 300 \times 10^{-6} \times 20 \times 100}{1000 \times 0{\cdot}5},$$

$$= 66 \times 10^{-6} = \underline{66\ \text{mm}^2}.$$

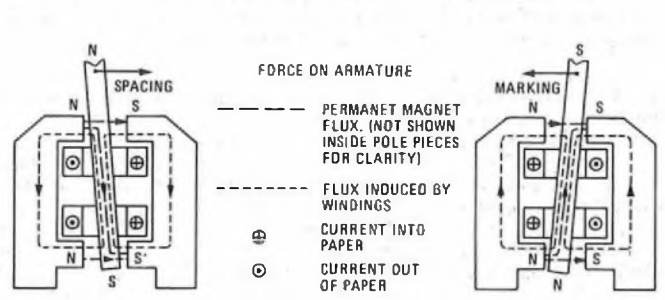
Q6 (*a*) *Draw a diagram to show clearly the magnetic circuit and explain the operation of a polarized teleprinter receive magnet.*

(*b*) *Describe the effect on the performance of the teleprinter if the magnet is biased.*

(*c*) *Describe the sequence of operations of a teleprinter when a* START *signal is received, assuming that the motor is running and is on speed.*



(*a*)



(*b*) (*c*)

A6 (*a*) Sketches (*a*), (*b*) and (*c*) show the construction and magnetic circuit of a polarized teleprinter receive magnet. With the current flowing as in sketch (*b*), the armature becomes a magnet with N and S polarity at the upper and lower ends respectively. As opposite poles attract and like poles repel, the armature moves to the right, or spacing, position as indicated by the arrow. When the current in the coil is reversed, the armature moves in the opposite direction. (Magnetic flux flows from N to S *outside* a magnet.)

(*b*) If the magnet is biased, it will respond faster (or slower) to either positive or negative potential and will effectively distort the incoming signals. When the teleprinter is receiving signals which are already distorted, the slow operation of the magnet could cause a transition to be undetected by the receive mechanism and thus mutilate a character. The magnet should be tested and adjusted from time to time to ensure that it is free from bias and responds equally to positive and negative signal elements.

(*c*) The following description refers to a BPO Teleprinter No. 15. When a START signal is received, the receive magnet moves to correspond to positive polarity (SPACE) and a link, connected to the armature, allows a receive cam to rotate. The cam controls 5 sequential levers which operate at 30, 50, 70, 90 and 110 ms from the beginning of the START element, and detect the polarity of the 5 character elements. The polarity of each element is registered on a storage latch and, at the end of the character, the combination of MARKS and SPACES is transferred to a link unit where the combination is stored. The selection unit then restores to normal to detect the next character, while the receive cam continues to rotate and transfer the combination from the link unit to the code slats, which move 5 slotted sectors to present one setting for the type lever, corresponding to the character received. Further movement of the cam causes the type lever to move and print the character.

A more comprehensive description of the printing mechanism is given in A6, Telegraphy B 1976, *Supplement*, Vol. 70, p. 38, July 1977.

Q7 (*a*) *Sketch a short length of 5-unit perforated tape suitable for use in an automatic transmitter.*

(*b*) *Describe, with the aid of a sketch, the perforating mechanism of a reperforator.*

(*c*) *Calculate the rate in metres per minute at which the paper tape is used for 7½-unit 75 baud signals. The distance between feed holes is 2·54 mm.*

A7 (*a*) and (*b*) See A5, Telegraphy B 1971, *Supplement*, Vol. 65, p. 5, Apr. 1972.

(*c*) One character consists of 7½ units; the modulation rate is 75 bauds, which is equal to one element in 1000/75 ms.

Hence each character takes $\frac{15}{2} \times \frac{1000}{75} = 100$ ms.

$\therefore$ In one minute, $\frac{60 \times 1000}{100} = 600$ characters are received.

$\therefore$ Rate of tape usage $= 600 \times 2{\cdot}54$ mm/min $= \underline{1{\cdot}524 \text{ m/min.}}$

Q8 (*a*) *With the aid of a flow chart, explain the origination, acceptance and delivery of telegrams at a large public telegraph office.*

(*b*) *Draw a trunking diagram of an automatic exchange suitable for switching telegrams between appointed offices (outstations).*

Q9 (*a*) *For an automatic Telex exchange*

(*i*) *list SIX main items of equipment and state the factors which influence their location, and*

(*ii*) *draw a diagram to show the main cabling arrangements in a typical 5-digit exchange.*

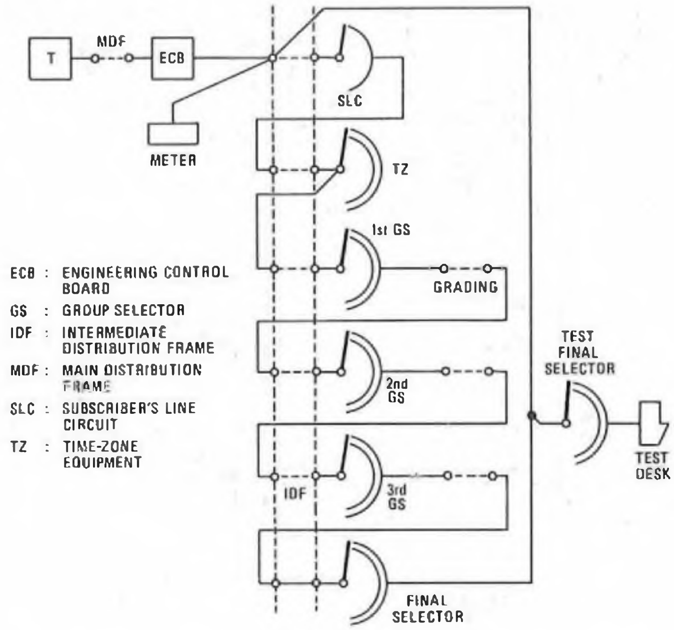
(*b*) *A subscriber's line unit rack exerts a force of 6 kN (equal to a weight of about 600 kg) on the floor of a telex exchange. Calculate the floor loading if the rack measures 1·4 m × 0·35 m and the apparatus and wiring gangways are 0·7 m and 0·5 m wide respectively.*

A9 (*a*) (*i*) Six main items of equipment and the factors which influence their location are as follows:

The main distribution frame (MDF) is located over the exchange cable chamber. This economizes in cable and provides a termination for the external cables immediately on entering the building. The engineering control board (ECB) is provided for testing and intercepting circuits. It is located near the test desk for convenience and near to the MDF to economize on cable. The intermediate distribution frame (IDF) is provided as a cross-connexion field for the switching equipment and as an entry for the subscribers' lines to the exchange switches. Two IDFs are sometimes supplied, one a subscribers' IDF, which is located close to the ECB and the subscribers' line circuit (SLC) racks and the other, an equipment IDF, which is located close to the selectors and time-zone equipment. The SLC equipment, the group and final selectors and the time-zone equipments are located together to economize on cable; they follow the switching sequence to facilitate call tracing.

The equipment racks are located at right angles to the windows for natural lighting and are provided with a narrow, rear, wiring gangway and a front wide, apparatus gangway for maintenance.

(*ii*) The sketch shows typical cabling arrangements in a 5-digit exchange.



(*b*) Floor loading is measured in pascals (newtons per square metre). A newton is the force exerted by a mass of 1 kg accelerating at 1 m/s². Gravity produces an acceleration of 9·81 m/s²; hence a mass of 1 kg exerts a force of 9·81 N on a floor. The presumed floor area over which the line-unit rack exerts a force of 6 kN is given by:

length of rack × {width of rack + ½ (width of apparatus gangway + width of wiring gangway)},

$= 1{\cdot}4 \times \{0{\cdot}35 + \frac{1}{2}(0{\cdot}7 + 0{\cdot}5)\} = 1{\cdot}4 \times (0{\cdot}35 + 0{\cdot}6),$

$= 1{\cdot}4 \times 0{\cdot}95 = 1{\cdot}33 \text{ m}^2.$

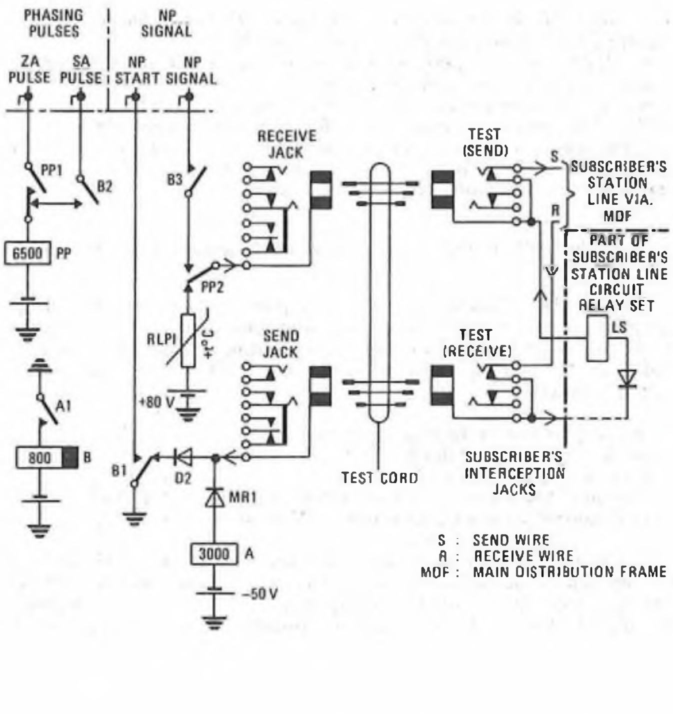
$\therefore$ floor loading $= \frac{6000}{1{\cdot}33} \approx 4500 \text{ Pa} = \underline{4{\cdot}5 \text{ kPa.}}$

Q10 (*a*) (*i*) *Under what circumstances would a subscriber's circuit be connected to a temporary out-of-service (TOS) jack and how would this be done?*

(*ii*) *What service signal would be received by another subscriber calling the out-of-service number?*

(*b*) *Draw a diagram and explain the operation of the TOS circuit.*

A10 (*a*) (*i*) A subscriber's circuit would be connected to a TOS jack if the subscriber's account had not been paid within a specified period. The TOS circuits are located on the engineering control board and



each circuit is connected to a subscriber's line by a double-ended plug and cord from the subscriber's station line-circuit interception jacks.

(*ii*) Any other subscriber calling a circuit which has been put out of service receives the service signal NP (no path); the clearing condition is then applied to the calling line.

(*b*) The circuit is shown in the sketch. When the connexion to the TOS circuit has been made, positive potential via resistor RLP1 operates relay LS, in the subscriber's station line circuits (SLC), to earth potential at contact B1. If a subscriber calls the TOS number, the final selector switches to the circuit, releases relay LS in the SLC and connects −80 V to the S-wire to operate relay A through rectifier MR1. Contact A1 operates relay B and contact B1 starts the NP signal. Contact B2 connects the phasing relay PP to the phasing pulses, and contact B3 prepares a circuit for the transmission of the service signal NP to the calling subscriber. The phasing pulse SA operates relay PP, which locks at contact PP1 to a 1500 ms ZA pulse. During the ZA pulse, contact PP2 connects the service signal.

When the final selector clears, the −80 V potential is removed and relay A releases. On the release of relay B, contact B1 connects earth potential to relay LS in the SLC and this again operates to prevent outgoing calls being made by the subscriber.

LINE PLANT PRACTICE B 1977

Students were expected to answer any 6 questions
The use of pocket calculators was permitted where appropriate

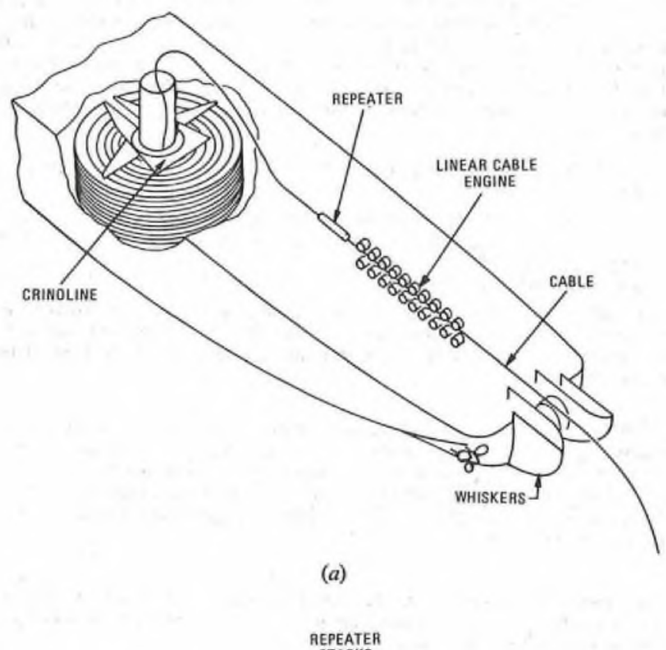
Q1 (*a*) *Describe in detail, with the aid of sketches, a cross-connexion cabinet suitable for terminating 600 distribution pairs.*

(*b*) *Describe the method of installation of such a cabinet in the footway.*

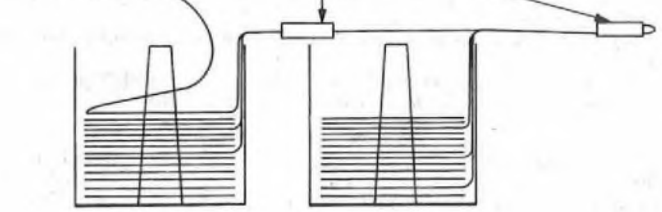
A1 See A4, Line Plant Practice B 1972, *Supplement*, Vol. 66, p. 84, Jan. 1974.

Q2 *With the aid of sketches, describe how a submarine cable with repeaters may be laid from a cableship in deep water.*

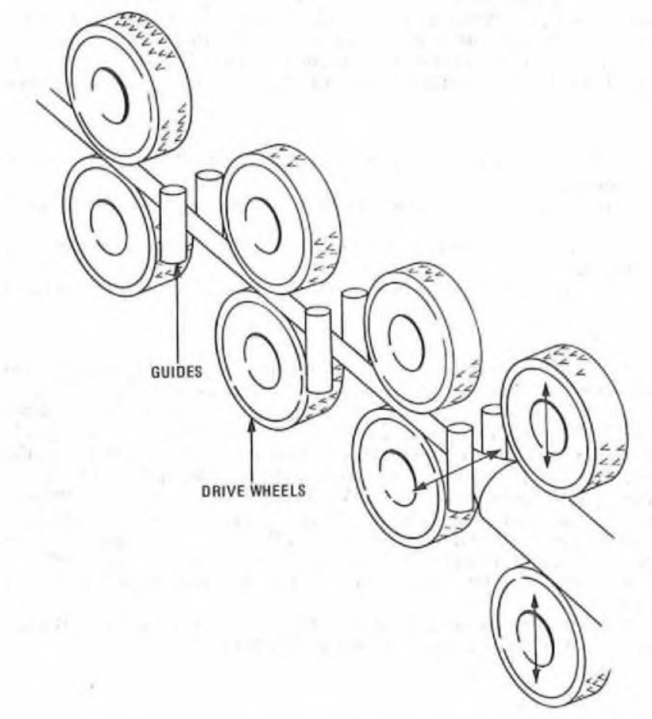
A2 Cable laying from a cableship in deep water is carried out over the stern of the ship. The single stern sheave, which is free-running on its axle, has a minimum diameter of 3 m in order that the cable and repeaters can pass safely over the stern without hindrance. Guards by the sheave, known as *whiskers*, protect the cable from damage during laying operations. The general arrangement is shown in sketch (*a*).



(*a*)



(*b*)



(*c*)

The cable to be laid is coiled in the cable ship's stowage tanks in horizontal lays. The repeaters which are inserted into the cable are not loaded in the tanks with the cable; the cable is brought out of the tank at the length at which a repeater is to be inserted and the repeaters, stacked together, are jointed into the cable before laying commences. (See sketch (*b*).) The stowage of the cable with its repeaters requires careful planning so that each repeater is taken out in the correct order.

To facilitate loading of the cable in the tanks and subsequent laying, three main features of the stowage tanks are:

(*i*) a truncated cone at the centre of the tank reaching to within 1 m of the top of the tank,

(*ii*) a horizontal framework (*crinoline*) positioned approximately 1 m above the level of cable to prevent the cable snagging in the tank during laying, and

(*iii*) a flared tubular framework at the tank opening which acts as a bellmouth and allows the cable to be drawn out in an aft direction for cable laying.

The tanks are sprayed with water to keep a constant temperature for transmission tests prior to laying in order that the correct equalization can be inserted.

For cable laying in deep water, the cable and repeaters are fed to the stern sheave via a linear cable engine, part of which is shown in sketch (*c*). This consists essentially of a number of pairs of rubber-tyred wheels (similar to road-vehicle wheels) interspersed with pairs of vertical guides. The engine, which is hydraulically operated, allows the speed at which the cable is fed to be controlled; the vertical guides serve to steer the cable between the wheels. As a repeater reaches the linear cable engine, the wheels and guides part further, but still grip the repeater case. Rubber cones are fitted to the ends of the repeater to maintain a smooth progression between the diameter of the cable and the diameter of the repeater.

The cable ship maintains a constant speed of approximately 14 km/h when laying cable; this speed drops to approximately 7 km/h when a repeater is laid. (*Note*: This method of laying replaces the older method of conveying the repeaters in a trough and by-passing a 5-sheave gear, and the consequent slowing, almost to a standstill, when a repeater was laid. The improved laying technique has also eliminated the parachute arrangement which was attached to the repeater to slow its rate of sinking to the sea bed.)

During cabling operations, the tension on the cable is constantly monitored to ensure that the tension at which the cable is laid is correct. Measurement of the distance travelled by the ship when paying out cable and repeaters cannot be obtained from the ship's mechanical log due to inaccuracies and tidal influence. Instead, measurement is taken from the *taut-wire gear* which pays out a thin piano wire under tension, and accurately measures the distance travelled from the initial laying point. The wire does not hug the sea bed but spans narrow ridges and hollows.

Once the cable has been laid, the amount of slack is required to be known for maintenance purposes. The measurement of slack is computed by a device known as the *slackmeter*; the information from the taut-wire gear, together with the information from the paying-out gear, is used by the slackmeter to measure the percentage of slack in the cable.

Q3 A cable consists of six 1·2/4·4 mm coaxial cable pairs and seven 0·63 mm pairs.

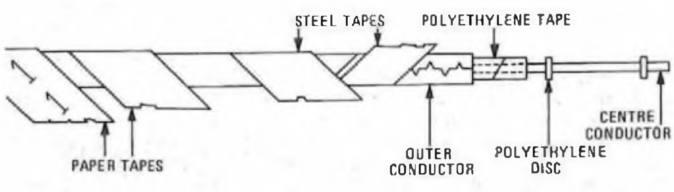
(a) With the aid of a sketch, describe the make-up of one coaxial pair.

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

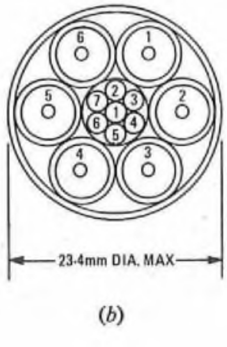
(c) Draw up a table of colour codes and marking of the 0·63 mm pairs.

A3 (*a*) A 1·2/4·4 mm coaxial pair consists of a solid copper central conductor, 1·2 mm in 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 disks. To provide adequate mechanical strength and electromagnetic screening, the pair is bound with 2 layers of mild-steel tapes. To insulate and identify the coaxial pair, 2 thicknesses of insulating paper tape are used, the outer one of which has an identifying number printed on it. The make-up of the pair is shown in sketch (*a*).

(*b*) The cross-section of a cable having six 1·2/4·4 mm coaxial pairs and seven 0·63 mm pairs is shown in sketch (*b*).



(*a*)



(*b*)

(*c*) Details of the colour codes and markings of the 0·63 mm pairs are given in the following table.

Pair No.	Colour	Marking	
1	Green	|	||
2	Orange	|	||
3	Orange	|||	||||
4	Blue	|	||
5	Blue	|||	||||
6	Blue	|	||
7	Blue	|||	||||

Q4 (a) Describe in detail the method of constructing a triangular-shaped concrete manhole, reinforced with straight steel bars, which would be suitable for leading two 24-way duct routes into a telephone exchange.

(b) Draw a plan view to show how cables and joints would be located in such a manhole.

Q5 (a) Describe the function of project planning and control.

(b) Describe THREE resource categories which are under the control of the planner.

(c) Describe briefly a simple form of displaying the planned progress of a job.

A5 (*a*) The function of project planning and control is to ensure that the project is completed as efficiently as possible within a specified time. The length of time available for a particular project will usually have been dictated by other factors, such as its position in an overall plan or the need to meet a customer's requirement. The project planner has, therefore, to organize the available resources so that the most efficient use is made of them, while still keeping within the specified time limits.

(*b*) Three resource categories are under the control of the project planner. These are:

(*i*) components and materials consumed by the project (stores),

(*ii*) tools and equipment employed during the execution of the project (plant), and

(*iii*) the workforce (labour).

In order to forecast the quantities of each category required for the project, and also to forecast when each will be required on site, it is necessary to construct an accurate plan of each part of the project in chronological order.

(*c*) When a project consists of a simple sequence of events, each event starting after the completion of its predecessor, a simple bar chart can be used to display the planned progress of a job. A project is divided up into a numbered sequence of activities and a duration is assigned to each activity. The sequence of activities would be displayed in the form of a bar chart.

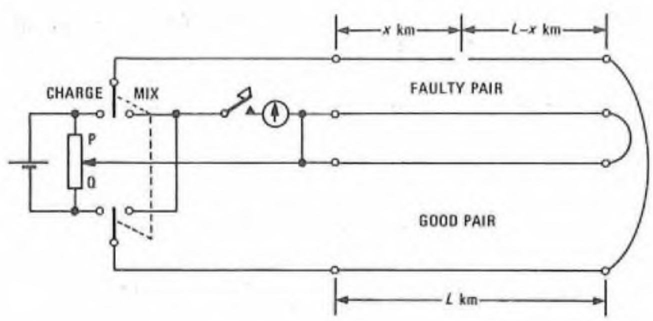
Q6 Describe in detail, with the aid of sketches, THREE types of feeder which could be used to connect an aerial to its transmitter equipment and indicate where they are used.

Q7 A disconnexion fault has occurred in one conductor of a loaded section of cable.

(a) Using the method of mixtures, describe how the fault could be located.

(b) If the fault had occurred in a conductor of a screened-pair cable, how would the test differ from that described in part (a)?

A7 (*a*) The equipment required and the circuit connexions to be made for a test using the method of mixtures is shown in the sketch. The equipment consists of a 1000 Ω slide-wire potentiometer (PQ), a reflecting-type galvanometer and shunt, and a double-pole changeover switch.



The test is made by charging the capacitance between the good loop and the 2 parts of the faulty loop from 2 different potentials (one of which must be adjustable), allowing the charges on the 2 parts of the faulty loop to mix by joining the ends of the loop together and allowing the residual charge to flow through the galvanometer by joining it between the loops. The potentials are adjusted until no residual charge is left, in which case the charges are equal. Since the charge or quantity of electricity (q) in a capacitor is equal to the capacitance multiplied by the potential difference across it, it follows that the capacitances of each part of the faulty loop to the good loop are inversely proportional to the potentials impressed upon them.

Depression of the CHARGE key connects the faulty pair across the battery. After an interval, to allow the capacitances to be charged, the key is changed over to MIX. This joins the 2 ends of the faulty pair together. Another interval is then allowed for the charges to mix before connecting the galvanometer to the junction of the ends of the faulty loop. The slide-wire is adjusted until no residual charge is shown by the galvanometer.

Since the same current flows through both resistances, the voltage across each is proportional to its reading in ohms.

Let C be the capacitance per unit length and x the distance to the fault.

Then Cx is the capacitance of one portion of the circuit and $C(2L - x)$ the capacitance of the other,

Let V_1 be the voltage charging Cx, V_2 be the voltage charging $C(2L - x)$, q_1 be the charge on Cx, and q_2 be the charge on $C(2L - x)$.

As the charge is equal to the product of capacitance and voltage,

$$q_1 = V_1Cx \text{ and } q_2 = V_2C(2L - x).$$

At balance, $q_1 = q_2$

$$\therefore \quad V_1Cx = V_2C(2L - x),$$

$$\therefore \quad \frac{V_2}{V_1} = \frac{x}{2L - x}.$$

$$\text{But } \frac{V_2}{V_1} = \frac{Q}{P}.$$

$$\therefore \quad x = 2L\frac{Q}{P + Q} \text{ kilometres.}$$

(*b*) When a disconnexion occurs on one conductor of a screened pair, the faulty wire is looped at its distant end with a good wire in the same cable. The galvanometer is connected to the sheath of the cable instead of the return wire.

Q8 Consider the effect on a telephone cable of earth-fault conditions from a power supply system.

(a) Define the term screening factor.

(b) What will the screening effect depend upon in,

(i) an overhead power system,

(ii) an underground power cable, and

(iii) an underground telephone cable?

A8 (*a*) The large external magnetic field producing inductive interference on a telephone line under earth-fault conditions occurs because the heavy fault current, spreading widely through the surrounding earth, has a mean path some distance away from the faulty phase-line. The magnitude of this external magnetic field can be reduced if all, or part, of the earth-return current takes a path, such as a continuous earth wire, cable sheath or metal pipe, which is nearer to the faulty phase-line than the mean earth path. The degree of screening afforded by such an earthed conductor is represented by a decimal fraction termed the *screening factor*.

The screening factor is defined as the ratio of the voltage induced in the telephone line in the presence of the screening conductor to the voltage which would be induced in the telephone line in the absence of the screening conductor. A low screening factor indicates a considerable screening effect.

(*b*) (*i*) For overhead power lines, the screening effect will depend upon the conductivity of the earth wire, its position in relation to the phase-line and the ground, and upon the earth's resistivity. Figures cannot be given for all combinations of these variables and, at the present time, a screening factor is introduced only when the power line carries a continuous earth wire with a copper equivalent of 48 mm² or more. In such cases, screening factors of 0·66 and 0·5 are assumed for earth wires with copper equivalents of 48 and 114 mm² respectively.

(*ii*) The sheath of an underground power cable will carry a relatively high proportion of the return earth-fault current and this will, of course, be in close proximity to the phase conductors. The screening effect of the sheath is therefore considerable.

(*iii*) The lead sheath of an underground telephone cable is subject to induced voltages from a faulty power line in the same way as the telephone conductors. The resulting current in the sheath sets up a magnetic field opposing that of the faulty power line and this provides a limited screening effect.

Q9 (a) Describe and distinguish between the TWO types of electro-chemical corrosion that can occur on a buried lead-sheathed telephone cable.

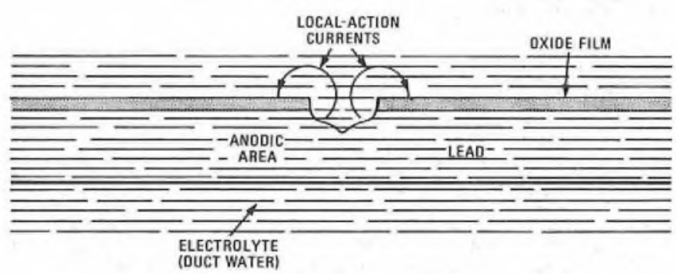
(b) Give ONE example of EACH type of corrosion described in (a).

A9 (*a*) Generally, electro-chemical corrosion is characterized by the localization of the anodic and cathodic processes at separate areas. These areas may be close together or at a distance apart from each other.

Non-electrolytic corrosion refers to those types of electro-chemical corrosion in which the anodic and cathodic areas are so close together that the current flow between the areas is non-measurable.

Electrolytic corrosion refers to those types of electro-chemical corrosion accompanied by the circulation of a measurable current, of any origin, between an anodic area or areas and a distant cathodic area or areas.

(*b*) (*i*) One example of non-electrolytic corrosion is *scratch corrosion*. The surface of any base metal will oxidize when exposed to air. This surface film of oxide is practically inert and will provide appreciable protection against further corrosion. A scratch on the metal surface will, however, damage the oxide film and produce adjacent dissimilar surfaces. If the metal is immersed in an electrolyte, for example duct water, the dissimilar surfaces will form the electrodes of an electrolytic cell and local currents will flow in the direction indicated in the sketch. As the action proceeds the scratch will deepen and the electrolyte at the bottom of the scratch will become oxygen starved. Corrosion thus increases due to differential aeration.



(*ii*) An example of electrolytic corrosion is that caused through long-line currents; where long cables pass through soils which differ geologically, the potential between cable sheath and earth may vary at points along the sheath. The differences in potential cause cells to be formed, in which the electrodes are a considerable distance apart. Sheath currents flow and corrosion occurs at the anodic area.

Q10 An aerial cable route changes direction by 43° at a pole provided with a stay in a position such that it bisects the angle made by the route.

The stay is attached to the pole 0·6 m above the aerial cable which is located on the pole 9 m above the ground. The stay is anchored at a distance of 6 m from the base of the pole.

(a) Calculate the tension in the stay if the tension in the cable is 4·3 kN.

(b) If the breaking load of the stay is 25 kN, what is the factor of safety?

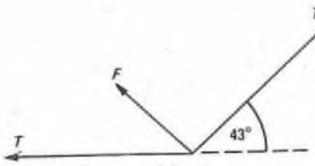
A10 (*a*) Referring to sketch (*a*).

The tension (T) in the cable is 4·3 kN.

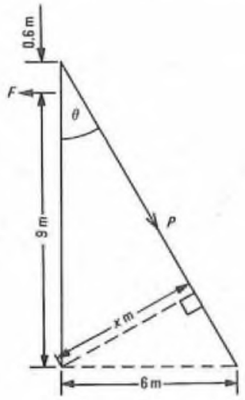
Thus the force (F) on the pole is $2T \sin 43°$ kilonewtons

$$= 2 \times 4{\cdot}3 \times 0{\cdot}682 \text{ kN},$$

$$= 5{\cdot}865 \text{ kN}.$$



(*a*)



(*b*)

Referring to sketch (*b*).

Let the tension in the stay be *P*.

Taking moments about A, $F \times 9 = P \times x$.

$$\text{Thus, } 5{\cdot}865 \times 9 = P \times 9{\cdot}6 \sin\theta = P \times 9{\cdot}6 \times \frac{6}{\sqrt{(6^2 + 9{\cdot}6^2)}}.$$

$$\therefore P = \frac{5{\cdot}865 \times 9 \times \sqrt{(6^2 + 9{\cdot}6^2)}}{9{\cdot}6 \times 6},$$

$$= 10{\cdot}37 \text{ kN}.$$

(*b*) The factor of safety is $\frac{25}{10{\cdot}37}$

$$= \underline{2{\cdot}41.}$$

TELECOMMUNICATION PRINCIPLES B 1977

Students were expected to answer any 6 questions

Q1 (*a*) *Describe briefly how the electron beam in a cathode-ray oscilloscope (CRO) is deflected in response to a signal.*

(*b*) *Explain with the aid of diagrams how a stationary wave pattern representing an alternating voltage is produced on the screen of a CRO.*

A1 See A5, Radio and Line Transmission B 1976, *Supplement*, Vol. 71, p. 37, July 1978.

Q2 (*a*) (*i*) *Name 2 sources of energy loss in a capacitor.*

(*ii*) *How can these energy losses be represented in an equivalent circuit?*

(*iii*) *Explain the meaning of loss angle for a capacitor.*

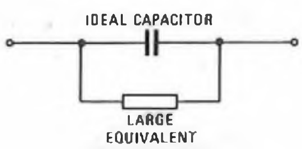
(*b*) *A 50 V 100 kHz supply is connected across a 0·1 μF capacitor and the power dissipated is then 200 μW. Calculate*

(*i*) *the reactive current,*
(*ii*) *the equivalent series circuit for the capacitor, and*
(*iii*) *the loss angle.*

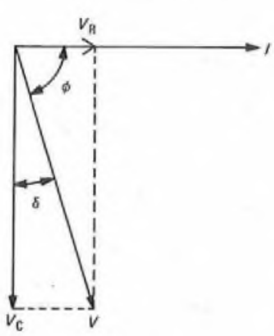
A2 (*a*) (*i*) For a capacitor operating from a direct voltage source, the only significant energy loss is due to the finite resistance of the dielectric. For a capacitor operating under AC conditions, there are 2 sources of energy loss: the loss due to the resistance of the electrodes and connexions, and the dielectric loss. The loss due to resistance includes eddy-current loss in the electrodes, which increases with frequency. Dielectric loss depends on the dielectric material, but is generally proportional to the square root of the frequency; it is usually larger than the resistance loss. The total loss in a good-quality capacitor is very small and is often ignored in ordinary circuit analysis.

(*ii*) The total energy loss can be represented by a resistor in an equivalent circuit of the capacitor. This can be a series resistor of very small value, or it can be a parallel resistor of large value. Sketches (*a*) and (*b*) show the 2 circuits.

(*a*)



(*b*)



(*c*)

(*iii*) At a given frequency, either of these equivalent circuits can be represented by a phasor diagram. Sketch (*c*) shows the phasor diagram for the series circuit of sketch (*a*). The voltage drop (V_R) due to the resistance is very small, while that due to the reactance of the capacitor (V_C) is much larger. The loss angle is the small angle (δ) between the resultant phasor (V) and V_C. Because the loss angle is so small, the angle in radians is numerically equal to its tangent; that is $\delta = V_R/V_C = R/X_C$ radians.

(*b*) (*i*) By Ohm's law, the reactive current $I = V/X_C$,

$$\text{where} \quad X_C = \frac{1}{2\pi \times 10^5 \times 0{\cdot}1 \times 10^{-6}} = 50/\pi\ \Omega.$$

$$\therefore I = \frac{50}{50/\pi} = \underline{3{\cdot}14 \text{ A.}}$$

(*ii*) The equivalent series circuit would be as shown in sketch (*a*) with $C = 0{\cdot}1\ \mu$F and R of such a value that $I^2R = 200\ \mu$W.

$$\therefore R = \frac{200 \times 10^{-6}}{3{\cdot}14^2}\ \Omega,$$

$$= \underline{20{\cdot}26\ \mu\Omega.}$$

(*iii*) The loss angle, δ, in radians $= R/X_C$,

$$= \frac{20{\cdot}20}{50/\pi}\ \mu\text{rad.} = 1{\cdot}27\ \mu\text{rad.}$$

Q3 (*a*) *Describe briefly the principle of a simple single-phase AC generator.*

(*b*) *What factors determine,*

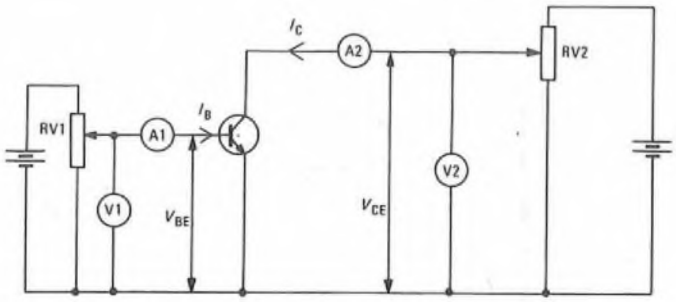
(*i*) *the frequency of the alternating current generated,*
(*ii*) *the voltage at the output terminals, and*
(*iii*) *the maximum safe electrical power output?*

Q4 (*a*) *Describe an experiment to determine the input and output characteristics of a junction transistor in common-emitter configuration. Include the test circuit, a brief account of the equipment required and typical results.*

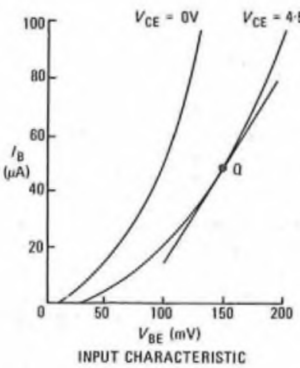
(*b*) *Name 2 transistor parameters that can be deduced from the gradients of the curves obtained.*

A4 (*a*) To determine the input and output characteristics of a transistor in common-emitter configuration, it is necessary to establish: the relation between the base current, I_B, and base-emitter voltage V_{BE}, for various constant values of collector-emitter voltage; and the relation between collector current, I_C, and collector-emitter voltage, V_{CE}, for various constant values of base current, I_B.

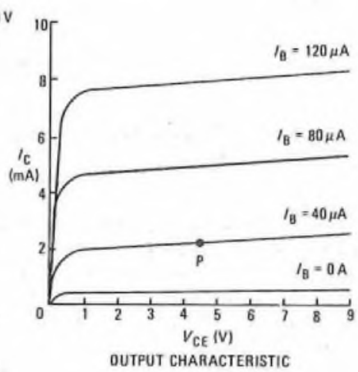
Sketch (*a*) shows a suitable circuit with meters positioned to measure the above parameters. Separate batteries are used for supplying input



(*a*)



(*b*)



(*c*)

and output circuits, with potentiometers RV1 and RV2 to give fine voltage adjustment. Two high-resistance voltmeters, one micro-ammeter A1, and one milliammeter A2.

The procedure is as follows:

(*i*) *Input Characteristics:* Potentiometer RV2 is used to hold voltage V_{CE} constant, while potentiometer RV1 is adjusted in steps to give a series of values of voltage V_{BE} and current I_B noted at each value. Potentiometer RV2 is then altered to give a new value of V_{CE} and the measurements are repeated. A curve is obtained for each value of V_{CE} and a family of input characteristics is thus produced.

(*ii*) *Output Characteristics:* Potentiometer RV1 is used to hold current I_B constant, while potentiometer RV2 is adjusted in steps to give a series of values of voltage V_{CE} and current I_C noted at each step. The readings are repeated for different values of current I_B to give a family of output curves.

In performing these tests, care must be taken not to exceed the maker's maximum values for transistor currents and voltages. Typical results are shown in sketches (*b*) and (*c*).

(*b*) The gradients of the curves obtained in part (*a*) give the input and output conductances of the transistor under static conditions.

In sketch (*b*), the slope of the curve at point Q is given by the slope of the tangent at point Q, as shown. From Ohm's law, the input resistance equals dV/dI; that is, the reciprocal of the slope.

In sketch (*c*), the output resistance is the reciprocal of the slope at point P.

Typical values are: input resistance in the range 0·5–2 kΩ; output resistance between 5–20 kΩ.

Q5 (*a*) *Define the decibel.*

(*b*) *Why is the decibel so useful in telecommunication engineering?*

(*c*) (*i*) *Calculate the equivalent of 10 dB relative to 1 W.*
(*ii*) *Calculate the equivalent of* −*10 dB relative to 1 mW.*
(*iii*) *Convert a power ratio of 5 into decibels.*

(*d*) *The amplifier in Fig. 1 has a high impedance input and provides 26 dB voltage gain. Express the output voltage V_3 in decibels relative to the input V_1 in the circuit.*

A5 (*a*) The decibel is defined as 10 times the logarithm to base 10 of the ratio of 2 powers. Since the power in a circuit is proportional to the square of the voltage and the square of the current, the definition of the decibel can be extended to 20 times the logarithm to the base 10 of the ratio of 2 voltages or 2 currents, provided they are measured in the same impedance.

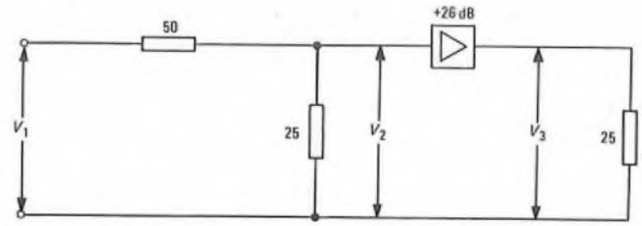


Fig. 1

(*b*) In telecommunications technology, gains and losses in circuits often occur in very large multiples. By using decibel notation, these large multiples are converted to logarithmic form, so that adding and subtracting small numbers replaces multiplication and division by very large numbers representing gains and losses. The use of decibels therefore greatly simplifies transmission calculations.

(*c*) (*i*) If P_1 and P_2 are 2 powers, they are related, in decibels, by $N = 10 \log_{10} \frac{P_1}{P_2}$.

When $P_2 = 1$ W and $N = 10$ dB, $10 = 10 \log_{10} \frac{P_1}{1}$.

$$\text{So } 10^1 = P_1,$$

$$\text{or } \underline{P_1 = 10 \text{ W}}.$$

(*ii*) The reference power is now 1 mW. So let P_1 be in milliwatts.

$$N = -10 \text{ dB and so } -10 = 10 \log_{10} \frac{P_1}{1}.$$

$$\therefore \log_{10} P_1 = -1,$$

$$\text{and so } P_1 = 10^{-1} = \underline{\frac{1}{10} \text{ mW}}.$$

(*iii*) The power ratio is 5.

$$\therefore N = 10 \log_{10} 5 = 10 \times 0{\cdot}699 \approx \underline{7 \text{ dB}}.$$

(*d*) As the amplifier input impedance is very high, it will not produce any appreciable shunting effect on the 25 Ω resistance at its input. Therefore, the ratio V_2/V_1 is the potentiometer ratio 25/(50 + 25).

$$\therefore V_1 = 3V_2.$$

The voltage gain of the amplifier is V_3/V_2, which is 26 dB.

$$\therefore 26 = 20 \log_{10} \frac{V_3}{V_2}, \text{ or } \log_{10} \frac{V_3}{V_2} = 1{\cdot}3.$$

Thus, $\frac{V_3}{V_2} = 10^{1\cdot3} = 19{\cdot}95$.

Hence, $V_3 = 19{\cdot}95\, V_2$ and, substituting for V_2 in terms of V_1, gives

$$V_3 = \frac{19{\cdot}95}{3} V_1 = 6{\cdot}65 V_1.$$

In decibels, the gain is $20 \log_{10} 6{\cdot}65 = 20 \times 0{\cdot}823$,

$$\approx \underline{16{\cdot}5 \text{ dB}}.$$

Q6 *For an ideal transformer, explain*

(*a*) *why the ratio of the EMFs at the terminals of the primary and secondary windings is the same as the turns ratio,*

(*b*) *why the ratio of the equivalent load of the primary to the load on the secondary is the square of the turns ratio, and*

(*c*) *what factors in a practical transformer modify this concept of an ideal transformer.*

Q7 *A 2 μF capacitor is to be charged through a 10 kΩ resistor from a 100 V battery.*

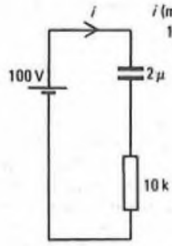
(*a*) (*i*) *Give the expression relating current to time from switching on.*
(*ii*) *Sketch the current/time curve.*
(*iii*) *Find the initial current.*

(*b*) *On the same time axis sketch the curves of the change of PD with time across*

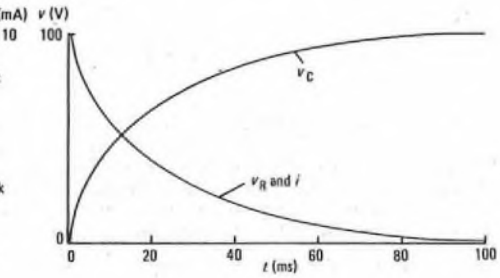
(*i*) *the capacitor, and*
(*ii*) *the resistor.*

(c) Explain why the voltage across the capacitor rises slowly.
(d) Determine the value of the time constant.

A7 (*a*) The circuit is shown in sketch (*a*).



(*a*)



(*b*)

(*i*) The current i amperes is related to the time t seconds after switching on by

$$i = \frac{V}{R}e^{-t/CR},$$

$$= \frac{100}{10^4}e^{-50t} \text{ amperes} = \underline{10\,e^{-50t} \text{ milliamps.}}$$

(*ii*) The current/time curve representing the expression in (*i*) above is shown in sketch (*b*).

(*iii*) At the instant of switching on, there is no charge in the capacitor, and so all the supply voltage falls across the series resistor. The initial current is therefore $I_0 = \frac{100}{10^4}\text{ A} = \underline{10 \text{ mA}}$.

(*b*) At any instant, the sum of the voltages across the resistor and the capacitor must equal the supply voltage, which is constant at 100 V.

(*i*) The instantaneous voltage across the capacitor, v_C, is equal to the supply voltage V minus v_R and is shown in sketch (*b*).

(*ii*) The instantaneous voltage across the resistor v_R is given by the product of the current $i = \frac{V}{R}e^{-t/CR}$ and the resistance R. Therefore, $v_R = Ve^{-t/CR} = 100e^{-50t}$ volts. The shape of the voltage curve is therefore the same as the current curve and is shown in sketch (*b*).

(*c*) Voltage v_C, builds up as charge Q flows into the capacitor due to the current through the resistor, in accordance with the relationship $v_C = Q/C$. However, the current decreases as voltage v_C increases because there is a corresponding reduction in the voltage v_R across the resistor ($v_R = V - v_C$). Hence, the voltage rises rapidly at first, but the rate of increase of v_C decreases progressively as it approaches the battery voltage.

(*d*) The time constant gives a measure of the rate at which the voltage across the capacitor builds up.

$$\text{Time constant} = CR = 2 \times 10^{-6} \times 10^4 \text{ s} = \underline{20 \text{ ms.}}$$

Q8 *(a) Sketch on the same axes the reactance/frequency curves for (i) an inductance of 0·5 H and (ii) a capacitance of 0·5 μF over the frequency range 0 to 1 kHz.*

(b) (i) Sketch on the same axes the reactance/frequency curve for these 2 components in series.

(ii) Hence, explain the meaning of series resonance.

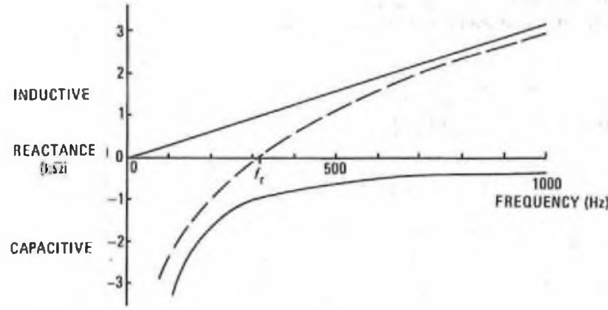
(iii) Show that there is only one frequency of series resonance.

(c) Calculate the frequency of resonance.

(d) If the inductor has a series resistance of 20 Ω, calculate the Q-factor of the circuit at resonance.

A8 (*a*) The reactance, X_L ohms, of an inductance of L henrys, at a frequency of f hertz, is given by $X_L = 2\pi fL$ ohms. The relationship between inductive reactance and frequency is therefore linear, with $X_L = 0$ when $f = 0$. One additional point is needed to draw the line: when $f = 1$ kHz, $X_L = 2\pi \times 10^3 \times 0{\cdot}5 = 3142\ \Omega$.

The reactance, X_C ohms, of a capacitance C farads is given by $X_C = -\frac{1}{2\pi fC}$ ohms and, when plotted against frequency, is a negative



rectangular hyperbola as shown in the sketch. To draw the actual curve, the reactance must be calculated at several frequencies as shown in the table

f(Hz)	100	300	500	700	1000
$X_C = -\frac{1}{2\pi fC}$ (Ω)	3183	1061	637	455	318

(*b*) (*i*) To obtain the total reactance/frequency relationship of the inductance and capacitance in series, the individual curves must be added algebraically, as shown in the sketch.

(*ii*) Series resonance occurs at the frequency, f_r, where the inductive and capacitive reactances are equal and opposite, giving zero net reactance.

(*iii*) As can be seen from the sketch, there is only one frequency where the total reactance is zero: below resonance, the total reactance curve is asymptotic to the capacitive reactance curve; above resonance, the total reactance curve is asymptotic to the inductive reactance curve.

(*c*) The resonant frequency f_r can be evaluated from the equation $2\pi f_r L = \frac{1}{2\pi f_r C}$, from which

$$f_r = \frac{1}{2\pi\sqrt{(LC)}}.$$

When $C = 0{\cdot}5\ \mu$F and $L = 0{\cdot}5$ H,

$$f_r = \frac{1}{2\pi\sqrt{(\frac{1}{4} \times 10^{-6})}} \text{ Hz},$$

$$= \frac{10^3}{\pi} = \underline{318 \text{ Hz.}}$$

(*d*) The Q-factor of the circuit is given by

$$Q = \frac{2\pi f_r L}{R}, \text{ where } R \text{ is the circuit resistance.}$$

$$\therefore\ Q = 2\pi\frac{L}{R} \times \frac{1}{2\pi\sqrt{(LC)}} = \frac{1}{R}\sqrt{\left(\frac{L}{C}\right)},$$

$$= \frac{1}{20}\sqrt{10^6} = \underline{50.}$$

Q9 *(a) Why is screening necessary in some telecommunication equipment?*

(b) Explain with the aid of sketches the difference in the principles of screening against a magnetic field and against an electric field.

(c) Give one application for each and describe how the screening is carried out.

A9 See A3, Telecommunication Principles B, 1974, *Supplement*, Vol. 69, p. 21, Apr. 1976.

Q10 *(a) Impedances denoted by 5 + j5 and −j3 are connected in parallel. Calculate the resultant impedance in a + jb form.*

(b) (i) What is the resultant impedance when 5 + j5 and −j3 are connected in series?

(ii) Illustrate these 3 impedances on a phasor diagram.

(c) Calculate the component values to give the resultant impedance in (b) at 500 Hz.

A10 (*a*) When 2 impedances, Z_1 and Z_2, are connected in parallel, the resultant impedance, Z, is given by

$$\frac{1}{Z}=\frac{1}{Z_1}+\frac{1}{Z_2}.$$

When $Z_1 = 5 + j5$ and $Z_2 = -j3$,

$$\frac{1}{Z}=\frac{1}{5+j5}-\frac{1}{j3}=\frac{j3-(5+j5)}{(5+j5)j3}.$$

$$\therefore\ Z=\frac{j15-15}{-j2-5}=\frac{15(1-j)}{5+j2}.$$

Multiplying top and bottom by $5 - j2$ gives

$$Z=\frac{15(1-j)(5-j2)}{25+4},$$

$$=\frac{15}{29}(3-j7).$$

$$\therefore\ \underline{Z = 1{\cdot}55 - j3{\cdot}62.}$$

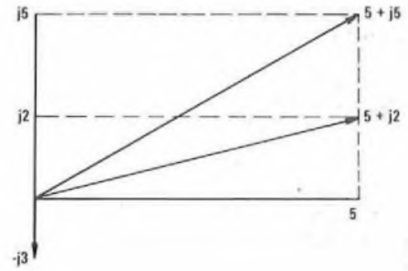
(*b*) (*i*) When the 2 impedances are connected in series, the resultant impedance is given by the algebraic sum; that is,

$$Z = Z_1 + Z_2,$$

$$= 5 + j5 + (-j3),$$

$$= \underline{5 + j2.}$$

(*ii*) These 3 impedances are illustrated in the phasor diagram shown in the sketch. The real term represents a resistance of 5 units.



The imaginary term represents a positive reactance of 2 units. The resultant phasor represents an impedance of $5 + j2$ units.

(*c*) Assuming the units of the impedance to be ohms, then the impedance of $5 + j2\ \Omega$ is made up of a resistance of $5\ \Omega$ in series with an inductance, L, having a reactance of $2\ \Omega$ at the given frequency of 500 Hz.

$$\therefore\ 2\pi fL = 2,$$

$$\text{and } L = \frac{1}{\pi f}\text{ henrys},$$

$$= \frac{1}{500\pi}\text{ H} = \underline{0{\cdot}636\text{ mH}.}$$

Therefore, the impedance consists of a resistance of $\underline{5\ \Omega}$ in series with an inductance of $\underline{0{\cdot}636\text{ mH}}$.

TELECOMMUNICATION PRINCIPLES C 1977

Students were expected to answer any 6 questions
The use of a pocket calculator was permitted where appropriate

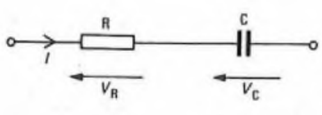
Q1 (*a*) *A 2 μF capacitor has a loss angle of 4×10^{-4} rad, and a 3 μF capacitor has a loss angle of 2×10^{-4} rad. Calculate the effective series and parallel loss resistances for* EACH *capacitor at 5 kHz.*

(*b*) *Calculate the overall capacitance and power factor at 5 kHz when the capacitors in part* (*a*) *are connected*

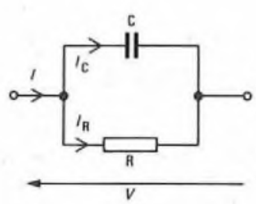
(*i*) *in series, and*
(*ii*) *in parallel.*

A1 (*a*) The equivalent series and parallel circuits for a capacitor with loss are shown in sketches (*a*) and (*b*) and the respective phasor diagrams in sketches (*c*) and (*d*).

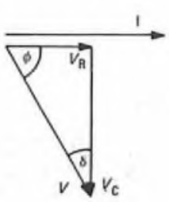
For a small angle, the loss angle, δ rad, is equal to $\tan\delta$.



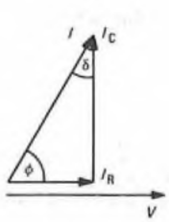
(*a*)



(*b*)



(*c*)



(*d*)

Therefore, the loss angle can be expressed as:

V_R/V_C for the series representation, and

I_R/I_C for the parallel representation.

Thus, for the series representation,

$$\delta=\frac{V_R}{V_C}=\frac{IR}{IX_C}=\underline{\omega CR,} \qquad \ldots\ldots\ (1)$$

where ω is $2\pi \times$ the frequency.

Therefore the loss resistances are:

for the 2 μF capacitor, $\dfrac{4\times10^{-4}}{2\pi\times5\times10^{3}\times2\times10^{-6}}=\underline{0{\cdot}0064\ \Omega,}$ and

for the 3 μF capacitor, $\dfrac{2\times10^{-4}}{2\pi\times5\times10^{3}\times3\times10^{-6}}=\underline{0{\cdot}0021\Omega.}$

For the parallel representation,

$$\delta=\frac{I_R}{I_C}=\frac{V/R}{V/X_C}=\frac{1}{\omega CR}. \qquad \ldots\ldots\ (2)$$

The loss resistances are:

for the 2 μF capacitor, $\dfrac{1}{2\pi\times5\times10^{3}\times2\times10^{-6}\times4\times10^{-4}}$

$$=\underline{39{\cdot}8\text{ k}\Omega,}\text{ and}$$

for the 3 μF capacitor, $\dfrac{1}{2\pi\times5\times10^{3}\times3\times10^{-6}\times2\times10^{-4}}$

$$=\underline{53{\cdot}0\text{ k}\Omega.}$$

(*b*) (*i*) For 2 capacitors in series, the total capacitance, C_S, is given by

$$C_S=\frac{C_1C_2}{C_1+C_2}=\frac{2\times3}{2+3}=\underline{1{\cdot}2\ \mu\text{F},}$$

and the total series resistance, R_S, is given by

$$R_S = R_1 + R_2 = 0{\cdot}0085\ \Omega.$$

Therefore, from equation (1),

$$\delta = 2\pi \times 5 \times 10^3 \times 1{\cdot}2 \times 10^{-6} \times 0{\cdot}0085 = 3{\cdot}2 \times 10^{-4}\ \text{rad},$$

and thus, the power factor is 0·00032.

(*ii*) For 2 capacitors in parallel the total capacitance, C_P, is given by

$$C_P = C_1 + C_2 = 5\ \mu\text{F},$$

and the total parallel resistance, R_P, is given by

$$R_P = \frac{R_1 R_2}{R_1 + R_2} = \frac{53{\cdot}0 \times 39{\cdot}8}{92{\cdot}8} = 22{\cdot}7\ \text{k}\Omega.$$

Therefore, from equation (2),

$$\delta = \frac{1}{2\pi \times 5 \times 10^3 \times 5 \times 10^{-6} \times 22{\cdot}7 \times 10^3} = 2{\cdot}8 \times 10^{-4}\ \text{rad},$$

and thus, the power factor is 0·00028.

Q2 (a) Explain how a Thévènin equivalent circuit may be converted to a Norton equivalent circuit.

(b) Determine an equivalent circuit for terminals AB of the network shown in Fig. 1.

(c) In what impedance, connected across AB, will maximum power be developed and what is the value of that power?

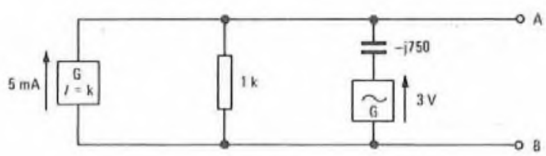


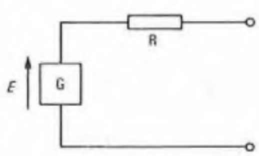
Fig. 1

A2 (*a*) A Thévènin equivalent circuit is shown in sketch (*a*) and a Norton equivalent circuit in sketch (*b*). For the 2 representations to be the same, the terminal behaviour has to be identical for all load conditions. Using the behaviour under open-circuit and short-circuit conditions enables values of I and G to be calculated in terms of R and E.

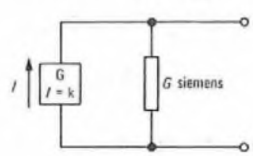
On open-circuit, the terminal voltages of both equivalent circuits must be equal, and therefore $E = I/G$.

On short-circuit, the currents flowing in each equivalent circuit must be equal, and therefore $I = E/R$.

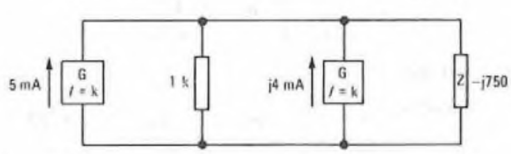
Thus it can be calculated that $G = I/E = 1/R$.



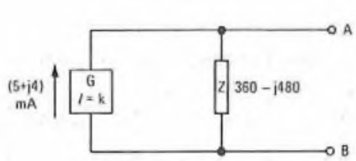
(*a*)



(*b*)



(*c*)



(*d*)

(*b*) The Thévènin equivalent circuit represented by the 3 V source and the −j750 Ω series impedance is converted to its Norton equivalent circuit. From part (*a*), the equivalent current source is 3/(−j750) which is equal to j4 mA and the equivalent parallel impedance is −j750 Ω. Sketch (*c*) shows the result of this.

The circuit can be simplified by combining the current sources and impedances. The equivalent current source is (5 + j4) mA, and the equivalent parallel impedance is $-j\dfrac{1000 \times 750}{1000 - j750}$

$$= \frac{-j(750 \times 1000)(1000 + j750)}{1000^2 + 750^2}$$

$$= -j0{\cdot}48(1000 + j750) = 360 - j480\ \Omega.$$

Sketch (*d*) shows the equivalent circuit.

(*c*) The impedance required for maximum power transfer is 360 + j480 Ω. The combination of the source impedance and the load impedance is $\dfrac{(360 - j480)(360 + j480)}{720} = 500\ \Omega.$

Thus the voltage across the load is $\dfrac{500(5 + j4)}{1000} = \dfrac{5 + j4}{2}$ V.

The power in the load is the real part of

$$\left(\frac{5 + j4}{2}\right)^2 \left(\frac{1}{360 + j480}\right) = \left(\frac{9 + j40}{4}\right)\left(\frac{360 - j480}{360^2 + 480^2}\right)\ \text{VA}.$$

$$\therefore\ \text{the power in the load is}\ \frac{9 \times 360 + 40 \times 480}{4 \times 360\,000} = 1{\cdot}56 \times 10^{-2}\ \text{W},$$

$$= 15{\cdot}6\ \text{mW}.$$

Q3 (a) A loss-free transmission line has an inductance of 1·2 mH/km and a capacitance of 0·05 μF/km. Calculate the characteristic impedance and the propagation coefficient of the line.

(b) A 0·4 km length of the line is terminated in its characteristic impedance and a voltage of 3 V at 500 kHz is maintained across the line input. Calculate:

(i) the line output voltage and its phase relative to the input voltage,

(ii) the velocity of propagation, and

(iii) the frequency at which the line length is equivalent to one wavelength.

A3 (*a*) The characteristic impedance (Z_0) is given by

$$Z_0 = \sqrt{\frac{L}{C}}\ \text{ohms}$$

where L is the inductance per unit length and C is the capacitance per unit length.

$$\therefore\ Z_0 = \sqrt{\left(\frac{1{\cdot}2 \times 10^{-3}}{0{\cdot}5 \times 10^{-7}}\right)} = 154{\cdot}9\ \Omega.$$

The propagation coefficient (λ) is given by

$$\lambda = \alpha + j\beta.$$

Since the line is loss free, $\alpha = 0$ and $\beta = \omega LC$

$$\therefore\ \text{at 500 kHz},\ \lambda = j2\pi \times 500 \times 10^3\sqrt{(1{\cdot}2 \times 10^{-3} \times 0{\cdot}5 \times 10^{-7})}$$

$$= j24{\cdot}33.$$

(*b*) (*i*) 0·4 km of the line corresponds to 1·549 × 2π rad. Thus the output voltage would be 3·0 V at an angle of 197·6° lagging with respect to the input voltage.

(*ii*) The velocity of propagation (V_P) is $\dfrac{\omega}{\beta}$ metres per second, and since the line is loss free,

$$\beta = |\lambda|.$$

$$\therefore\ V_P = \frac{2\pi \times 500 \times 10^3}{24{\cdot}33} = 129\ \text{km/s}.$$

(*iii*) The frequency at which 0·4 km corresponds to one wavelength is the frequency at which the phase shift is exactly 2 rad. Since the phase coefficient is proportional to frequency, the frequency required is

$$\frac{2\pi \times 500 \times 10^3}{2\pi \times 1{\cdot}549}\ \text{Hz} = 322{\cdot}8\ \text{kHz}.$$

Q4 (*a*) *Describe a laboratory method for measuring the Q-factor of a coil at a single frequency.*

(*b*) *For a high-Q series circuit, the current in the region of resonance is given by:*

$$\frac{I_0}{1 + j\dfrac{2Q\delta f}{f_0}},$$

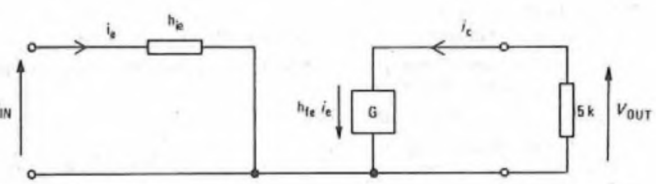
where I_0 is the current at resonance; Q is the Q-factor of the circuit; f_0 is the resonant frequency and δf is the frequency deviation from resonance.

For a particular circuit, $I_0 = 10\ mA$, $Q = 80$ and $f_0 = 40\ kHz$. Calculate the frequencies at which the current, I, is:

(*i*) *7·07 mA,*
(*ii*) *5 mA, and*
(*iii*) *2 mA.*

Q5 (*a*) *A common-emitter transistor amplifier has a collector load resistance of 5 kΩ. The transistor used is one of a type in which h_{oe} and h_{re} are negligible while the values of h_{ie} and h_{fe} are within the ranges 1·2 to 1·5 kΩ and 45 to 60, respectively. Calculate the maximum and minimum possible values of the voltage gain and the ratio of these gains.*

(*b*) *2% of the output voltage of the amplifier above is fed back to the input as negative feedback in series with the input. Calculate the ratio of the maximum and minimum voltage gains of the feedback amplier.*



A5 (*a*) The sketch shows the hybrid equivalent circuit of the transistor. The voltage gain is defined as V_{out}/V_{in}, where V_{out} is the output voltage and V_{in} is the input voltage.

$$V_{in} = h_{ie}i_e \qquad \ldots\ldots \quad (1)$$

$$V_{out} = -i_c 5000 = -h_{fe}i_e 5000 \qquad \ldots\ldots \quad (2)$$

Thus, the voltage gain is $\dfrac{-h_{fe}5000}{h_{ie}}$. ...... (3)

∴ the maximum gain is $\dfrac{60 \times 5000}{1\cdot2 \times 1000} = \underline{-250,}$

and the minimum gain is $\dfrac{45 \times 5000}{1\cdot5 \times 1000} = \underline{-150.}$

The ratio of the maximum gain to minimum gain $= \underline{1\cdot67.}$

(*b*) The gain of the amplifier with feedback is given by,

$$A_f = \frac{A}{1 + \beta A},$$

where A is the modulus of the gain without feedback, A_f is the modulus of the gain with feedback, and β is the fraction of the input fed back to the input.

Thus, when $A = -250$, $A_f = \dfrac{250}{1 + 0\cdot02 \times 250} = 41\cdot7$

and, when $A = -150$, $A_f = \dfrac{150}{1 + 0\cdot02 \times 150} = 37\cdot5.$

∴ the ratio of the maximum gain to minimum gain $= \underline{1\cdot11.}$

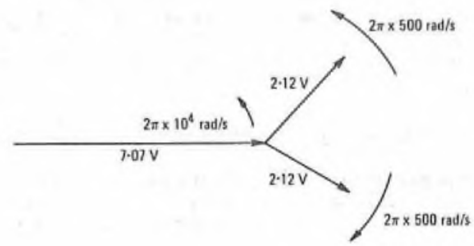
Q6 (*a*) *An amplitude modulated wave is given by,*

$$e_m = 10(1 + 0\cdot6 \sin 2\pi 500t) \sin 2\pi 10^4 t \text{ Volts}$$

Expand this expression to show that the wave comprises 3 separate frequency components and calculate each RMS value and frequency. What is the RMS value of the modulated wave?

(*b*) *Sketch a phasor representation of the amplitude-modulated wave.*

(*c*) *Calculate the instantaneous voltage of the wave when $t = 40\ \mu s$.*



A6 (*a*) Using the identity $\sin A \sin B = \frac{1}{2}\{\cos(A - B) - \cos(A + B)\}$,

$e_m = 10 \sin 2\pi 10^4 t + 3 \cos 2\pi 9\cdot5 \times 10^3 t + 3 \cos 2\pi 10\cdot5 \times 10^3 t.$

Therefore the components of the modulated wave are:

(*i*) 10 kHz with an RMS value of $10/\sqrt{2} = \underline{7\cdot07\ V,}$
(*ii*) 10·5 kHz with an RMS value of $3/\sqrt{2} = \underline{2\cdot12\ V,}$ and
(*iii*) 9·5 kHz with an RMS value of $3/\sqrt{2} = \underline{2\cdot12\ V.}$

The RMS value of the wave is

$$\sqrt{(7\cdot07^2 + 2\cdot12^2 + 2\cdot12^2)} = \underline{7\cdot68\ V.}$$

(*b*) The phasor diagram is shown in the sketch.

(*c*) The instantaneous value when $t = 40\ \mu s$ is

$$e_m = 10\{1 + 0\cdot6 \sin(360° \times 500 \times 40 \times 10^{-6})\} \times \sin(360° \times 10^4 \times 40 \times 10^{-6}),$$

$$= 10(1 + 0\cdot6 \sin 7\cdot2°) \sin 144°,$$

$$= 10 \times 1\cdot075 \times 0\cdot587 = \underline{6\cdot32\ V.}$$

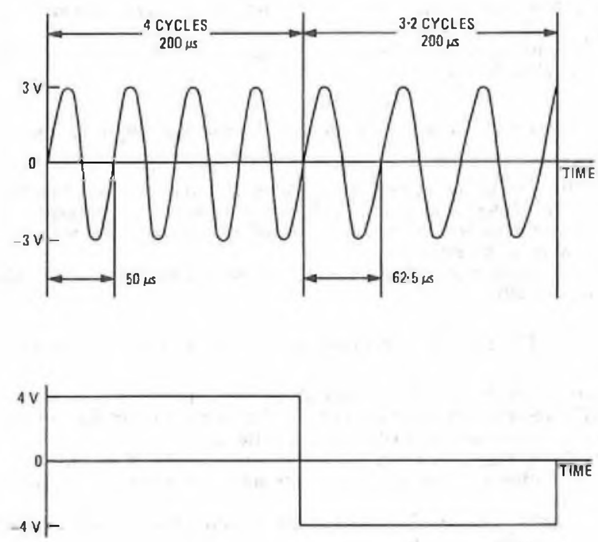
Q7 (*a*) *What is meant by frequency modulation of a sinusoidal carrier?*

(*b*) *An 18 kHz sinusoidal carrier having an amplitude of 3 V is frequency modulated using a modulator with a sensitivity of 500 Hz/V of modulating signal. The modulating signal is a 2·5 kHz square wave of amplitude ±4 V. Sketch the waveform of the modulated carrier over one cycle of the modulating signal.*

(*c*) *The modulating signal is replaced by a sine wave of amplitude 1·5 V and frequency 3 kHz. Write down an expression for the instantaneous voltage of the modulated wave.*

A7 (*a*) and (*c*) See A7, Telecommunication Principles C 1974, *Supplement*, Vol. 68, p. 55, Oct. 1975.

(*b*) The waveform is shown in the sketch.



Q8 (*a*) *Explain the factors which cause power loss in iron-cored inductors. Why does the total power loss increase with frequency.*

(*b*) *An iron-cored inductor may be represented by 0·5 H in parallel with a resistance which varies with frequency. When a 30 V, 200 Hz supply is applied to the inductor, the power dissipated is 45 mW. When* *the source frequency is increased to 400 Hz with the voltage maintained at 30 V, the power dissipated is 120 mW. Calculate for* EACH *frequency the value of the resistance and the power factor of the inductor.*

A8 (*a*) See A3, Telecommunication Principles C 1976, *Supplement*, Vol. 70, p. 54, Oct. 1977.

(*b*) The power dissipated in the inductor at any frequency is given by V^2/R, where V is the RMS value of the applied voltage and R is the parallel resistance at that particular frequency. Thus, at 200 Hz,

$$R_{200} = \frac{30 \times 30}{45 \times 10^{-3}} = \underline{20\ \text{k}\Omega},$$

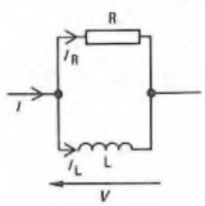
and at 400 Hz, $$R_{400} = \frac{30 \times 30}{120 \times 10^{-3}} = \underline{7 \cdot 5\ \text{k}\Omega.}$$

Sketch (*a*) shows the circuit diagram and sketch (*b*) the phasor diagram.

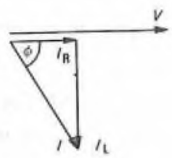
For a small power factor, $\cos\phi \approx I_R/I_L = L/R$.

Thus, at 200 Hz the power factor is $\frac{2\pi \times 200 \times 0 \cdot 5}{20 \times 1000} = \underline{0 \cdot 0314,}$

and, at 400 Hz the power factor is $\frac{2\pi \times 400 \times 0 \cdot 5}{7 \cdot 5 \times 1000} = \underline{0 \cdot 167.}$



(*a*)



(*b*)

Q9 (*a*) *A tuned amplifier has a maximum small-signal voltage gain of 45. A fraction of the output voltage is fed back to the input as positive feedback. What is the minimum value of this fraction for the circuit to act as an oscillator? Explain why the feedback factor is usually larger than the minimum in a practical oscillator.*

(*b*) *Sketch a circuit diagram for a practical oscillator and explain its operation.*

Q10 *The collector characteristics of a n p n transistor are given below.*

Collector–Emitter Voltage V_{EC} *(V)*	*Collector Current,* I_c *(mA), for base current,* I_b *(mA) =*						
	0	*1*	*2*	*3*	*4*	*5*	*6*
0	*0*	*0*	*0*	*0*	*0*	*0*	*0*
2	*0·75*	*31*	*61*	*91*	*91*	*91*	*91*
5	*1*	*32*	*65*	*97*	*129*	*160*	*192*
10	*1·5*	*33*	*67*	*99*	*131*	*165*	*198*
20	*2*	*35*	*70*	*104*	*136*	*170*	*204*
30	*2·5*	*37*	*74*	*108*	*140*	*176*	*210*

The transistor is so mounted that the maximum permitted collector dissipation is 1·6 W. It is to be used as the output stage of an amplifier with its collector connected to a 15 V DC supply in series with the primary of an output transformer.

(*a*) *Plot the characteristics and insert the dissipation curve.*

(*b*) *Select a suitable bias point and draw an AC load line for maximum output at moderate distortion.*

(*c*) *For a sinusoidal signal, estimate:*

(*i*) *the maximum output power,*
(*ii*) *the collector dissipation when the transistor delivers this power, and*
(*iii*) *the collector efficiency.*

TELEPHONY C 1977

Students were expected to answer any 6 questions

Q1 (*a*) *Explain how a transistor can be used to operate a heavily-loaded relay.*

(*b*) *What precautions are necessary to prevent damage to the transistor?*

(*c*) *How could the circuit be modified to provide a release period greater than 100 ms?*

A1 See A1, Telephony C 1975, *Supplement*, Vol. 69, p. 72, Oct. 1976.

Q2 (*a*) *For a local crossbar exchange, list the principal functions of an own-exchange transmission relay-group (TRG), or equivalent.*

(*b*) *What factors determine the number of such TRGs provided at a particular exchange?*

(*c*) *Explain why calls incoming from other exchanges use a different group of TRGs.*

A2 (*a*) The principal functions of a TRG on an own-exchange call are:

(*i*) connecting a calling subscriber to a register,
(*ii*) providing a transmission bridge with current-feeding to the calling and called subscribers' transmitters,
(*iii*) applying ringing current to the called subscriber's line,
(*iv*) returning appropriate supervisory tones to the calling subscriber,
(*v*) detecting called-subscriber-answer conditions, and disconnecting the ringing current,
(*vi*) applying a metering pulse to the calling subscriber's meter when the called subscriber answers, and commencing local-call timing,
(*vii*) providing a holding condition for the appropriate crosspoints for the duration of the call, and
(*viii*) detecting the clearing down of the calling subscriber, and releasing the crosspoints.

(*b*) The principal factors determining the number of such TRGs provided are:

(*i*) the number of subscribers connected to the exchange,
(*ii*) the average busy-hour calling rate for each subscriber,
(*iii*) the percentage of the total originating traffic destined for subscribers (or services) on the same exchange,
(*iv*) the minimum growth steps for TRGs,
(*v*) the amount of traffic each TRG can carry, and
(*vi*) the grade of service provided by the TRGs.

For example, if an exchange has 4000 subscribers with an average busy-hour calling rate of 0·05 erlangs of originating traffic, then the total originating traffic in the busy hour is 4000 × 0·05 = 200 erlangs.

If each TRG is capable of carrying 0·7 erlang of traffic, the total number of TRGs to be provided is 200/0·7 ≈ 286.

If the own-exchange percentage of the originating traffic is 25%, the number of own-exchange TRGs required is 0·25 × 286 ≈ 72, this number probably being rounded up to the next suitable growth step. (In practice, this number would be slightly reduced to allow for the specified grade of service.)

(*c*) Different types of TRG are needed for incoming calls because

(*i*) local-call timing is not required,
(*ii*) backward supervisory-signal repetition over the incoming junction is required,
(*iii*) standard central-battery conditions are required on the incoming junction, instead of subscriber's line-current feeding, and
(*iv*) the appropriate class-of-service signal indicating an incoming-junction call needs to be forwarded to the register to indicate how many digits are to be expected. If the exchange is within a non-director linked-numbering scheme, then own-exchange calls may have 6 digits, whereas incoming-junction calls will probably have only 4 digits.

Q3 (*a*) *For a TXE2 (small electronic exchange), explain how reed relays are assembled into basic units used to form a typical A-switch group.*

(*b*) *Show how the units are interconnected, and explain how the method adopted improves the distribution of traffic.*

(*c*) *What factors determine the size of an A-switch group?*

A3 (*a*) and (*b*) See A8, Telephony and Telegraphy A 1976, *Supplement*, Vol. 70, p. 51, Oct. 1977; and A10, Telephony C 1975, *Supplement*, Vol. 69, p. 75, Oct. 1976.

The distribution of traffic is improved by ensuring that each line circuit has access to any one of 5 A-switch-to-B-switch trunks, each trunk going to a different B-switch. Each B-switch has access to any one of 10 B-switch-to-C-switch trunks, with each trunk going to a different C-switch. Each C-switch has access to supervisory relay-sets and D-switches, so that each subscriber has possible access to every supervisory relay-set or D-switch in the exchange. Also, business and residential subscribers' lines are connected evenly over the A-switches to help give an even distribution of traffic.

(*c*) The size of an A-switch group is determined by

(*i*) the number of subscribers connected to the exchange,

(*ii*) the average busy-hour calling rate for each subscriber,

(*iii*) the average busy-hour terminating-traffic rate for each subscriber (since A-switches also carry terminating traffic), and

(*iv*) the amount of traffic each A-switch can carry.

Q4 (*a*) *What assumptions are made in the derivation of Erlang's full-availability formula?*

(*b*) *A full-availability group of 5 trunks is offered 2 erlangs of traffic. Determine*

(*i*) *the grade of service,*

(*ii*) *the traffic carried by the first trunk,*

(*iii*) *the traffic carried by the last trunk, and*

(*iv*) *the total traffic carried.*

A4 (*a*) The assumptions made in the derivation of Erlang's full-availability formula are that

(*i*) each circuit in a group can be tested by each source of traffic (that is, full-availability conditions must exist),

(*ii*) the traffic is of a purely random nature,

(*iii*) every call originating when all the trunks are busy is lost,

(*iv*) the holding time of these lost calls is zero,

(*v*) the traffic is at the average level for a large number of busy-hours, and

(*vi*) statistical equilibrium conditions exist (that is, during a very short interval of time, the total number of calls that terminate is, on average, equal to the number of calls that originate).

(*b*) (*i*) The grade of service, B, is given by

$$B = \frac{\dfrac{A^N}{N!}}{1 + A + \dfrac{A^2}{2!} + \dfrac{A^3}{3!} + \dots \dfrac{A^N}{N!}},$$

where A is the traffic offered (erlangs), and N is the number of circuits (or trunks).

$$\therefore\ B = \frac{\dfrac{2^5}{120}}{1 + 2 + \dfrac{2^2}{2} + \dfrac{2^3}{6} + \dfrac{2^4}{24} + \dfrac{2^5}{120}} = \frac{\dfrac{32}{120}}{\dfrac{872}{120}} = \underline{0 \cdot 037.}$$

(*ii*) The traffic carried by the first trunk

$$= \frac{A}{1 + A} = \frac{2}{1 + 2} = \underline{0 \cdot 67 \text{ erlang}}.$$

(*iii*) The traffic carried by the last trunk

$$= B(N - A) = 0 \cdot 037(5 - 2) = \underline{0 \cdot 11 \text{ erlang}}.$$

(*iv*) The total traffic carried is given by the traffic offered minus the traffic lost, where the traffic lost is the traffic offered multiplied by the grade of service. The traffic lost is $2 \times 0 \cdot 037 = 0 \cdot 074$ erlang. Hence, the traffic carried

$$= 2 - 0 \cdot 074 = \underline{1 \cdot 926 \text{ erlangs}}.$$

Q5 (*a*) *What are the relative merits of pulse correction and pulse regeneration?*

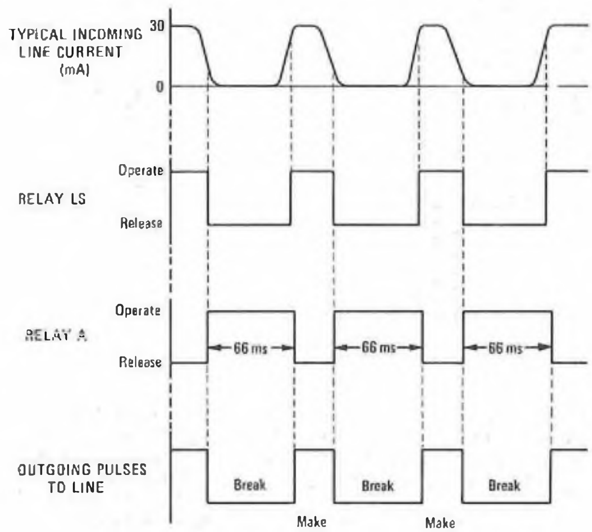
(*b*) *With the aid of circuit-element and pulse-waveform sketches, describe the principle of operation of a dial-pulse corrector.*

A5 (*a*) In pulse correction, existing pulses are individually corrected in respect of MAKE or BREAK timing without alteration to the speed of the pulse train. In pulse regeneration, a complete train of pulses (i.e., a digit) is stored and retransmitted (i.e., completely regenerated) at the correct speed and ratio.

Pulse correction has the advantage that the correction circuit is relatively simple, comprising only one or two relays (with associated components), but has the disadvantage that, unless the incoming pulses are at the correct speed, the MAKE to BREAK ratio of the outgoing pulses will be incorrect. Normally, pulse correction is used only on routes where the distant pulse-sending element is a mechanical device such as a register; usually a corrector giving a 66 ms fixed BREAK pulse is employed. Thus, if the incoming pulse speed happened to increase from 10 pulses/s to 12 pulses/s, the outgoing MAKE pulse would fall from 33 ms to about 16 ms, giving a MAKE to BREAK ratio of approximately 1 : 4 instead of the nominal 1 : 2.

Pulse regeneration has the advantage that, however distorted in speed and ratio the incoming pulses are (provided they can be recognized correctly), the outgoing pulses are transmitted at the correct speed and with the correct MAKE to BREAK ratio. Pulse regeneration is often used where the original sending element is a subscriber's dial. However, pulse regenerators have the disadvantage that the storage and regenerative circuitry tends to be somewhat complex, and therefore more expensive than that of pulse correctors.

(*b*) See A5(*c*), Telephony C 1973, *Supplement*, Vol. 67, p. 70, Oct. 1974. The pulse waveforms are shown in the sketch.



Q6 *For a typical in-band single-frequency signalling system,*

(*a*) *describe the signalling code,*

(*b*) *state what factors determine the duration of each signal, and*

(*c*) *say to what extent the signalling code assists in achieving voice immunity.*

Q7 *For a unit automatic exchange (UAX),*

(*a*) *describe how a single group of junctions can provide for both STD and non-STD calls from ordinary and coin-box subscribers to the group switching centre (GSC),*

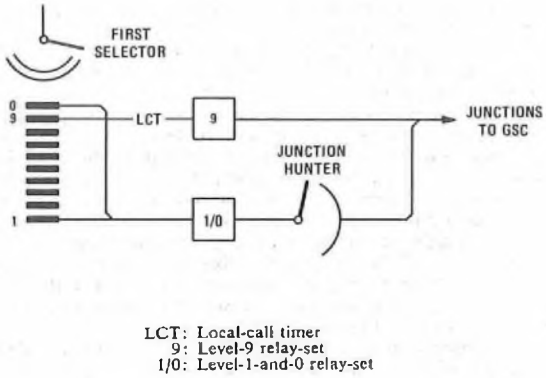
(*b*) *explain why this method of working is used, and*

(*c*) *explain in detail how coin-box discrimination is provided within the UAX.*

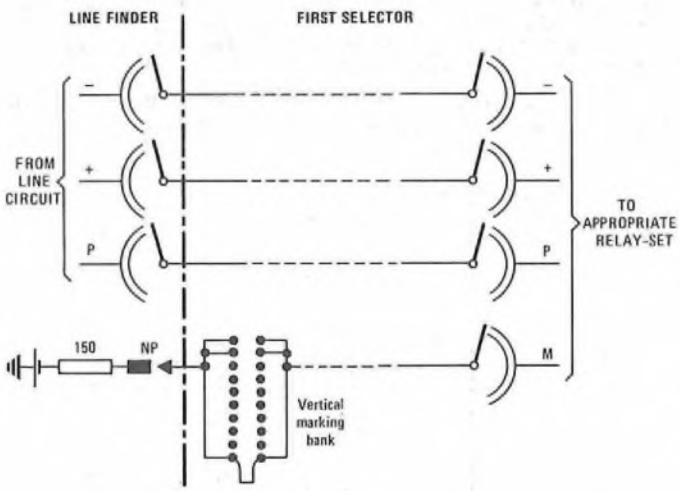
A7 (*a*) Sketch (*a*) shows the arrangements at a UAX which enable a single group of junctions to the GSC to be used for ordinary and coin-box subscribers, for both STD and non-STD traffic.

Non-STD calls (except calls to the operator) are routed via a level-9 relay-set, the facilities of which are largely those of a general auto-to-auto relay-set with the addition of a digit-barring facility for unauthorized codes. If an ordinary or coin-box subscriber dials 9, a level-9 relay-set is seized, together with an outgoing junction to the GSC. Further digits are repeated to the GSC.

Non-STD calls to the operator (or to other service codes) are routed via a level-1-and-0 relay-set. If an ordinary or coin-box susbcriber dials a 1*XX* code, a level-1-and-0 relay-set is seized from level 1 of the first selector; the second and, possibly, third digits are examined and, provided the code is authorized, an outgoing junction to the GSC is seized via the junction hunter. The 1*XX* code is repeated to the GSC.



(*a*)



(*b*)

STD calls are also routed via a level-1-and-0 relay-set. If an ordinary or coin-box subscriber dials 0, a level-1-and-0 relay-set is seized from level 0 of the first selector, and an outgoing junction to the GSC is seized via the junction hunter upon receipt of the next BREAK pulse. The relay-set forwards the digit 0 to the GSC. Subsequent digits, including a class-of-service digit, are then repeated forward.

(*b*) See A2(*c*), Telephony C 1975, *Supplement*, Vol. 69, p. 72, Oct. 1976.

(*c*) In a UAX, all coin-box subscribers are connected to the same level of the line finders. Normal-post (NP) springs operate when a line finder is on that level. Thus, if a call originates from a coin-box subscriber, the line finder concerned will be on, for example, level 8, and the NP springs extend a 150 Ω battery condition to the vertical marking bank in the first selector. For levels 1, 9 and 0, this condition is further extended via the first selector's M-wire to the appropriate relay-set for discrimination purposes. (Other levels requiring coin-box discrimination are strapped as required on the vertical marking bank.) The arrangements are illustrated in sketch (*b*).

Q8 STD is to be introduced into a small country. The telephone population is expected to grow to about 1-million connexions served by about 1000 exchanges.

(*a*) *Devise a suitable numbering and charging scheme.*
(*b*) *Explain how the exchanges are to be interconnected.*
(*c*) *Describe how a long-distance call will be set up.*

A8 (*a*) The following assumptions are made:

(*i*) that the country is divided into 100 charging-group areas,

(*ii*) 10 charging groups are in high-telephone-density areas, and the remaining 90 charging groups are in low-telephone-density areas,

(*iii*) each high-density charging group (HDCG) has 10 large exchanges, one being designated the central large exchange,

(*iv*) each low-density charging group (LDCG) has one large and 9 small exchanges, and

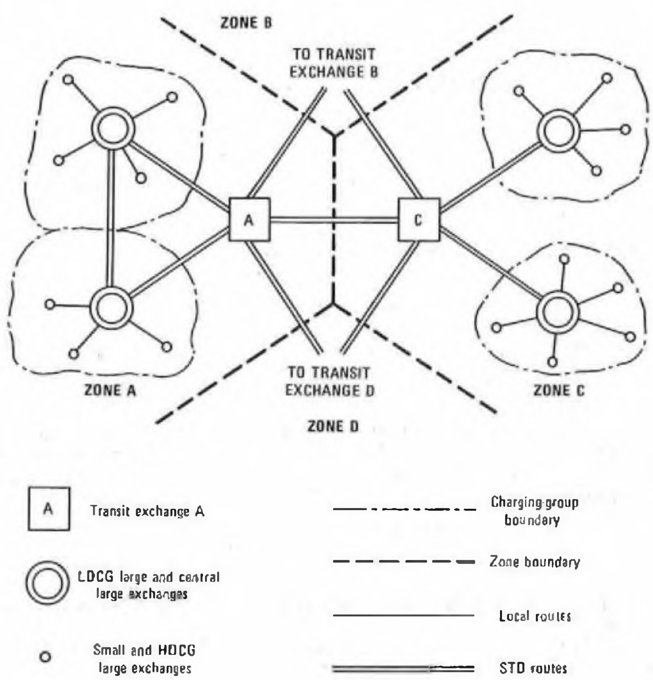
(*v*) 70% of the telephone connexions are to large exchanges, with the remaining 30% being to small exchanges.

Thus the number of large exchanges is $(10 \times 10) + (90 \times 1) = 190$, and the number of small exchanges is $90 \times 9 = 810$. Hence there will ultimately be $700\,000/190 \approx 3700$ connexions per large exchange, and $300\,000/810 \approx 370$ connexions per small exchange.

Assuming the country to have a simple Strowger telephone system, the numbering scheme could be as shown in the table below.

Levels	Small Exchanges	LDCG Large Exchanges
1	Service codes (via LDCG large exchange)	Service codes
2–5	370 subscribers in range 2*XX*–5*XX*	3700 subscribers in range 2*XXX*–5*XXX*
6–8	Spare	Spare
9	Access to LDCG large exchange	Access to LDCG small exchanges via 9*X* codes
0	STD access via LDCG large exchange	STD access

Levels	HDCG Large Exchanges	Central Large Exchanges
1	Service codes (via central large exchange)	Service codes
2–5	3700 subscribers in range 2*XXX*–5*XXX*	3700 subscribers in range 2*XXX*–5*XXX*
6–8	Spare	Spare
9	Access to central large exchange	Access to HDCG large exchanges via 9*X* codes
0	STD access via central large exchange	STD access



Each charging group can be allocated a 2 or 3-digit national-number-group (STD) code as shown below. (The code would be prefixed by the STD access code, 0, and suffixed by the called subscriber's number. The ISD access code would be suffixed by the appropriate country code.)

1, 3, 5–9: Spare
$2X$: Allocated to HDCGs
$4XX$: Allocated to LDCGs
0: ISD access.

Thus, a subscriber connected to a central large exchange could have a national number (including the STD-access digit) of the form $0\,2X\,2XXX$; a subscriber connected to an HDCG large exchange, $0\,2X\,9X\,3XXX$; an LDCG large-exchange subscriber, $0\,4XX\,4XXX$; and a small-exchange subscriber, $0\,4XX\,9X\,5XX$.

Local (non-STD) calls would be charged at a fixed local rate, calls within a charging group being classified as local. Calls between charging groups (i.e., calls prefixed by the STD-access code, 0) would be trunk calls.

For trunk calls, charging could be based on distance and time, with the number-group code being examined to determine the distance, and hence the charge rate to be applied. If periodic metering is used, then the charge rate determines the periodicity of metering.

(*b*) The sketch shows how LDCG large exchanges and central large exchanges might be interconnected for routing STD calls. Each is connected to a transit exchange, and to other LDCG and central large exchanges where traffic justifies a direct route. The country is divided into 4 zones, each with one transit exchange, and each transit exchange has direct access to the other three.

(*c*) STD (long-distance) calls are those which involve 2 charging groups; it can be seen from the sketch that there are 3 possible types of long-distance routing, one involving 2 transit exchanges, one involving one transit exchange, and one involving only LDCG or central large exchanges.

Digit 0 gives access to STD equipment in LDCG-large or central-large exchanges. The equipment examines the number-group codes for charging and routing purposes, and then forwards routing digits followed by the called subscriber's number.

Note: Students would not be expected to give such a full description of the local numbering schemes. The information has been included here for educational purposes, to complement the description of national numbering.

Q9 (*a*) *With the aid of sketches of circuit elements, describe how periodic-metering facilities are provided on local calls.*

(*b*) *Describe the sequence of operation for periodic metering on an STD call.*

(*c*) *Explain how meter pulses can be transmitted between exchanges.*

A9 See A2, Telephony C 1976, *Supplement*, Vol. 70, p. 61, Oct. 1977.

Q10 *A telephone exchange is provided with call-failure-detection equipment.*

(*a*) *What are the uses and limitations of this type of equipment?*

(*b*) *With the aid of a block diagram, describe its principle of operation.*

(*c*) *Show, on a typical exchange trunking diagram, where it may be connected.*

TELEGRAPHY C 1977

Students were expected to answer any 6 questions
The use of a pocket calculator was permitted where appropriate

Q1 *For a subscriber's Telex station equipment, draw a diagram and explain the circuit operation for*

(*a*) *calling the exchange,*
(*b*) *transmitting dial pulses,*
(*c*) *taking a local record of teleprinter signals, and*
(*d*) *clearing the call.*

Q2 *Explain, with the aid of a block diagram, the main purposes of* EACH *of the following in an intercontinental Telex exchange.*

(*a*) *A 1–5 wire converter.*
(*b*) *A selection transmit unit.*
(*c*) *A keyboard register.*
(*d*) *A translator.*
(*e*) *A marker relay-set.*

Q3 *A document typed on A4-size paper (210 × 297 mm) is to be sent by facsimile telegraphy.*

(*a*) *Describe, with the aid of sketches, the operation of a suitable transmitter.*

(*b*) *If the machine has a scanning rate of 180 lines/min and a pitch of 0·265 mm, calculate the time taken to transmit the document if the paper is loaded with the longer side along the axis of the drum.*

(*c*) *What is the minimum time to transmit the same information by Telex, assuming 60 full lines each of 10 words.*

A3 (*a*) See A9, Telegraphy C 1971, *Supplement*, Vol. 65, p. 37, July 1972.

(*b*) Each revolution of the drum causes it to move longitudinally 0·265 mm; that is, one line. For a rate of scanning of 180 lines/min, the drum will move longitudinally

$$180 \times 0{\cdot}265 \text{ mm} = 47{\cdot}7 \text{ mm/min.}$$

Hence the time required to transmit the document is

$$297 \div 47{\cdot}7 = \underline{6{\cdot}2 \text{ min}}.$$

(*c*) For Telex the speed of signalling is 50 bauds, that is each signal element has a duration of 1 s ÷ 50 = 20 ms. Each character comprises $7\frac{1}{2}$ elements and has duration $7\frac{1}{2} \times 20 = 150$ ms. An average word is 6 characters, hence one line is 60 characters. The time taken to transmit 60 lines is

$$60 \times 60 \times 150 \text{ ms} = \underline{9 \text{ min}}.$$

In practice, at the end of each of 59 lines the characters CARRIAGE RETURN and LINE-FEED will require to be sent in place of word space.

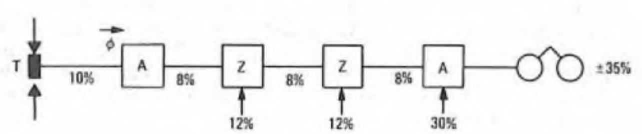
$$\therefore \quad \text{total time} = 9 + \frac{59 \times 150}{1000 \times 60} \text{ min},$$

$$= \underline{9 \text{ min } 8{\cdot}85 \text{ s}}.$$

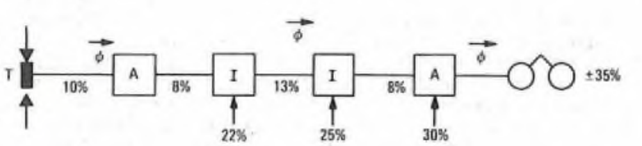
Q4 (*a*) *Sketch and explain the Telex transmission plan with typical distortion values for*

(*i*) *inland calls, and*
(*ii*) *international calls*

(*b*) *Describe the operation of equipment which would be added to a circuit where the distortion is outside the limit.*



INLAND



INTERNATIONAL

$\vec{\phi}$: Position at which regenerative repeater can be inserted, with direction of transmission indicated
A: Area exchange
I: International exchange
Z: Zone exchange

A4 (*a*) The sketch shows typical limiting connexions for an inland and an international Telex call. The values of permissible distortion are shown for a call originating at the left-hand teleprinter in each case. Typical distortion limits for various sections of the line or of the equipment are as follows:

one voice-frequency channel	8%,
teleprinter transmitter	5%.

For values of distortion of circuits in tandem, the RMS value is taken; the following table gives the CCITT recommendations for limiting values of start-stop distortion.

Distortion on entry to the long distance network	12%
Distortion at the input of the distant local section	30%
Distortion at the exit from the national network	22%
Distortion of the international trunk circuit	13%

The purpose of the transmission plan is to ensure that, under normal circumstances, no combination of switching paths can distort the transmitted signal by more than $\pm 35\%$, which is the lower limit of the margin of a teleprinter in correct adjustment. Where a combination of circuits can produce more distortion than is permissible, a regenerative repeater is installed at a suitable point, shown in the sketch. The repeater regenerates the distorted signal and re-transmits each character with zero distortion.

(*b*) See A2, Telegraphy C 1973, *Supplement*, Vol. 67, p. 78, Jan. 1975.

Q5 *Describe briefly how the following may be employed to reduce the incidence of distorted or mutilated telegraph signals on a long-distance high-frequency (HF) radio-telegraph circuit:*

(*a*) *two-tone working,*
(*b*) *frequency diversity,*
(*c*) *synchronous transmission, and*
(*d*) *error-detecting code.*

A5 Signals on long-distance HF radio-telegraph circuits can suffer distortion and mutilation due to a number of reasons. The signals could suffer from fading, which is a variation in receiver signal strength due to variation in the conditions of propagation with time; from multi-path propagation, which results in two or more signals arriving at instants differing by up to one or two milliseconds, having traversed different paths; and from noise or interference which can seriously affect a signal which is fading. To reduce distortion and mutilation the following methods are applied.

(*a*) *Two-tone Working*. It has been found that more satisfactory reception is achieved if a signal is always present on a radio path and a two-tone system, using one tone for the MARK and a different tone for the SPACE signal, is used. By this method, a common level control for both frequencies can be used, as a tone is always present to control the gain. The frequencies of the tones are normally close, so that fading or noise affects both equally, and the effects therefore tend to be self-cancelling; providing a reasonable signal-to-noise ratio is maintained, a satisfactory service can be obtained.

(*b*) *Frequency Diversity*. Fading on a radio circuit is often selective, to the extent that one circuit may be severely affected while a similar circuit, with a frequency separation of only a few hundred hertz, may work satisfactorily. By combining two channels, separated by 600 Hz or more, to operate in parallel, and selecting the best signal at the receiver at any instant, an improvement can be made in the received message. At the same time, noise and the weak signal from the channel subject to fading are suppressed. A disadvantage of the system is that a wider bandwidth is required and a penalty is paid in a reduction in the permissible power per tone and hence in the signal-to-noise ratio. This disadvantage can be overcome by using space diversity, whereby the aerials which transmit the two signals simultaneously are separated by a short distance.

(*c*) *Synchronous Transmission*. For a 50 baud start-stop character, the timing for examining the polarity of each of the character elements is derived from the leading edge of the START element. The leading edge of this element may (and probably will) itself be distorted, with the result that the examination instants may not occur at the mid-point of each signal element and could be advanced or retarded according to the amount of distortion of the start element. In this way a character element may be mis-read and mutilation result. A synchronous system times the examining instants as an average of many transitions so that the optimum time is always chosen near the theoretical centre of each element, allowing the element under detection to have the highest possible distortion value. The synchronous system also has the advantage that it cannot readily be thrown out of synchronism due to excessive distortion, and will withstand a worse level of noise for a given error rate. A further advantage is that all signals transmitted by a synchronous system are regenerated at the output. The disadvantages of a synchronous system are that it is costly and complicated.

(*d*) See A9(*c*), Telegraphy C 1976, *Supplement*, Vol. 70, p. 68, Oct. 1977.

Q6 (*a*) *Describe, with the aid of a sketch, the operation of a docket printer suitable for recording faults found by automatic routiners.*

(*b*) *Draw a sketch of a typical fault docket, labelling each entry and section.*

(*c*) *Describe briefly the sequence of operations if two routiners each are required to print a docket simultaneously.*

A6 (*a*) Sketch (*a*) shows the operation of a docket printer suitable for use with an automatic routiner.

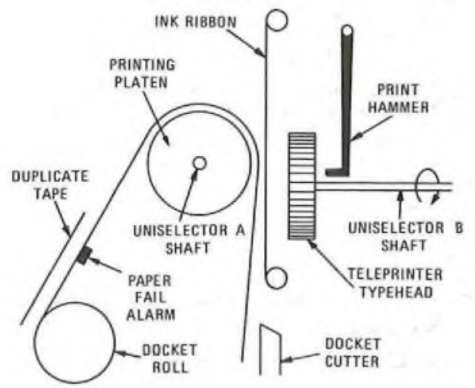
The docket printer consists of two uniselector mechanisms, one of which (A) drives the printing platen, the other (B) drives the typehead. The dockets are supplied in a roll which is fed over the printing platen; a hole in the docket allows a sensing arm to drop into a groove in the platen and give an electrical indication of the exact position of each docket. Each uniselector is controlled by marking the banks so that uniselector A positions the docket in the correct place for printing the character selected by uniselector B on the typehead.

When a fault is detected by a routiner, the routiner is connected to the docket printer by the routiner-fault-translation-and-docket-machine control equipment. Signals detailing the characters to be printed are fed, one at a time, to the recorder, where a docket will be in position for the first character to be printed. The typehead revolves to the position marked on the bank of uniselector B, corresponding to the character to be printed, and the print hammer operates. The platen steps to the next position ready for the next character, and the cycle is repeated until all characters have been printed on the docket. The docket is then automatically moved on, a second docket is moved into position and the control equipment is ready to process another fault. The dockets are separated by the docket cutter and stacked for issue to the maintenance staff.

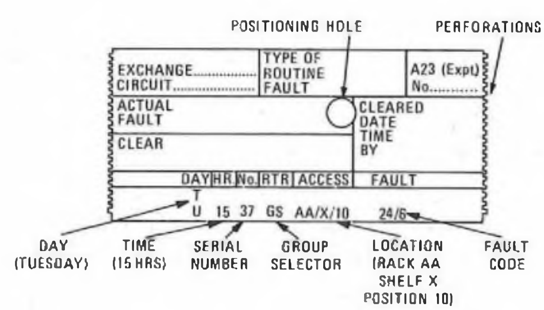
A control duplicate tape may also be used; this is fed over the dockets and takes the printing. The duplicate tape is backed with carbon so that the docket receives a carbon copy; the duplicate tape is fed to a take-up spool and does not pass through the docket cutter.

(*b*) Sketch (*b*) shows a typical fault docket.

(*c*) If two routiners try to seize the docket printer at the same time, the routiner hunter in the control equipment will connect the routiner in the earlier position on the hunter banks and print the docket. When the DOCKET COMPLETE signal is received, the hunter will search for the second routiner and process that fault. If the delay in connecting the second routiner is prolonged, an alarm is given.



(*a*)



(*b*)

Q7 (a) Describe a method of checking the receive margin of a teleprinter and explain why it is important that the margin to early and late signals should be equal.

(b) Describe THREE *defects of a teleprinter which could affect the margin.*

(c) A 50 baud teleprinter has a selection period of 4·0 ms. If the motor of the machine is 1% slow,

(i) draw a timing diagram to show the action of the selecting mechanisms, and

(ii) calculate the margin of the machine to incoming signals.

A7 (*a*) When a signal has been transmitted over a line it suffers from distortion, and the transitions in the signal rarely occur at the ideal instants; the receiver must therefore be capable of accepting signals which are distorted. The capability of a receiver to translate distorted signals correctly is known as the *margin* of the receiver, and must be tested from time to time in order that the receiver may be adjusted to maximum efficiency.

To test the margin of a receiver, a test message is transmitted to the machine from a central point. The amount of distortion in the test message is varied until the received copy begins to be mutilated; this determines the margin. The CCITT recommends that the margin should be measured by using the sentence THE QUICK BROWN FOX JUMPS OVER THE LAZY DOG transmitted with identical distortion on all transitions, obtained firstly by lengthening the START signal and secondly by repeating the test with a shortened START signal. The messages are repeated with increasing values of distortion. The margin is numerically equal to the distortion which results in less than one error per test sentence and is the lesser of the two values of early and late distortion. Modern teleprinters have a margin in excess of 40% and electronic machines can approach 50%.

As distortion on a circuit may be early or late for any given signal, or may be early or late for any received message, it is better that a receiver has an equal margin to either type of distortion. In this way, a teleprinter will not fail to signals of, say, early distortion while having an excessive margin to distortion of opposite value.

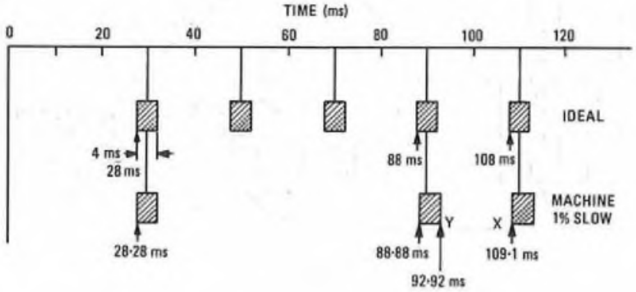
(*b*) The margin of a teleprinter may be affected by many factors, three of which are described below:

(*i*) All electro-mechanical teleprinters have many linkages, cams, rollers and levers in the receiver selection section of the machine. A new teleprinter has certain manufacturing tolerances built-in to the mechanical parts during manufacture to avoid undue costs due to matching individual parts; the tolerances also allow for items to be replaced from stock. Thus, the mechanisms of a new teleprinter have a certain amount of play, which increases due to wear during the lifetime of the machine. The wear may cause a linkage or cam to act slightly later than the optimum timing, such that a badly distorted signal may be mutilated because it is on the limit of the machine.

(*ii*) The receive magnet of the machine may be out of adjustment, so that the tongue may take longer to react to a negative signal than to a positive signal. This is known as bias and, however good the mechanical portion of the machine, receive-magnet bias causes a reduction in margin before the first machine linkage is operated. The bias may be due to mechanical reasons, for example the lack of neutrality in adjustments, or to electrical reasons, for example residual magnetism or earth currents.

(*iii*) The speed of the motor may also affect the margin of a teleprinter, and this is illustrated in part (*c*) below.

(*c*) (*i*) The timing diagram is shown in the sketch. For 50 baud signals, each character element has a nominal duration of $\frac{1000}{50} = 20$ ms and, if the selection period is 4 ms, this should occur 2 ms before to 2 ms after the theoretical mid-point of each element. The effect of a reduction in motor speed is cumulative during the character and has maximum effect at points Y and X. Each selection period is delayed by 1%; for example the first selection period starts at $(30 - 2) + \frac{1}{100}(30 - 2) = 28 \cdot 28$ ms and ends at 32·32 ms. Similarly, point Y will occur at $92 + \frac{1}{100} \times 92 = 92 \cdot 92$ ms and point X will occur at $108 + 1 \cdot 08 = 109 \cdot 08$ ms.



(*ii*) Margin is the capability of accepting late or early transitions which do not occur in the selection period. For point X the margin is

$$109 \cdot 08 - 100 = 9 \cdot 08 \text{ ms}$$

or $$\frac{9 \cdot 08}{20} \times 100 = 45 \cdot 4\% \text{ to late signals.}$$

For point Y, the margin is

$$100 - 92 \cdot 92 = 7 \cdot 08 \text{ ms,}$$

$$= \frac{7 \cdot 08}{20} \times 100 = 35 \cdot 4\% \text{ to early signals.}$$

The margin of the machine is therefore quoted as 35%, compared with a margin of 40% if the motor was running at the correct speed.

Q8 Describe the application of the following to a telegraph message switching centre:

(a) serial numbering,
(b) multi-address traffic,
(c) message format, and
(d) duplex circuit operation.

A8 (*a*) A serial number normally forms part of the heading of a telegraph message where, for any reason, the message is sent over a circuit which gives the originator no assurance that the message has reached the distant terminal. Serial numbers are given to each message sent via that circuit and are checked at the distant terminal either manually, using a tick sheet, or automatically. The absence of one of the numbers in a series indicates a lost message or identifies a badly mutilated message and, as copies are normally retained at the transmitting station, the message may be retransmitted.

(*b*) Multi-address traffic consists of messages which have more than one destination. This is indicated in the preamble to the message by listing the addresses to which the message must be sent; if several addresses are available at the next station, the list of addresses is limited accordingly before retransmission. The practice of using one message for multi-address work saves the originating operator from sending many separate messages, and has a corresponding economy in line utilization. At the receiving station, the multi-address message may be treated in different ways depending on the type of centre. For a manual re-transmission centre, the message is taken to a *tape factory*, where sufficient copies are made by local transmission from an automatic transmitter to a number of printing reperforators, so that individual messages can be sent to each address. At a semi-automatic centre, the circuits may be seized at a broadcast position and the message broadcast once to all stations. A fully-automatic system stores the message in the centre and transmits to each addressed circuit as it becomes free; alternatively a number of circuits may be seized if free and a broadcast message transmitted.

(*c*) See A8 (*d*), Telegraphy C 1976, *Supplement*, Vol. 70, p. 67, Oct. 1977.

(*d*) Duplex operation of a circuit is the name given to a method of operation whereby messages may be transmitted in both directions at the same time. This has the obvious attraction for high-cost, heavy-usage, long-distance circuits, in that the traffic may be doubled compared with a simplex circuit. A disadvantage is that no immediate assurance can be given that the message is reaching the distant terminal and serial numbering has to be used. Duplex operation is normally adopted between relay centres, but is not normally used on local circuits.

Q9 For a frequency-shift (frequency-modulated) multi-channel voice-frequency telegraph system:

(a) draw a circuit diagram and explain,

(i) how the carrier frequency is generated, and
(ii) how the carrier frequency is varied according to the incoming teleprinter signals.

(b) sketch graphs to show the relationship between the DC input and the output frequency of the oscillator-modulator.

A9 (*a*) See A3, Telegraphy C 1971, *Supplement*, Vol. 65, p. 35, July 1972.

Q10 (a) Under what circumstances may a band-pass filter be required for the transmission of telegraph signals?

(b) Sketch the impedance characteristics of this type of filter.

(c) Explain how the filter will attenuate signals at certain frequencies and will pass signals at other frequencies.

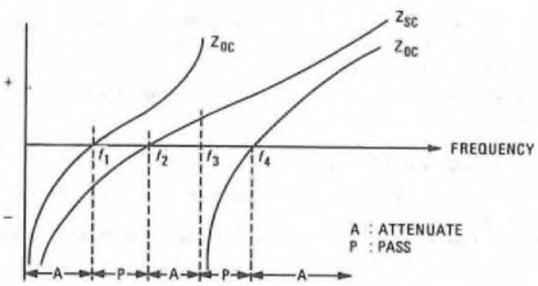
(d) What other type of filter is used in a telegraph circuit and what is its purpose?

A10 (*a*) Multi-channel voice-frequency telegraphy is a system which permits the simultaneous transmission of a number of telegraph messages over a telephony circuit without interference between the separate transmissions. The system employs frequency-division principles, whereby a different carrier frequency is allotted to each channel of transmission and the message is sent by modulating the carrier frequency; in this way, up to 24 different frequencies may be present on the circuit. The channels are separated electrically by the use of band-pass filters, each of which permits signals within a narrow band of frequencies to pass, while severely attenuating signals outside the band. Filters are provided at the input to each channel, before the channels are combined, so that only signals of the required frequency are transmitted to line. The filter restricts the sidebands of the modulated carrier frequency, offers high impedance to line at the operating frequencies of other channels so that one channel does not draw appreciable energy from other channels, and prevents the transmission of unwanted harmonics which may be present. Similar filters are also provided at the receive terminal of the system to select the band of frequencies required for the particular channel.

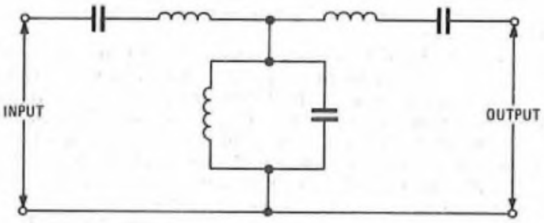
A square-wave telegraph signal may be considered as consisting of the sum of the fundamental frequency of the signal and all the odd harmonics of that frequency. When such a signal is used to modulate a carrier frequency, it is necessary to transmit only the signal resulting from the carrier frequency and the sidebands of the fundamental frequency. With a carrier frequency of, say, 900 Hz and modulating telegraph signals at a speed of 50 bauds, the products of modulation would include the 900 Hz carrier frequency and the side-frequencies 900 ± 25 Hz, 900 ± 75 Hz, 900 ± 125 Hz etc. The first 2 side-frequencies only are required; these have a bandwidth of 50 Hz and a channel spacing of 120 Hz allows a conservative design of the system.

(*b*) The impedance characteristics are shown in sketch (*a*).

(*c*) Sketch (*b*) shows the components of a typical band-pass filter. Ideally the elements of a filter are non-dissipative, that is no power is absorbed in the filter. As the frequency of the input signal is increased, the impedance as seen at the input (Z_{in}) varies from resistive to reactive at certain frequencies. When Z_{in} is resistive, the generator must deliver power but, as the filter is non-dissipative, the power is passed by the filter to the load; the range of frequencies over which this occurs is known as the *pass band*. Conversely when Z_{in} is reactive, no power is taken from the generator and none is delivered to the load; this is known as the *stop band*.



(*a*)



(*b*)

Now, Z_{in} is the geometric mean of the impedance of the filter measured with the output open circuit (Z_{oc}) and the impedance measured with the output short-circuit (Z_{sc}). When Z_{oc} is opposite in value to Z_{sc}, Z_{in} approaches zero, and a pass band is indicated. When Z_{in} has a positive or negative value, the filter acts as an attenuator.

(*d*) A low-pass filter is also used in telegraphy. This is installed between a DC transmitter and a physical circuit when the latter is routed in a telephone cable. A DC telegraph signal contains all the odd harmonics to infinity of the fundamental frequency, and harmonics which occur in the speech band could cause interference in the form of a series of clicks in neighbouring telephone pairs. The low-pass filter allows the third (75 Hz) and fifth (125 Hz) harmonics of the 50 baud fundamental frequency of 25 Hz to pass but attenuates all frequencies above about 140 Hz.

LINE PLANT PRACTICE C 1977

Students were expected to answer any 6 questions.
The use of electronic calculators was permitted where appropriate

Q1 What is meant by,

(a) the tensile strength of a material and how is it measured,
(b) the shear strength of a material and how is it measured,
(c) the elasticity of a material and how is it measured,
(d) ductility, and
(e) fatigue?

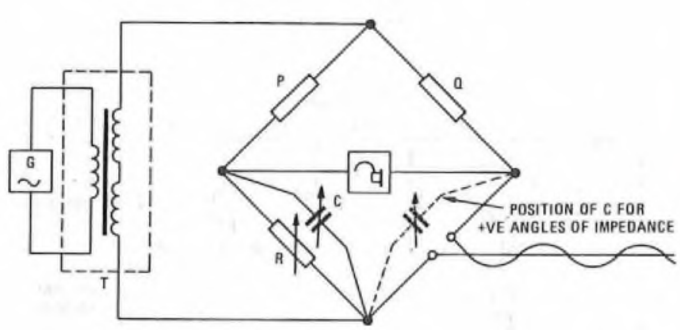
Q2 A fault is suspected in a loading coil in a cable route. Describe in detail the equipment and method used to carry out an impedance/frequency test to locate the fault.

A2 An impedance/frequency test would be used to locate a faulty loading coil in a cable route. The following apparatus is used:

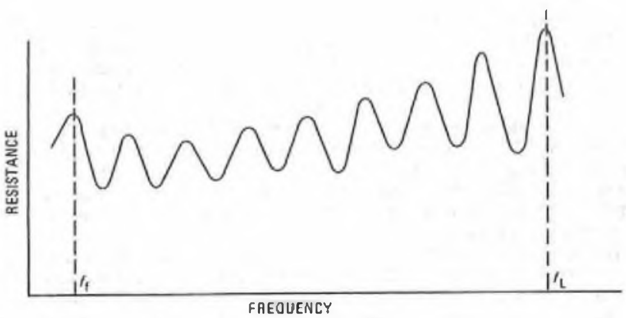
(*i*) 2 non-reactive ratio arms, 1000 + 1000 Ω (P and Q),
(*ii*) variable capacitors, 0–1 μF and 0–1200 pF (together making capacitor C),
(*iii*) variable resistor, 11 110 Ω (R),
(*iv*) balanced and screened transformer (T),
(*v*) headphones, and
(*vi*) continuously variable oscillator, 300–3000 Hz.

The apparatus is assembled as shown in sketch (*a*), the variable capacitor, C, being connected in parallel with the variable resistor if the angle of the impedance is negative, or in parallel with the line if the angle is positive.

The faulty line under test is closed at its far end with its characteristic impedance, usually by extending the line with similar pairs to obtain infinite-line conditions. The oscillator is then set to a convenient frequency in the range 300–2000 Hz, and R and C adjusted until the bridge is balanced; that is, silence is obtained in the headphones. The procedure is then repeated at regular frequency steps, usually 100 Hz, in the range 300–2000 Hz. The upper frequency limit must not exceed



(*a*)



(*b*)

75% of the cut-off frequency of the line. The value of R at each frequency is then plotted against frequency as shown in sketch (*b*). It may be necessary to take further readings at other frequencies in order that the maxima and minima are determined accurately. The mean frequency-interval, F, between peaks is then calculated by dividing the frequency difference between the first and last peaks by the number of intervals. In the example shown this is

$$F = \frac{f_L - f_1}{8}.$$

The distance to the fault is then calculated from the relationship $X = \frac{k}{F}$, where X is the distance to the fault in kilometres and k is a constant. The constant, k, can be determined by introducing a similar fault at a known position on an otherwise good pair and making an impedance/frequency test as described above.

The fault is confirmed by breaking down the joints on both sides of the loading coil and measuring the inductance of the coil using an AC bridge.

Q3 (a) Explain the term pneumatic resistance as applied to a cable-pressurization scheme.

(b) The pneumatic resistance of a cable having 0·5 mm conductors is 60 mbar h/g km for each 100 pairs. If the cable has 800 pairs, calculate the rate of air flow under conditions of maximum leak at the far end of a 500 m length if air is applied at a pressure of 600 mbar at the exchange end.

A3 (*a*) The pneumatic resistance of a cable is the resistance to gas flow through the spaces between the insulated conductors of the cable. The pneumatic resistance of a cable depends upon the length, size and type of cable concerned.

The rate of gas flow, Q_m grams/hour is given by,

$$Q_m = \frac{P}{R_{pn}} \text{ g/h},$$

where P is the pressure difference between the two ends of the cable (in millibars) and R_{pn} is the pneumatic resistance. Pneumatic resistance has the units millibars × hours/grams. However, it is often expressed for a 1 km length of cable containing 100 pairs since the total pneumatic resistance is proportional to length and the number of pairs. This is then abbreviated to mbar h/g km per 100 pairs.

(*b*) The total pneumatic resistance is given by

$$R_{pn} = 60 \times \frac{500}{1000} \times \frac{100}{800} = 3\cdot75 \text{ mbar h/g}.$$

Thus, $$Q_m = \frac{600}{3\cdot75} = \underline{160 \text{ g/h}}.$$

Q4 (a) Give reasons why site supervision is required on a civil engineering contract.

(b) Describe SIX duties which the supervisor would be expected to carry out during the period of work.

Q5 (a) What is prestressing in relation to concrete?

(b) Describe creep in pre-stressed concrete and say how its effect is reduced.

(c) Describe how a small pre-stressed slab would be constructed.

A5 (*a*) Pre-stressing is a technique of construction whereby initial compressive stresses are set up in a member to resist, or annul, the tensile stresses produced by the load. Since concrete is a material with a high compressive strength and a relatively low tensile strength, the advantages of pre-stressing are considerable. In pre-stressed concrete, up to the limit of the working load, the steel pre-stressing wires are not used for reinforcement, but as a means of producing a compressive strength in the concrete. A member made of pre-stressed concrete is permanently under compression, the stress varying with the load between chosen maxima and minima. As a consequence, there is complete avoidance of cracks under normal loads, and, under an overload, provided it is not greater than the elastic limit, any cracks that occur will close up again without deterioration of the structure. One advantage of pre-stressing is that, under dead load, a section may be designed to the minimum concrete stress at the bottom fibres. When the live load is applied, the stresses are reversed, giving the maximum concrete stress at the top fibres, and the minimum concrete stress at the bottom fibres.

With pre-stressed concrete, it is possible to obtain lighter members than with reinforced concrete, and considerable savings of concrete and steel are effected.

(*b*) Creep, in both steel and concrete, is an important factor in pre-stressing. A steel wire, held under stress shows an increase in length over a period of time. A loss of stress due to a creep of 15–20% is often allowed for in a pre-stressed structure, but the magnitude of the creep can be reduced by subjecting the wires to a brief overload before use. Creep also occurs in concrete, but this is often a useful property in that it enables a readjustment of stress to take place when local stresses of high intensity might, otherwise, result in failure of the structure.

(*c*) For casting a small pre-stressed slab, the pre-tensioning process would be used with advantage.

In the pre-tensioning process a high-tensile-steel wire is stressed by means of hydraulic jacks, or some other mechanism, and firmly held by wedges. The concrete is then cast around the steel wire and allowed to set. When the concrete is fully hardened, the wedges are removed and the stress is therefore transferred from the wires to the concrete, due to adhesion between the steel and the concrete.

Q6 A cable is to be pulled into a duct from E to W. The duct runs straight for 70 m up a slope rising to 12 m, it then levels out to another straight section of 36 m and then bends round a short 26° arc followed by a straight horizontal section of 28 m. The cable weighs 50 N/m and the coefficient of friction between duct and cable is 0·4. Calculate,

(a) the tension required to pull the cable in from E to W, and

(b) the tension required to pull the cable in from W to E.

A6 The duct route details are shown in the sketch.

(*a*) *Drawing in A–D (east to west)*

The pulling tension in section AB is given by,

$$T_{AB} = lw(\mu \cos\theta + \sin\theta),$$

where μ is coefficient of friction, l is length of the section (metres), w is the weight per unit length of the cable (Newtons per metre), and θ is angle of the gradient.

$$\therefore\ T_{AB} = 70 \times 50\,(0\cdot4 \cos\theta + \sin\theta)$$

$$= 3500\,(0\cdot4 \times 0\cdot99 + 0\cdot17) = 1981 \text{ N}.$$

The pulling tension in BC is given by,

$$T_{BC} = \mu l w = 0\cdot4 \times 36 \times 50 = 720 \text{ N}.$$

If the angle at bend C is β radians, the pulling tension after the bend is given by

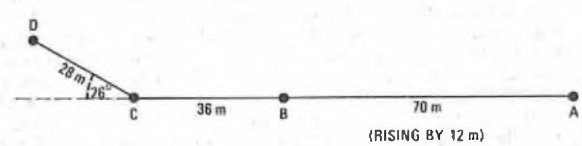
$$T_C = (T_{AB} + T_{BC})e^{\mu\beta} = 2701 \times e^{0\cdot4 \times 0\cdot454} = 3239 \text{ N}.$$

The pulling tension in section CD is given by,

$$T_{CD} = \mu w l = 0\cdot4 \times 50 \times 28 = 560 \text{ N}.$$

Therefore total pulling tension in section AD pulling east to west is

$$3239 + 560 = \underline{3799 \text{ N}}$$



(*b*) *Drawing in D–A (west to east)*

$$T_{DC} = 560 \text{ N},$$

$$T_C = T_{DC} e^{\mu\beta} = 560\, e^{0\cdot4\times0\cdot454} = 671 \text{ N},$$

$$T_{CB} = 720 \text{ N},$$

$$T_{BA} = 50 \times 70\,(\mu \cos\theta - \sin\theta) =$$

$$50 \times 70\,(0\cdot4 \times 0\cdot99 - 0\cdot17) = 791 \text{ N}.$$

Therefore, the total pulling tension in section DA pulling west to east is

$$671 + 720 + 791 = \underline{2182 \text{ N}}.$$

Q7 (*a*) *A circular microwave aerial 2 m in diameter is mounted on a wooden pole at a centre height of 14 m above the ground. The pole is set 3 m in the ground and the aerial is subjected to a wind pressure of 600 Pa. What must be the minimum diameter of the pole if the maximum wood-fibre stress at the ground line must not exceed 12·5 N/mm²? Neglect the effect of the wind on the pole. (The moment of inertia of a circular section of radius r about a diameter is $\pi r^4/4$.)*

(*b*) *State the relationship between wind velocity and the resultant pressure on an exposed surface.*

(*c*) *Briefly describe one practical situation where wind-velocity effects are important and indicate how they are reduced.*

A7 (*a*) The pressure on the aerial dish

$$= 600 \times \pi \times 1^2 = 1885 \text{ N}.$$

Now,
$$\frac{M}{I} = \frac{f}{y} \qquad \ldots\ldots (1)$$

where M is the moment about the ground line, I is the moment of inertia, f is the maximum fibre stress and y is the depth of the neutral axis.

Now,
$$M = 1885 \times 14 \text{ Nm},$$

$$I = \frac{\pi \frac{d^4}{2^4}}{4}, \text{ and}$$

$$f = 12\cdot5 \text{ N/mm}^2 \text{ (given)}.$$

Thus, substituting in expression (1)

$$\frac{1885 \times 14 \times 2^4 \times 4}{\pi \times d^4} = \frac{12\cdot5 \times 10^6 \times 2}{d}.$$

$$\therefore\ d^3 = \frac{14 \times 1885 \times 2^4 \times 4}{12\cdot5 \times 10^6 \times 2 \times \pi}.$$

$$\therefore\ \underline{d = 278 \text{ mm}.}$$

(*b*) The force on a structure exposed to the wind is determined from an equation of the form,

$$F = 0\cdot614 V^2 CA,$$

where V is the wind velocity in metres/second, C is a force coefficient describing the aerodynamic interaction between the wind and the structure (and includes shape and shielding factors), and A is the silhouette area of the windward face of the structure in square metres.

(*c*) Wind-velocity effects are important on exposed sites and can be reduced by ensuring that the structure design presents as small an area as possible on the prevailing-wind side. This is A in the formula given in part (*b*).

Q8 (*a*) *Describe in detail how a 1040-pair PCQT cable would be drawn into and positioned in a 2·1 m concrete-segment-lined cable tunnel 100 m long and located at an average depth of 20 m. Include details of the mechanical aids that would be used.*

(*b*) *How would transmission equipment be housed in the tunnel?*

A8 (*a*) The cable drum should be set up at the shaft-head as close as possible to the cable feed-pipe. The cable is fed into the bell mouth of the cable feed-pipe by hand. A brake fitted to the cable drum is necessary to control the speed of entry of the cable into the pipe, which would otherwise increase as the weight of cable hanging in the pipe increased. As the cable leaves the bottom of the cable feed-pipe, it is passed through a cable guide temporarily fixed to the floor of the tunnel. The passage of the cable through the guide corrects any sets which may have been introduced as the cable passed down the feed-pipe. When the cable leaves the guide, it is laid on cable trolleys placed at 2 m intervals. These support it clear of the tunnel floor and allow easy movement along the tunnel. As the cable leaves the shaft, supported on the trolleys, it is pulled manually or mechanically along the tunnel.

If, at the end of the route, the cable has to be brought to the surface via an exit shaft, the end of the cable is attached to a cable grip which is joined by a rope to a winch at the surface. As the cable is hauled slowly up the shaft, the trolleys are removed until the front end of the cable reaches the surface. The cable is then led to the point where it will be jointed or terminated.

If the cable cannot be removed from the cable feed-pipe, it is necessary to cut the cable, remove it from the pipe and joint it to another length. The new length must be lowered to the foot of the shaft but not via the feed pipe. If a joint is undesirable, the cable can be lowered out of the feed pipe by continuing to draw the cable along the tunnel and out of the exit shaft. When the cable is free of the pipe, the cable is drawn back up the shaft, again not via the feed pipe. Trolleys are used to carry the cable along the tunnel during this operation.

When both ends of the cable have been located in the shafts, the trolleys are removed and the cable is placed in its correct position on the cable brackets. The vertical sections of cable are then clamped to the appropriate tacking bars.

(*b*) When loading is required in tunnel cabling, 2 methods are used. The first, and more usual method, consists of the provision of special tunnel-type loading cases. The cases range in size from the smallest type containing 2 to 24 coils, to the largest containing from 488–542 coils.

The case, although different in shape from the manhole type, is similar in construction. The case is provided with filling plugs, cable glands, cable brackets and lifting rings. The base of the case is flat and rests on the cantilevers when in its installed position, and is designed to occupy as small a space as possible.

An alternative method sometimes used to provide loading case accommodation is by the use of special *loading laterals* situated at right angles to the main tunnel. These laterals are used to house normal manhole-type loading units. This method finds its greatest advantage in long tunnel routes and where the majority of the cables within the tunnel require loading.

Digital repeaters for pulse-code modulation (PCM) systems are readily accommodated in standard housings and can be installed in tunnel enlargements in a manner similar to that used for loading cases.

Q9 *A reinforced-concrete beam is freely supported at its ends over a span of 5 m. It has a rectangular cross-section 260 mm deep and 180 mm wide and is reinforced with two 12 mm steel bars placed at 220 mm from the upper face. The safe working stress of steel and concrete are 130 MPa and 3·5 MPa respectively and the modular ratio is 15.*

(*a*) *Calculate the maximum concentrated load that can be supported at 2 m from one end of the span.*

(*b*) *Draw a bending-moment diagram for the loaded beam.*

A9 (*a*) The total area of steel is

$$A_S = 2 \times \pi \times 6^2 = 226 \text{ mm}^2.$$

The ratio of area of steel to area of concrete is

$$r = \frac{226}{220} \times 180.$$

Thus,
$$r \times m = \frac{15 \times 226}{220 \times 180} = 0\cdot0856,$$

and
$$r^2 m^2 = 0\cdot00733.$$

If h is the depth of the neutral axis and d is the depth of the reinforcing bars,

$$\frac{h}{d} = \sqrt{(r^2 m^2 + 2rm)} - rm$$

$$= 0\cdot327.$$

Thus,
$$h = 74\cdot12 \text{ mm}.$$

The maximum bending moment the beam can sustain is given by

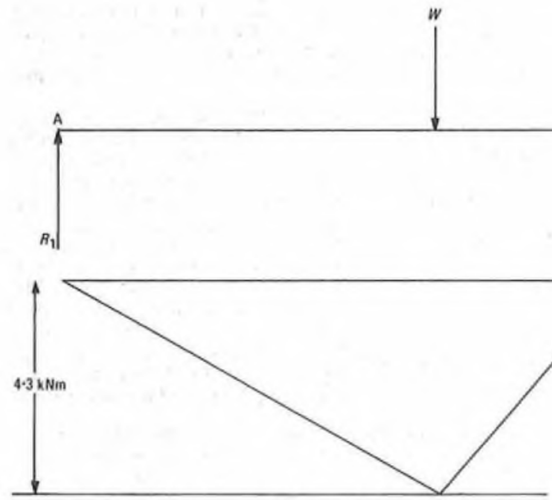
$$\tfrac{1}{2} f_c b h\left(d - \frac{h}{3}\right) = \tfrac{1}{2} \times 3\cdot5 \times \frac{180 \times 74\cdot12}{10^6}(220 - 24\cdot1)$$

$$= 4\cdot57 \text{ kNm},$$

where f_c is the safe working stress of the concrete and b is the breadth of the beam.

The stress in the steel can be checked using

$$\text{bending moment} = f_S A_S\left(d - \frac{h}{3}\right),$$



where f_S is the stress in the steel.

Thus, $$f_S = \frac{4 \cdot 57 \times 10^6}{226 \times 196} \approx 103 \text{ MPa},$$

which is within the safe working limit of 130 MPa.

If the load, W, is supported 2 m from one end, the maximum bending moment is $6W/5$.

$$\therefore\ W = \frac{4 \cdot 57 \times 5}{6} = \underline{3 \cdot 81 \text{ kN.}}$$

(*b*) The bending-moment diagram is shown in the sketch.

Q10 *(a) Explain how the presence of the running rails of a 25 kV, 50 Hz electric railway can effect screening in respect of the interference caused to a telephone cable running parallel with the railway.*

(b) Describe TWO *methods which can be employed at the power supply source to increase the screening factor.*

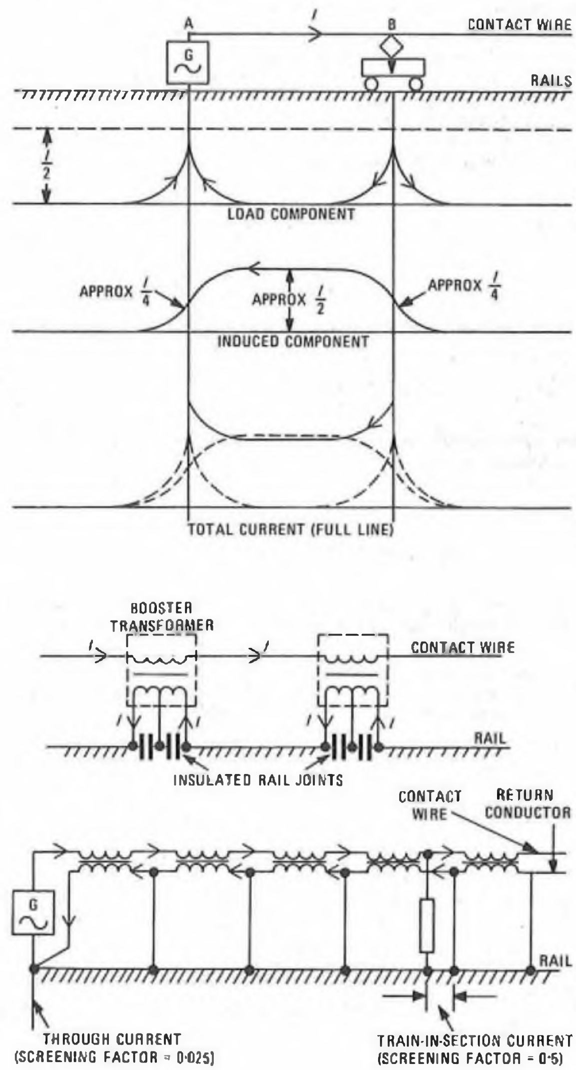
A10 (*a*) With single-phase, high-voltage, electrified railways, the alternating current supplied to the trains through the overhead contact wire returns to the feeding station, partly through the return rails and, due to the low insulation resistance of the rails to earth, partly through the earth. Voltages may therefore be induced in parallel telephone circuits by magnetic induction from the contact-wire current. When the trains are equipped with rectifiers and DC motors, harmonics which spread over the speech-frequency range appear in the contact-wire current and, in consequence, the voltages induced in telephone circuits also contain these harmonics. Such induced voltages can give rise to noise troubles and cause functional misoperation of DC telephone-signalling equipment. Danger may also arise with long close parallelisms.

The longitudinal voltage, V, induced in a telephone line by an earth return current, I, flowing in a parallel wire is

$$V = 2\pi f M I,$$

where f is the frequency and M the mutual inductance between the two lines.

If the return current could be wholly retained in the rails the inducing effect would be that from a comparatively narrow loop formed by the contact wire and the rails, and would be relatively small. In practice, the load current rapidly leaves the rails for earth as shown in sketches (*a*) and (*b*). The rails are themselves subject to an induced voltage from the contact-wire current which causes a current, virtually in antiphase to the contact-wire current, to flow in the rails as shown



(*a*)

(*b*)

(*c*)

(*d*)

(*e*)

(*f*)

in sketch (*c*). The current attains a maximum uniform value equal to the induced voltage per kilometre divided by the series impedance per kilometre of the rails, and is usually of the order of 0·5 times the contact-wire current. Combining the induced current with the load current, the distribution of total rail current is as shown in sketch (*d*). The total current is never smaller than the maximum uniform value attained by the induced component. It can be assumed therefore, that the rails exert a screening effect which is not more adverse than that due to the maximum value of the induced component. Hence, a screening (or reduction) factor of about 0·5 can be applied to the formula for induced voltage given above.

(*b*) Booster transformers are used to increase the screening factor either by a rail-connected system or by a return-conductor system. Sketch (*e*) shows how the booster transformers are connected to the rails and sketch (*f*) shows the method of connexion using the return-conductor system.

COMMUNICATION RADIO C 1977

Students were expected to answer 6 questions.
The use of electronic calculators was permitted where appropriate

Q1 *(a) What is meant by the terms*

(i) multipath fading, and
(ii) selective fading?

(b) A sinusoidal carrier at a frequency of 30 MHz travels via two paths between transmitter and receiver. If one path has 6 dB more attenuation than the other path, what is the ratio of the maximum possible signal strength to the minimum possible signal strength at the receiver?

(c) What are the causes of multipath propagation at

(i) high frequencies (HF), and
(ii) very high frequencies (VHF).

A1 (*a*) (*i*) Multipath fading is the variation of received signal with time arising from the simultaneous propagation by two or more paths which produce out-of-phase addition at the receiver.

(*ii*) Selective fading is the variation of received signal resulting from the propagating medium affecting unequally the frequency components of a modulated wave so as to cause distortion.

(*b*) If the signal strength received via one path is V_1 and the signal strength received via the second path is V_2

then $$6 = 20 \log_{10} \frac{V_1}{V_2},$$

whence $$V_2 = \frac{V_1}{\text{antilog}_{10}\, 0{\cdot}3} = \frac{V_1}{2}.$$

The maximum signal strength, V_{max}, occurs when V_1 and V_2 are in phase.

$$\therefore\ V_{max} = V_1 + V_2 = \frac{3V_1}{2}.$$

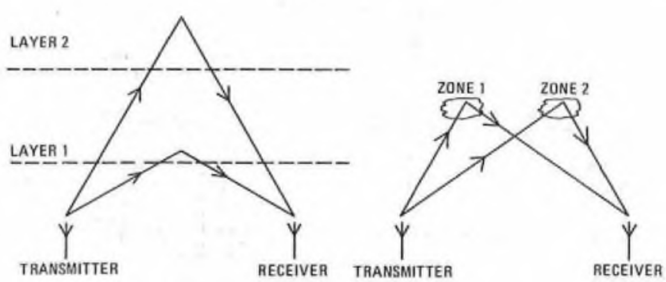
The minimum signal strength, V_{min}, occurs when V_1 and V_2 are 180° out of phase.

$$\therefore\ V_{min} = V_1 - V_2 = \frac{V_1}{2}.$$

$$\therefore\ \frac{V_{max}}{V_{min}} = \frac{3V_1}{2}\ \frac{2}{V_1} = \underline{3}.$$

(*c*) (*i*) Multipath propagation at HF may occur by reflections at different layers within the ionosphere (see sketch (*a*)) or by zones having different refractive indices (see sketch (*b*)), arising from sunspot activity, within a given layer.

(*ii*) At VHF, energy may be received via a direct wave and via reflections from large obstructions such as buildings.



(*a*) (*b*)

Q2 (a) Explain clearly why noise factor is an important measure of the performance of a radio receiver.

(b) The noise power in a given bandwidth delivered to a receiver is 20 pW. If the noise factor of the receiver is 10, what is,

(i) the total noise power in the given bandwidth at the output of the receiver if it has a power gain of 100,

(ii) the contribution of the receiver to the output noise power in this bandwidth,

(iii) the contribution of the receiver to the output noise power if the bandwidth is halved, and

(iv) the contribution of the amplifier to the output noise power if the noise factor is halved?

A2 (*a*) Noise factor (N_f) is defined as the ratio of the total noise output from a receiver (N_o) to that noise output due to the input source alone. It is, therefore, indicative of the noise contributed by the receiver in which processes of amplification and/or frequency translation are linear.

Since the noise output due to the noise at the source is equal to the product of the source noise (N_i) and receiver gain (G), the noise factor may be expressed as

$$N_f = \frac{N_o}{N_i \times G}. \qquad \ldots\ldots (1)$$

(*b*) (*i*) From equation (1), $N_o = N_i \times N_f \times G$.
Substituting the given values,

$$N_o = 20 \times 10^{-12} \times 10 \times 100 = \underline{0{\cdot}02\ \mu W}.$$

(*ii*) Noise at the output due to source, N_{os}, is given by

$$N_{os} = 20 \times 10^{-12} \times 100.$$

$\therefore$ Noise contributed by the receiver (N_r) = $N_o - N_{os}$

and $$N_o = 20 \times 10^{-12} \times 10 \times 100.$$

$$\therefore\ N_r = (20 \times 10^{-12} \times 10 \times 100) - (20 \times 10^{-12} \times 100)$$
$$= 20 \times 10^{-12} \times 100(10 - 1)$$
$$= \underline{0{\cdot}018\ \mu W}.$$

(*c*) (*iii*) If the bandwidth is halved, the noise contributed by the receiver, N_r is given by,

$$N_r = (20 \times 10^{-12} \times 9 \times 100)/2 = \underline{0{\cdot}009\ \mu W}.$$

(*iv*) If the noise factor is halved, the noise at the output due to the source, N_{os}, is,

$$N_{os} = 20 \times 10^{-12} \times 100,$$

and $$N_o = 20 \times 10^{-12} \times 5 \times 100.$$

Therefore the noise contributed by the receiver, N_r, is given by

$$N_r = N_o - N_{os} = (20 \times 10^{-12} \times 5 \times 100) - (20 \times 10^{-12} \times 100),$$
$$= 20 \times 10^{-12} \times 100\,(5 - 1) = \underline{0{\cdot}008\ \mu W}.$$

Q3 (a) Briefly discuss the considerations which enter into the design of the output stage of a high-frequency (HF) transmitter.

(b) Give TWO *reasons why each aerial at an HF transmitting station is not permanently associated with a transmitter.*

(c) Explain briefly why a transmitter must be matched to an aerial feeder.

A3 (*a*) and (*b*) See A5, Communication Radio C 1974, *Supplement*, Vol. 68, p. 58, Oct. 1975.

(*c*) When a transmitter having an output impedance Z_1 is connected to an aerial feeder having an impedance Z_2, where Z_1 does not equal Z_2, some of the transmitter power is reflected. There is thus a reduction in transmission efficiency since not all the available power is transferred to the aerial feeder. Also, there is a danger of the reflected power producing standing waves, involving high-voltage components which could cause dielectric breakdown. The power reflected is reduced to zero when the transmitter and feeder impedances are equal. However, there are many types of feeder available having impedances in the range 50–600 Ω, depending on their construction.

Q4 (a) What design factors affect the efficiency of a class-C frequency multiplier?

(b) The output of a multiplier (V_{out}) is related to the input (V_{in}) by the equation

$$V_{out} = 2V_{in}^2 + 4V_{in}^3.$$

If the input is 8 sin Ωt, what are

(i) the output frequencies, and

(ii) the amplitudes at each of these frequencies?

A4 (*a*) The efficiency, η, of a class-C valve amplifier used as a frequency multiplier is given by

$$\eta = \frac{\text{power delivered to the tank circuit}}{\text{power supplied by the HT source}}.$$

The power delivered to the tank circuit is the product of the RMS value of the fundamental component of the anode current, I_{af}, and the RMS value of the voltage developed across the tank circuit, V_l.

The power supplied by the HT source is the product of the mean value of the anode current, I_{am}, and the supply voltage, V_{HT}.

$$\therefore\ \eta = \frac{\dfrac{I_{af}}{\sqrt{2}}\ \dfrac{V_l}{\sqrt{2}}}{I_{am}\, V_{HT}} = \frac{I_{af}(V_{HT} - V_a)}{2 I_{am}\, V_{HT}},$$

where V_a is the minimum value of anode voltage.

For high efficiency the numerator needs to be large, while the denominator should be small. This may be achieved by increasing the value of I_{af} or reducing the values of I_{am} or V_a.

Now, $$I_{am} \approx \frac{1}{2} \times \frac{\text{angle of flow}}{360°} \times \text{peak value of anode current}.$$

I_{am} may therefore be reduced by reduction of the angle of flow. However, a reduction of the angle of flow also reduces the fundamental component of anode current supplied to the tank circuit (I_{af}). In turn, the voltage developed across the tank (V_l) is reduced and V_a is increased.

A compromise solution is to control the angle of flow to lie between about 180°–150°, when efficiencies of between 60% and 80% can be achieved.

The above argument applies equally to a semiconductor amplifier operating in class-C.

(*b*) $V_{out} = 2V_{in}^2 + 4V_{in}^3$

$V_{in} = 8 \sin \Omega t$

$\therefore V_{in}^2 = 64 \sin^2 \Omega t$

and $V_{in}^3 = (64 \sin^2 \Omega t)(8 \sin \Omega t)$

$$\therefore V_{out} = 2(64 \sin^2 \Omega t) + 4(64 \sin^2 \Omega t)(8 \sin \Omega t)$$
$$= 128 \sin^2 \Omega t\,(1 + 16 \sin \Omega t)$$

Using the trigonometric identity $\sin^2 A = \dfrac{1 - \cos 2A}{2}$

$$V_{out} = 64\,(1 - \cos 2\Omega t)(1 + 16 \sin \Omega t)$$
$$= 64\,(1 - \cos 2\Omega t + 16 \sin \Omega t - 16 \sin \Omega t \cos 2\,\Omega t)$$

Using the trigonometric identity

$$2 \sin A \cos B = \sin (A + B) - \sin (A - B),$$

$$V_{out} = 64\,(1 - \cos 2\Omega t + 16 \sin \Omega t - 8 \sin 3\Omega t + 8 \sin\ \Omega t)$$

and substituting for $\Omega = 2\pi f$ gives

$$V_{out} = 64\,\{1 + 24 \sin 2\pi f t - \cos 2\pi(2f)t - 8 \sin 2\pi(3f)t\}.$$

The frequency components of V_{out} are the DC component and f, $2f$ and $3f$ having respective relative amplitudes 64, 1536, 64 and 512.

Note: It is more usual to use ω to represent $2\pi f$ rather than Ω. However, the question has been reproduced as set.

Q5 (*a*) *Briefly explain what is meant by the terms*

(*i*) *padding, and*
(*ii*) *ganging*

as applied to a superheterodyne receiver.

(*b*) *A superheterodyne receiver employs ganged capacitors in its aerial and local-oscillator circuits with an additional parallel capacitor in the local-oscillator circuit. When the capacitance in the signal circuit varies from 60 pF to 240 pF, the receiver is tuned from 1200 kHz to 600 kHz. If the local-oscillator capacitance variation is from 120 pF to 300 pF and the intermediate frequency is 433 kHz, what is*

(*i*) *the frequency to which the receiver is tuned when the signal-circuit capacitance is 150 pF,*

(*ii*) *the local-oscillator frequency when the local-oscillator capacitance is 210 pF, and*

(*iii*) *the tracking error when the capacitance is at the midpoint of its range?*

A5 (*a*) (*i*) Padding is the technique of adding a series capacitor in the tuned circuit of the local oscillator of a superheterodyne receiver, the value of the capacitor being designed to minimize the divergence from the correct tracking.

(*ii*) Ganging is the technique of linking mechanically a number of tuned circuits so that their frequencies of resonance can be adjusted by a common control.

(*b*) (*i*) The signal frequency f_{s1} is given by

$$f_{s1} = \frac{1}{2\pi\sqrt{(LC_{A1})}},$$

where L is the inductance of the aerial tuned circuit and C_{A1} is the capacitance of the aerial tuned circuit.

Similarly the signal frequency f_{s2} is given by

$$f_{s2} = \frac{1}{2\pi\sqrt{(LC_{A2})}}.$$

$$\therefore \frac{(f_{s1})^2}{(f_{s2})^2} = \frac{C_{A2}}{C_{A1}}.$$

Using the values given, the required signal frequency, f_s, is given by

$$f_s^2 = \frac{1200 \times 10^3 \times 1200 \times 10^3 \times 60 \times 10^{-12}}{150 \times 10^{-12}}.$$

$$\therefore f_s = \underline{758{\cdot}95\ \text{kHz}}.$$

(*b*) (*ii*) Assuming the oscillator frequency, f_o, is the sum of signal and intermediate frequencies f_s and f_i respectively, the frequency range of the oscillator is 1033 – 1633 kHz. These extreme values are related to the extreme oscillator capacitor values 120 pF and 300 pF by

$$\frac{(f_{o1})^2}{(f_{o2})^2} = \frac{C_{o2}}{C_{o1}}.$$

Therefore the frequency f_o when the oscillator capacitor is 210 pF is given by

$$f_o \approx \sqrt{\left\{\frac{300 \times 10^{-12}}{210 \times 10^{-12}} \times (1033 \times 10^3)^2\right\}} = \underline{1234{\cdot}7\ \text{kHz}}.$$

(*iii*) At the midpoint of the capacitance range, $f_o \approx 1234{\cdot}7$ kHz, while the intermediate frequency, $f_i = 433$ kHz.

$$\therefore f_s \approx f_o - f_i = 801{\cdot}7\ \text{kHz} = f_{sa}, \text{ the actual signal frequency.}$$

In part (*i*) it was calculated that the true mid-range frequency $f_{st} = 758{\cdot}95$ kHz.

Therefore the tracking error, e, is given by

$$e = f_{st} - f_{sa} = 801{\cdot}7 - 758{\cdot}95 = \underline{42{\cdot}75\ \text{kHz}}.$$

Q6 (*a*) *What is meant by the following terms in connexion with frequency modulation (FM):*

(*i*) *modulation index,*
(*ii*) *frequency deviation, and*
(*iii*) *practical bandwidth?*

(*b*) *When the modulation index of a certain FM transmitter is 7 in a practical bandwidth of 160 kHz, what is its frequency deviation?*

(*c*) *An interfering sinusoidal signal is close in frequency to that of the carrier of the wanted signal. Explain the effect on the receiver output of increasing the deviation of the wanted signal.*

A6 (*a*) (*i*) The modulation index (m) is the ratio of the frequency deviation (d_f) to the frequency of the modulating waveform (f_m).

(*ii*) Frequency deviation is the peak difference between the instantaneous frequency of the modulated wave and the unmodulated carrier frequency in a cycle of modulation.

(*iii*) Practical bandwidth (B) is at least twice the sum of the frequency deviation and the frequency of the modulating wave.

(*b*) Using the above relationships for modulation index and bandwidth gives

$$m = d_f / f_m,$$

and $$B = 2(d_f + f_m) = 2\left(d_f + \frac{d_f}{m}\right).$$

Hence, $$d_f = B/2\left(1 + \frac{1}{m}\right) = m\,B/2(m + 1).$$

Substituting the given values for B and m gives

$$d_f = \frac{7 \times 160 \times 10^3}{2(7 + 1)}\ \text{Hz} = \underline{70\ \text{kHz}}.$$

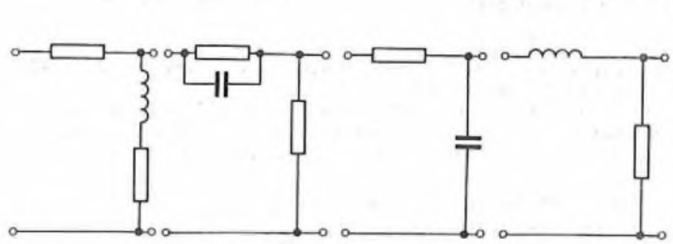
(*c*) See A6, Communication Radio C 1970, *Supplement*, Vol. 64, p. 73, Jan. 1972.

Q7 (*a*) *Draw the circuit diagram of*

(*i*) *a pre-emphasis circuit, and*
(*ii*) *a de-emphasis circuit.*

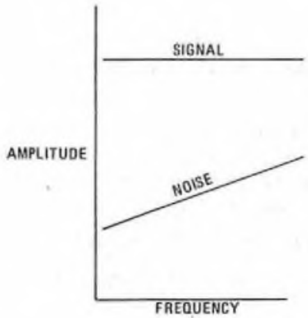
(*b*) *With the aid of typical frequency spectra, show the effects of pre-emphasis and de-emphasis.*

A7 (*a*) The circuits of pre-emphasis networks are shown in sketches (*a*) and (*b*) and those for de-emphasis networks in sketch (*c*) and (*d*).

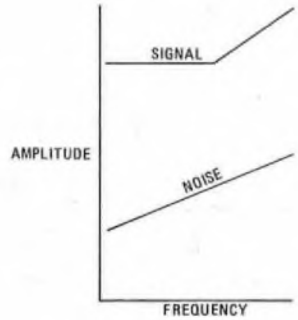


(*a*) (*b*) (*c*) (*d*)

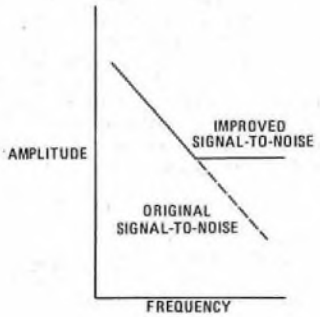
(*b*) For a frequency modulated signal, the phase deviation, ϕ, introduced by the action of a noise-frequency component upon the



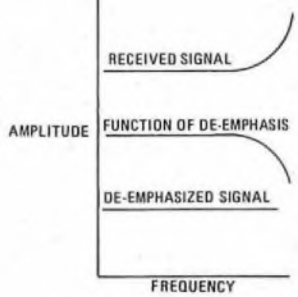
(*e*)



(*f*)



(*g*)



(*h*)

signal-frequency component is given by

$$\phi = \phi_{max} \sin 2\pi f_d t,$$

where f_d is the frequency difference between the noise and signal-frequency components and t is time.

Also, the angular velocity is given by $\omega = \dfrac{d\phi}{dt}$,

$$\therefore\ f = f_d \phi_{max} \cos 2\pi f_d t,$$

where f is the deviation of the signal frequency resulting from the application of noise, and is a maximum when $\cos 2\pi f_d t = 1$, whence the maximum signal frequency deviation is $\phi_{max} f_d$.

The peak deviation of the signal is proportional to the frequency of the interfering component, and gives rise to a triangular noise spectrum. Sketch (*e*) shows the noise and the normally constant-amplitude signal plotted against frequency. It is evident that as the frequency increases, the signal-to-noise ratio decreases. This may be overcome by arranging for the amplitude of the signal to increase as a function of frequency. Unfortunately, the signal cannot be made to rise in the same manner as the noise, so as to obtain a constant signal-to-noise ratio. This is because an increase in signal amplitude results in increased frequency deviation and hence demand for larger bandwidth. However, the energy of the higher-order components of the baseband signal is not very great, so that it is possible to increase the amplitude of those components above 1 kHz with only a slight increase in required bandwidth. This emphasis of a selected portion of the baseband spectrum is known as *pre-emphasis*, and is illustrated in sketch (*f*) with the improvement in signal-to-noise ratio shown in sketch (*g*).

At the receiver it is necessary to restore the relative magnitudes of the baseband signal, so a complementary function known as *de-emphasis* is applied. The effect of the latter upon the received signal characteristics is shown in sketch (*h*).

Q8 (*a*) *Describe, with the aid of a block diagram, the drive and radio frequency (RF) stages of a high power, independent-sideband high-frequency (HF) transmitter. How is crosstalk between sidebands minimized?*

(*b*) *Compare and contrast independent sideband operation with*

(*i*) *double sideband, and*
(*ii*) *single sideband operation.*

Q9 (*a*) *What is meant by* EACH *of the following terms in connexion with aerials:*

(*i*) *feeder,*
(*ii*) *directivity,*
(*iii*) *front-to-back ratio, and*
(*iv*) *beamwidth?*

(*b*) *A transmitting aerial and an identical receiving aerial are aligned in the direction of maximum gain. Each aerial has an efficiency of 50% and a gain of 20 dB. If the power delivered to the transmitting aerial is 8 kW, what is the power supplied to the feeder of the receiving aerial?*

Q10 Describe a method of measuring each of the following, numbering each step in the procedure and listing the equipment required:

(*a*) *the image-channel rejection ratio of a medium-wave broadcast receiver, and*
(*b*) *the noise factor of such a receiver.*

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Students were expected to answer any 6 questions
The use of an electronic calculator was permitted where appropriate

Q1 (*a*) *With the aid of diagrams, which clearly show the E and H components and the direction of propagation, describe what is meant by*

(*i*) *a TEM wave,*
(*ii*) *a TM wave, and*
(*iii*) *a TE wave.*

(*b*) *In some circumstances, it is not possible to propagate a TEM wave between a pair of parallel metal strips. Explain this statement.*

Q2 (*a*) *A coaxial cable has a characteristic impedance of 80 Ω. What is meant by this statement?*

(*b*) *A 120 Ω resistive load is connected to a radio-frequency signal generator by a λ/4 section of low-loss coaxial cable of characteristic impedance 60 Ω. The input voltage to the section is 15 V. Calculate*

(*i*) *the reflection coefficient of the load,*
(*ii*) *the voltage across the load,*
(*iii*) *the power dissipated in the load, and*
(*iv*) *the current supplied by the generator.*

A2 (*a*) The statement means that the impedance to alternating current looking into an infinite length of the coaxial cable is 80 Ω. The same result would be given by a finite length of the cable terminated in a load having the same value as the characteristic impedance.

The characteristic impedance of a coaxial cable is resistive and equal to $\sqrt{\dfrac{L}{C}}$ where L is the inductance (henrys) and C the capacitance (farads) per unit length.

(*b*) (*i*) The reflection coefficient is defined as $\dfrac{\text{reflected current}}{\text{incident current}}$ and is equal to $\dfrac{Z_0 - Z_L}{Z_0 + Z_L}$ where Z_0 is the characteristic impedance and Z_L the load impedance. In the example the coefficient is,

$$\rho = \frac{60 - 120}{60 + 120} = \underline{-0{\cdot}33.}$$

(*ii*) At the load, the voltage, V_L, is equal to V_i plus V_r where the suffixes i and r denote reflected and incident values.

$$V_L = V_i - \rho V_i = V_i(1 + 0{\cdot}33) = 1{\cdot}33 V_i. \quad \ldots\ldots (1)$$

The incident and reflected voltages are in phase at the load. At the source, V_i is 90° earlier in phase than at the load because the line is a quarter-wavelength long, while V_r is 90° later. They are therefore in anti-phase at the source, where

$$V_s = V_i(1 - 0{\cdot}33) = 0{\cdot}67 V_i. \quad \ldots\ldots (2)$$

From equations (1) and (2)

$$V_L = \frac{1\cdot 33}{0\cdot 67} V_s$$

$$= \frac{1\cdot 33}{0\cdot 67} \times 15 = \underline{29\cdot 78\ \text{V}}.$$

(*iii*) The power dissipated at the load is

$$\frac{V_L^2}{R_L} = \frac{29\cdot 78^2}{120} = \underline{7\cdot 39\ \text{W}}.$$

(*iv*) The current at the load, I_L, is

$$\frac{V_L}{R_L} = \frac{29\cdot 78}{120}\ \text{A}. \qquad \ldots\ldots (3)$$

At the load,

$$I_L = I_i(1 - 0\cdot 33) = 0\cdot 67 I_i,$$

because the incident and reflected currents are in antiphase, while at the source,

$$I_s = I_i(1 + 0\cdot 33) = 1\cdot 33 I_i,$$

due to an overall change in relative phase of 180° over the quarter-wavelength line.
Thus, the current supplied by the generator is,

$$I_s = \frac{1\cdot 33}{0\cdot 67} I_L.$$

But, from equation (3), $I_L = \frac{29\cdot 78}{120}$

$$\therefore\ I_s = \frac{1\cdot 33}{0\cdot 67} \times \frac{29\cdot 78}{120} = \underline{0\cdot 493\ \text{A}}.$$

Q3 (a) As a safeguard against excessive attenuation when dominant-mode propagation is used in a rectangular waveguide, the guide wavelength should not be greater than 5/3 of the free-space wavelength. Calculate the highest frequency desirable for a waveguide having a cross-section 5 cm × 1·5 cm.

(b) Briefly explain, with the aid of diagrams, the principle of a capacitive iris. For what purpose is this used?

A3 (*a*) In a rectangular waveguide,

$$\frac{1}{\lambda_g^2} = \frac{1}{\lambda_0^2} - \frac{1}{(2a)^2},$$

where λ_g is the guide wavelength, λ_0 is the free space wavelength, and a is the width of waveguide.

When $a = 3$ cm,

$$\frac{1}{\lambda_g^2} = \frac{1}{\lambda_0^2} - \frac{1}{36}. \qquad \ldots\ldots (1)$$

The highest desirable frequency is stated to correspond to $\lambda_g = \frac{5}{3}\lambda_0$.

Substituting in equation (1), $\frac{1}{\left(\frac{5\lambda_0}{3}\right)^2} = \frac{1}{\lambda_0^2} - \frac{1}{36}.$

Multiplying both sides by λ_0^2 gives

$$\frac{9}{25} = 1 - \frac{\lambda_0^2}{36}.$$

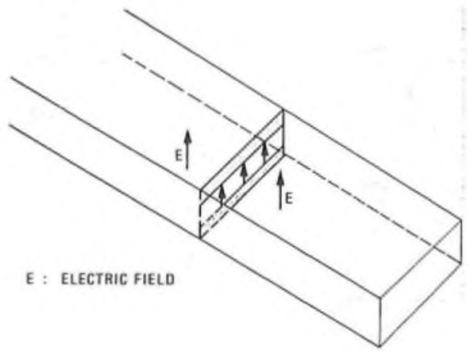
$$\therefore\ \lambda_0^2 = 36\left(1 - \frac{9}{25}\right),$$

and $$\lambda_0 = \sqrt{\left\{36\left(1 - \frac{9}{25}\right)\right\}} = \frac{24}{5}\ \text{cm}.$$

But $\lambda_0 f = c$, where c is the speed of light (3×10^{10} cm/s) and f is the frequency (Hz).

$$\therefore\ f = \frac{5}{24} \times 3 \times 10^{10}\ \text{Hz},$$

$$= \underline{6\cdot 25\ \text{GHz}}.$$



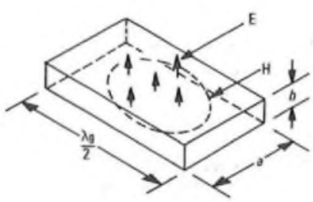
(*b*) A capacitive iris is shown in the sketch. It is made from conducting material and is sufficiently thin for the transverse electric field to be the same on both sides of the iris. It collects charge from the top and bottom of the guide and therefore stores electric energy, and is equivalent to a lumped capacitance shunted across a transmission line.

It can be used to compensate for a mismatch in the waveguide. For example, at a certain distance from a mismatch, the admittance will be the guide characteristic admittance, Y_0, shunted by an inductance so that $Y/Y_0 = 1 - jB$. An iris placed at this point with a shunt capacitive reactance of jB will cancel the reactance, leaving the characteristic admittance Y_0.

Q4 (a) A resonant cavity is formed by enclosing an 8 cm length of rectangular waveguide of cross-section 6 cm × 3 cm. Determine the lowest resonant frequency of this cavity.

(b) Describe a simple adjustable waveguide filter for excluding a narrow band of frequencies.

A4 (*a*) The lowest resonant frequency in the cavity will occur with the TE_{10} mode as shown in sketch (*a*). The field pattern will consist of standing waves with the cavity half a guide wavelength $\left(\frac{\lambda_g}{2}\right)$ long.



(*a*)

The equation relating λ_g to the free-space wavelength, λ_0, and the broad dimension of the waveguide, a, is

$$\frac{1}{\lambda_g^2} = \frac{1}{\lambda_0^2} - \frac{1}{(2a)^2}.$$

In the example given, $\frac{\lambda_g}{2} = 8$ cm and $a = 6$ cm.

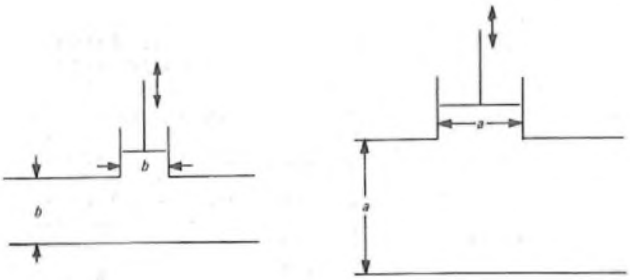
$$\therefore\ \frac{1}{16^2} = \frac{1}{\lambda_0^2} - \frac{1}{12^2},$$

and $$\lambda_0 = \frac{1}{\sqrt{\left(\frac{1}{256} + \frac{1}{144}\right)}} = 9\cdot 60\ \text{cm}.$$

Since $\lambda_0 f = c$, where f is the frequency and c is the speed of light (3×10^{10} cm/s),

$$f = \frac{3 \times 10^{10}}{9\cdot 60}\ \text{Hz} = \underline{3\cdot 125\ \text{GHz}}.$$

(*b*) The transmission of a narrow band of frequencies can be excluded by connecting a parallel resonant cavity, as described in the first part of the question. This is coupled by a hole in the waveguide in either of the two relative positions shown in sketch (*b*). The resonant frequency can be adjusted by means of a plunger which alters the length of the cavity. The energy extracted from the waveguide by the cavity is greatest at the resonant frequency and hence the device acts as a band-rejection filter.



(*b*)

Q5 A sectoral horn formed by flaring out one dimension of a rectangular waveguide provides a feed for a parabolic reflector.

(a) With the aid of diagrams, explain whether the narrow or the wide dimension should be flared. (Dominant-mode propagation within the waveguide may be assumed.)

(b) State why the sectoral horn provides a better feed than the unflared end of the waveguide.

Q6 (a) Fig. 1 shows the pattern obtained when a uniform pulse train is width-modulated by a sine wave. Copy this pattern on squared paper and beneath it reconstruct to scale the modulating waveform.

(b) Determine from the diagram in part (a),

(i) the pulse-repetition frequency of the unmodulated pulse train,
(ii) the frequency of the modulating wave,
(iii) the duration of the unmodulated pulses, and
(iv) the highest frequency that could be sampled.

(c) Explain briefly one advantage of pulse-width modulation in comparison with pulse-amplitude modulation.

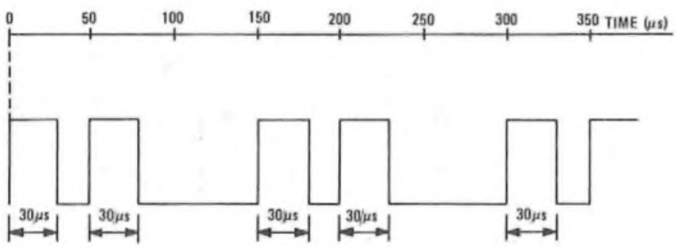
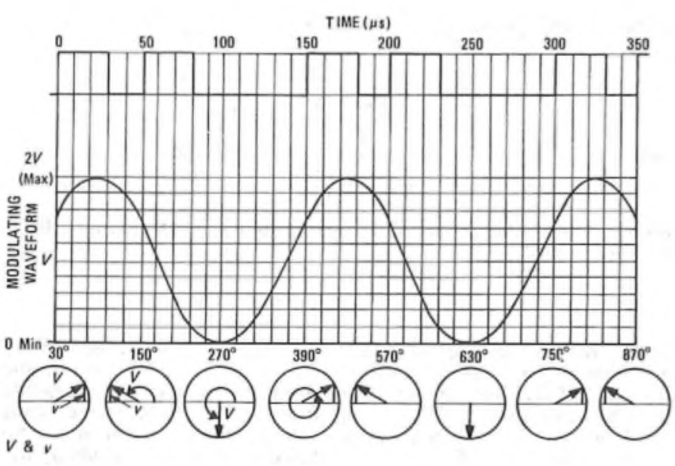


Fig. 1

A6 (*a*) The modulating waveform is constructed as follows. The pulse width is measured from the instant the pulse rises, and this instant corresponds with the moment at which the instantaneous



(*a*)

voltage is sampled. The pulse width of 30 µs is proportional to the instantaneous voltage. The first two pulses at $t = 0$ and $t = 50$ µs correspond to the same voltage, the third pulse at $t = 100$ µs must be of zero width and corresponds to the minimum instantaneous voltage as shown. The sinusoidal voltage is represented by v, the perpendicular dropped from the rotating phasor V, which rotates through 360° for each cycle. The duration of a cycle of the modulating waveform is 150 µs, from the pulse pattern, and the phasor rotates through 120° from one sampling point when $t = 0$ to the next. For the voltage waveform to satisfy these conditions, when $t = 0$ the phasor must be at 30°.

(*b*) (*i*) The pulse-repetition frequency (PRF) is $\dfrac{1}{\text{pulse period}}$

$$\therefore \ \text{PRF} = \frac{1}{50\ \mu\text{s}} = \underline{20\ \text{kHz}}.$$

(*ii*) The period of the modulating wave is 150 µs.

$$\therefore \ f = \frac{1}{150\ \mu\text{s}} = \underline{6{\cdot}67\ \text{kHz}}.$$

(*iii*) The pulse duration is proportional to the instantaneous voltage, v. When $v = \dfrac{3V}{2}$, the pulse duration is 30 µs and, when $v = -V$, the duration is 0 µs. Therefore, 30 µs corresponds to a voltage difference of $\left(\dfrac{V}{2} + V\right)$. With unmodulated pulses, the voltage is V, and the duration is

$$30 \times \frac{V}{3/2V} = \underline{20\ \mu\text{s}}.$$

(*iv*) By the sampling theorem, the highest frequency, $f_{\max}$, that could be sampled is half the PRF.

$$\therefore \ f_{\max} = \frac{20}{2} = \underline{10\ \text{kHz}}.$$

(*c*) One advantage of pulse-width modulation is that interference mainly affects the amplitude of the signal, and thus has a minimal effect on the pulse width. With pulse-amplitude modulation, the amplitude variations due to interference will be included with the signal by the detector stage of the receiver.

Q7 (a) Describe, with the aid of a diagram, the construction of a tunable microwave oscillator which uses ONE *of the following active devices*

(i) a tunnel diode, or
(ii) a Gunn diode.

(b) Briefly describe the principle of the active device selected in part (a).

Q8 The following data refer to a microwave-link receiver designed to accommodate one 8 MHz television channel together with a 1·1 MHz channel for telephony.

Intermediate frequency	*70 MHz*
Overall gain	*80 dB*
Noise factor	*9 dB.*

(a) Calculate the minimum input power for a signal-to-noise ratio of 40 dB at the output. (Assume $kT = 4 \times 10^{-21}$ J).

(b) Briefly describe how the required gain and bandwidth are achieved in the IF amplifier of such a receiver.

A8 (*a*) The noise factor (F) can be defined as

$$F = \frac{\text{Input signal-to-noise ratio}}{\text{Output signal-to-noise ratio}}.$$

In the question F is given as 9 dB and output signal-to-noise ratio as 40 dB.

$\therefore$ input signal-to-noise ratio $= (40 + 9)$ dB

$= 7{\cdot}94 \times 10^4$ as a power ratio .... (1)

The input noise $= kTB$ watts, where kT is 4×10^{-21} J (given) and the minimum bandwidth, B, is $(8 + 1{\cdot}1)$ MHz.

Minimum input signal = (input noise power) × (input signal-to-noise ratio)

$$= 4 \times 10^{-21} \times 9{\cdot}1 \times 10^6 \times 7{\cdot}94 \times 10^4\ \text{W}$$

$$= \underline{0{\cdot}00289 \times 10^{-6}\ \text{W} = 2{\cdot}89\ \text{pW}}.$$

(*b*) A modern intermediate frequency (IF) amplifier uses transistors with a cut-off frequency of about 1·5 GHz, allowing the use of wide-bandwidth (≈ 30 MHz) common-emitter circuits at 70 MHz. Several main stages each consist of two transistors connected as a feedback pair. The gain of each stage is controlled for automatic gain control (AGC) purposes by a p i n diode in the emitter load of the output, so that the gain of the stage can be varied between 0 and 10 dB by applying a direct current through the diode, which alters its impedance at 70 MHz. A pre-amplifier with a typical noise factor of 1·5 dB ensures that the overall noise factor of 9 dB can be achieved, referred to the mixer input.

Q9 (*a*) *Fig. 2 is a simplified block diagram of the transmitter for a 40 km microwave communication link designed to provide 960 telephone channels and one television channel. Explain why*

(*i*) *a mixer stage rather than a frequency multiplier is used to provide drive for the travelling-wave tube,*
(*ii*) *the mixer output is filtered, and*
(*iii*) *pre-emphasis is used.*

(*b*) *Draw a labelled block diagram of a receiver suitable for this link.*

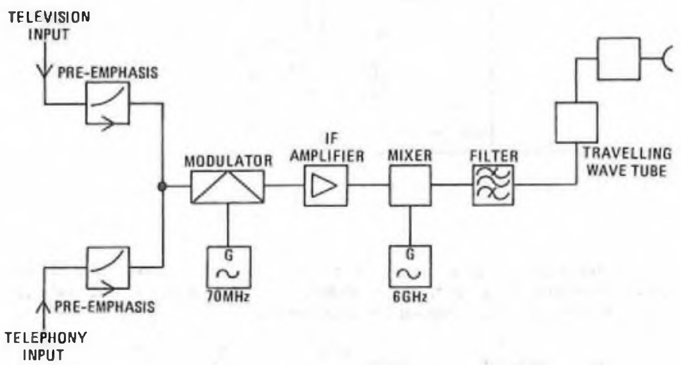
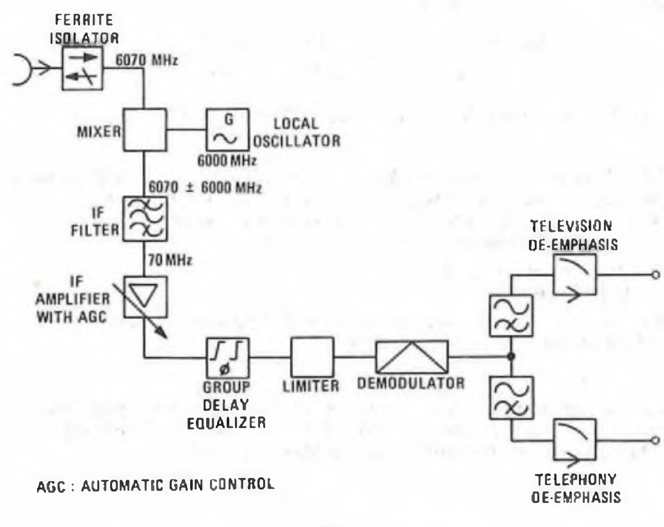


Fig. 2



(*a*)

A9 (*a*) (*i*) Assuming the bandwidth required to carry the frequency-modulated output from the 70 MHz modulator is ±10 MHz, the use of multipliers with an overall factor of, say 81, would produce a carrier of 70 × 81 = 5670 MHz and a bandwidth of 20 × 81 = 1620 MHz which would be absurdly large. The alternative of a mixer will add 6000 MHz to translate the carrier to 6000 + 70 = 6070 MHz, and leave the bandwidth intact at 20 MHz.

(*ii*) The output from the mixer will contain frequencies of 6000 ± 70 MHz, together with a relatively low amplitude of 6000 MHz if a balanced mixer is used. A filter is required to select, say, the 6070 MHz signal and reject the 5930 MHz and 6000 MHz components.

(*iii*) With frequency modulation and no pre-emphasis/de-emphasis, the signals to be detected will not be so large compared with the noise from the receiver and will be affected more than when pre-emphasis of the high frequencies is used.

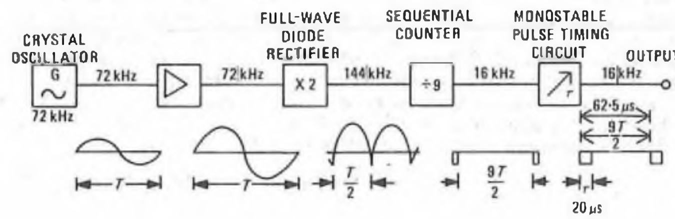
Pre-emphasis gives a more uniform noise distribution in telephony systems and reduces distortion in television systems. Different pre-emphasis curves are used for telephony and television.

(*b*) The block diagram of a suitable receiver is shown in sketch (*a*).

Q10 *A 72 kHz crystal oscillator is used as a master timer for generating a uniform train of rectangular pulses, each of duration 20 μs, recurring at intervals of 62·5 μs.*

(*a*) *Draw a labelled block diagram to show how the pulse train could be generated. Waveforms at the input to each block are to be shown.*

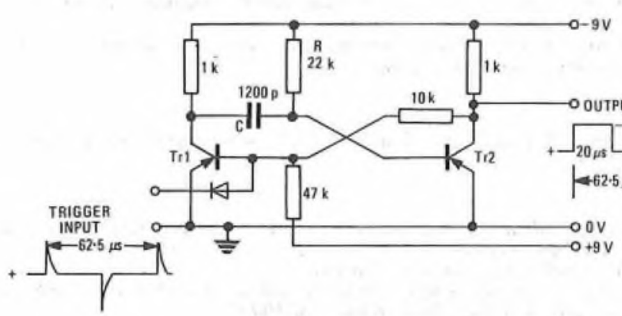
(*b*) *Draw a circuit diagram of the stage that determines pulse duration. State the components that determine the pulse duration.*



(*a*)

A10 (*a*) One method of forming the required pulses is shown in the block diagram of sketch (*a*), together with the waveforms at each stage. The output pulses must recur at 62·5 μs intervals, corresponding to $\frac{1}{62 \cdot 5\ \mu s} = 16$ kHz. To reduce the oscillator frequency from 72 kHz to 16 kHz, the signal must be multiplied by 2 and divided by 9, as shown in the sketch.

(*b*) The monostable circuit used to determine the pulse duration is shown in sketch (*b*). The circuit is triggered by a negative-going pulse at the input. Transistor Tr1 then conducts and transistor Tr2 cuts off. Transistor Tr2 is held off until the capacitor C, which is holding the base of transistor Tr2 positive relative to the emitter, has discharged through resistor R sufficiently to allow transistor Tr2 to conduct and the circuit to flip over by means of negative feed-back, to the quiescent state with transistor Tr1 cut off and transistor Tr2 conducting. The pulse lasts for about 0·7*CR* seconds and can be adjusted by altering the value of R or C.



(*b*)

Students were expected to answer any 6 questions
The use of electronic calculators was allowed where appropriate

Q1 (*a*) *Explain how the impedance/frequency characteristic of a faulty line can be used to determine the position of the fault.*

(*b*) *Calculate the position of a fault on a line whose measured impedance/frequency characteristic shows a regular pattern of maximum and minimum values at an interval of 2·0 kHz. The loop inductance of the line is 1 mH/km and the loop capacitance is 0·1 μF/km.*

A1 (*a*) The impedance/frequency characteristic of a uniform transmission line is a smooth curve. As, in practice, some transmission lines are not uniform, and the curve may not be smooth, it is usual practice to keep a copy of the original impedance frequency curve for comparison purposes. Any fault on a transmission line results in an impedance irregularity and a reflection from the fault.

The impedance/frequency characteristic of such a line exhibits a regular pattern of maxima and minima caused by the effect of the reflections arriving at the sending end in a phase relationship which depends upon the distance to the fault, the frequency of the test signal, and the line characteristics. Comparison of the original curve with the fault characteristic curve allows a difference curve to be plotted which shows the maxima and minima caused by the fault. To locate a fault x kilometres from the sending end of the transmission line, it is necessary to terminate the line at the far end with its characteristic impedance and to transmit a test signal. Part of this signal will be reflected from the fault back to the sending end after travelling a distance of $2x$ kilometres and will have undergone one phase change whilst travelling and another at the fault. The total phase change will be $2\beta x + \phi$, where β is the phase change coefficient in radians/kilometre and ϕ the phase change in radians due to the fault. These values will depend upon the testing frequency.

Suppose successive maxima occur at frequencies f_1 and f_2; that is, the phase change for f_1 is $2\beta_1 x + \phi_1$ and for f_2 is $2\beta_2 x + \phi_2$. The difference between successive maxima must be 2π radians.

$$\therefore\ 2\beta_2 x + \phi_2 = 2\beta_1 x + \phi_1 + 2\pi, \quad \text{where } f_2 > f_1.$$

$$\therefore\ x = \frac{\pi + \frac{1}{2}(\phi_1 - \phi_2)}{\beta_2 - \beta_1}.$$

But ϕ_1 and ϕ_2 are usually small and approximately equal.

$$\therefore\ x \approx \frac{\pi}{\beta_2 - \beta_1}.$$

But, $\beta = \omega\sqrt{(LC)}$ where L and C are the primary coefficients for loop inductance per kilometre and loop capacitance per kilometre.

$$\therefore\ x \approx \frac{\pi}{\omega_2\sqrt{(LC)} - \omega_1\sqrt{(LC)}} = \frac{\pi}{(\omega_2 - \omega_1)\sqrt{(LC)}},$$

$$= \frac{1}{2(f_2 - f_1)\sqrt{(LC)}}\ \text{kilometres.}$$

(*b*) The distance to the fault from the sending end is

$$\frac{1}{2 \times 2 \times 10^3\sqrt{(10^{-3} \times 10^{-7})}} = \frac{100}{4} = \underline{25\ \text{km}}.$$

Q2 (*a*) *Sketch the circuit arrangement of a frequency-measuring bridge.*

(*b*) *Derive an expression for the measured frequency in terms of the bridge components.*

(*c*) *State what precautions are necessary to give a reasonable degree of accuracy in the measurement.*

A2 See A2, Line Transmission C 1975, *Supplement*, Vol. 69, p. 77, Oct. 1976.

Q3 (*a*) *Explain the function of a 2-wire–4-wire terminating set in a repeatered audio circuit.*

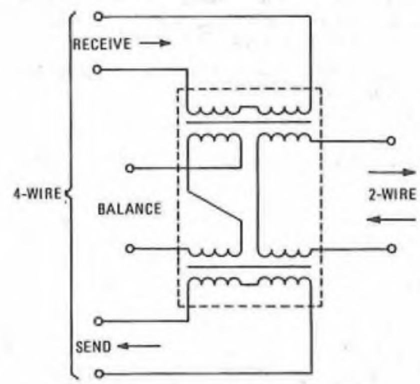
(*b*) *Sketch the circuit of such a set.*

(*c*) *Calculate the balance return-loss for a 2-wire line of impedance 800 ∠ −30° Ω and a balance resistor of 600 Ω.*

A3 (*a*) A 2-wire–4-wire terminating set is necessary at each end of a 4-wire audio-frequency, repeatered circuit to combine the unidirectional paths in the main 4-wire circuit with the bidirectional path in the 2-wire circuit. Theoretically, under ideal conditions, the signal passing from the 2-wire line to the SEND portion of the 4-wire circuit is attenuated by 3 dB, as is the signal passing from the RECEIVE path of the 4-wire circuit to the 2-wire line. In practice, however, there are losses in the transformers, and the balance is not a perfect match for the 2-wire line, so it is usual to allow for a 4 dB loss of signal power in both cases mentioned.

Similarly, the practical transmission loss from the 2-wire circuit to the balancing network and from the RECEIVE path to the SEND path is very high but not infinite as would be so theoretically.

(*b*) The circuit of a terminating set is shown in the sketch.



(*c*) The balance return-loss is a measure of the quality of the impedance match between a balancing network having an impedance Z_B and 2-wire line having an impedance Z_0.

$$\text{Balance return loss} = 20\log_{10}\left|\frac{(Z_0 + Z_B)}{(Z_0 - Z_B)}\right|\ \text{dB}.$$

$$Z_0 = 800\ \angle -30° = 800\cos(-30°) + \text{j}800\sin(-30°),$$

$$= 693 - \text{j}400\ \Omega,$$

and $$Z_B = 600\ \Omega.$$

$$\therefore\ \left|\frac{Z_0 + Z_B}{Z_0 - Z_B}\right| = \left|\frac{1293 - \text{j}400}{93 - \text{j}400}\right| = \frac{1353}{411} = 3{\cdot}29.$$

$$\therefore\ \text{balance return loss} = 20\log_{10} 3{\cdot}29 = \underline{10{\cdot}35\ \text{dB}}.$$

Q4 *A cable pair has a characteristic impedance of 800 Ω (non-reactive) and at a particular frequency is half a wavelength long. Its transmission loss is 6 dB. The far end is open-circuited.*

(*a*) *Obtain by phasor diagrams or otherwise*

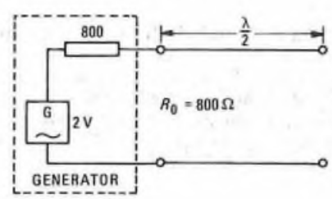
(*i*) *the current, and*
(*ii*) *the voltage*

at the input of the line assuming it to be fed from a matching source.

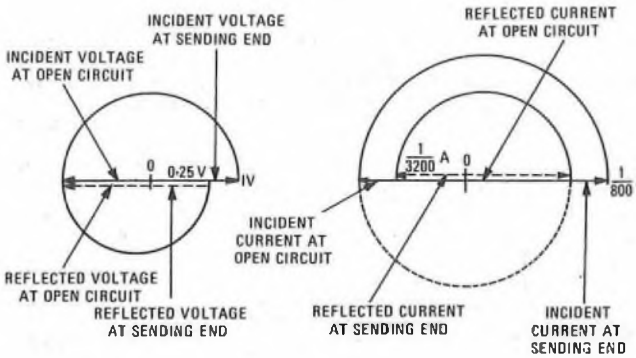
(*b*) *Calculate the input impedance.*

A4 (*a*) Assume the cable pair is fed by a generator having an internal impedance of 800 Ω and an EMF of 2 V as shown in sketch (*a*).

The phasor diagram for voltage is shown in sketch (*b*).



(*a*)



(*b*)

On reaching the far end, the phase of the voltage wave has changed by π rad and its magnitude has been attenuated by 6 dB. The far end is open circuit and therefore there is no change of phase at that point, and the wave is reflected back to the sending end with a further phase change of π rad and an attenuation of 6 dB.

Thus, the incident voltage wave returns to the sending end with an attenuation of 12 dB and a phase change of 2π rad (that is, in phase with the incident wave at the sending end).

The phasor diagram for current is also shown in sketch (*b*). This wave undergoes the same attenuation and change of phase as the voltage wave but also experiences a phase change of π rad at the open circuit.

Thus, the current wave undergoes an attenuation of 12 dB and a phase change of 3π rad by the time it returns to the sending end (that is, in antiphase to the incident wave).

Current at sending end	= 1/800 A
Received current at open circuit	= 1/1600 A
Reflected current at sending end	= 1/3200 A
Effective current at sending end	= 1/800 − 1/3200
	= 0·938 mA
Voltage at sending end	= 1 V
Received voltage at open circuit	= 1/2 V
Reflected voltage at sending end	= 1/4 V
Effective voltage at sending end	= 1·25 V

(*b*) Input impedance $= \dfrac{1\cdot25}{0\cdot938 \times 10^{-3}} = \underline{1333\ \Omega.}$

Q5 A cable pair has the following primary coefficients at an angular velocity of 5000 rad/s:

$R = 30\ \Omega/km$
$L = 1\ mH/km$
$G = 1\ \mu S/km$
$C = 0\cdot2\ \mu F/km.$

Calculate

(*a*) *the characteristic impedance,*
(*b*) *the attenuation coefficient,*
(*c*) *the phase-change coefficient, and*
(*d*) *the attenuation in decibels over a length of 15 km.*

A5 (*a*) For a uniform transmission line, the characteristic impedance, Z_0, is given by the expression

$$Z_0 = \sqrt{\left(\frac{R + j\omega L}{G + j\omega C}\right)} \text{ ohms,}$$

where R is the loop resistance in ohms per kilometre. L is the loop inductance in henrys/kilometre, G is the loop leakance in siemens per kilometre, C is the loop capacitance in farads per kilometre, and ω the angular velocity in radians/second.

Substituting the given values:

$$R + j\omega L = 30 + j5000 \times 10^{-3} = 30 + j5 = 30\cdot41 \angle 9\cdot46^\circ$$

$$G + j\omega C = 10^{-6} + j5000 \times 0\cdot2 \times 10^{-6} = (1 + j1000)10^{-6}$$
$$= 1000 \times 10^{-6} \angle 89\cdot94^\circ.$$

$$\text{Modulus of } Z_0 = \sqrt{\left(\frac{30\cdot41}{1000 \times 10^{-6}}\right)} = 174\cdot38\ \Omega.$$

$$\text{Argument of } Z_0 = \frac{9\cdot46^\circ - 89\cdot94^\circ}{2} = \angle -40\cdot24^\circ.$$

$\therefore$ the characteristic impedance $= \underline{174\cdot38 \angle -40\cdot24^\circ\ \Omega.}$

(*b*) The propagation coefficient of a uniform transmission line, γ, is given by the expression

$$\gamma = \sqrt{\{(R + j\omega L)(G + j\omega C)\}} = \alpha + j\beta,$$

where α is the attenuation coefficient (nepers per kilometre), and β is the phase change coefficient (radians per kilometre).

$$\therefore\ \gamma = \sqrt{(30\cdot41 \times 1000 \times 10^{-6})}\ \angle \frac{9\cdot46 + 89\cdot94}{2}$$
$$= 0\cdot1744 \angle 49\cdot7^\circ.$$

Attenuation coefficient, α, $= 0\cdot1744 \cos 49\cdot7^\circ = \underline{0\cdot1128\ \text{Np/km.}}$

(*c*) Phase change coefficient, β, $= 0\cdot1744 \sin 49\cdot7^\circ$
$= \underline{0\cdot133\ \text{rad/km.}}$

(*d*) Attenuation over a length of 15 km $= 0\cdot1128 \times 15$
$= 1\cdot692$ Np
$= \underline{14\cdot69\ \text{dB.}}$

Q6 (*a*) *Show how a superposed (phantom) circuit can be provided over two cable pairs.*

(*b*) *How can crosstalk between the phantom and side circuits be minimized?*

(*c*) *Explain how the phantom circuit can be coil-loaded without effect on the side circuits.*

A6 See A1, Line Transmission C 1975, *Supplement*, Vol. 69, p. 76, Oct. 1976.

Q7 For a uniform transmission line, the propagation coefficient is given by the expression

$$\gamma = \sqrt{\{(R + j\omega L)(G + j\omega C)\}}$$

where R, L, G and C are the primary coefficients.

(*a*) *From this expression derive an approximate expression for the high-frequency attenuation in terms of the primary coefficients only.*

(*b*) *Explain why, in practice, the high frequency attenuation varies with frequency.*

A7 (*a*) Given that $\gamma = \sqrt{\{(R + j\omega L)(G + j\omega C\}}$,

$$R + j\omega L = j\omega L\left(\frac{R}{j\omega L} + 1\right),$$

and
$$G + j\omega C = j\omega C\left(\frac{G}{j\omega C} + 1\right).$$

Thus

$$(R + j\omega L)(G + j\omega C) = j\omega L j\omega C\left(1 + \frac{R}{j\omega L} + \frac{G}{j\omega C} - \frac{RG}{\omega^2 LC}\right),$$

and
$$\gamma = j\omega\sqrt{\left\{LC\left(1 + \frac{R}{j\omega L} + \frac{G}{j\omega C} - \frac{RG}{\omega^2 LC}\right)\right\}}.$$

At high frequencies, the term containing ω^2 in the denominator can be neglected. Thus, using the binomial expansion and again ignoring terms containing ω^2 and the higher powers of ω in the denominator

$$\gamma = j\omega\surd(LC)\left\{1 + \frac{1}{2}\left(\frac{R}{j\omega L} + \frac{G}{j\omega C}\right)\right\}.$$

$$\therefore\ \gamma \approx j\omega\surd(LC) + \frac{R}{2}\sqrt{\left(\frac{C}{L}\right)} + \frac{G}{2}\sqrt{\left(\frac{L}{C}\right)}.$$

But
$$\gamma = \alpha + j\beta,$$

where α is the attenuation coefficient and β is the phase coefficient. Therefore by equating the real parts, at high frequencies

$$\alpha \approx \frac{R}{2}\sqrt{\left(\frac{C}{L}\right)} + \frac{G}{2}\sqrt{\left(\frac{L}{C}\right)} \text{ Nepers per kilometre.}$$

(*b*) Part (*a*) of this question shows that at high frequencies the attenuation coefficient has two terms. The first term represents the series loss, and as shown, it is proportional to *R*, whilst the second represents the shunt loss, and is proportional to *G*.

In modern high-quality cables, *G*, and hence the shunt loss, is very small, and so the series loss, and thus *R*, becomes the main factor of the attenuation coefficient.

At high frequencies, due to the skin effect, the effective resistance becomes proportional to the square root of the frequency, that is, the attenuation coefficient is substantially proportional to the square root of the frequency.

Q8 (*a*) *Show how the sending performance and receiving performance of a central-battery telephone set both depend upon the electrical properties of the local line.*

(*b*) *Explain why side tone is a desirable feature of the telephone set and state how it affects the sending performance.*

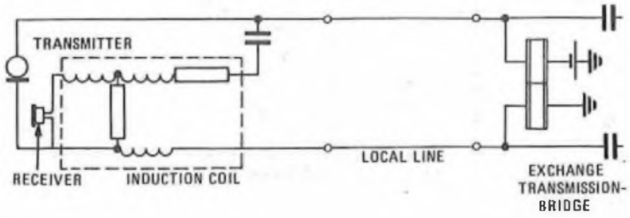
A8 (*a*) In a central-battery telephone set, the carbon transmitter is connected in series with the line and is energized by the direct current fed through the exchange transmission bridge along the customer's line. The receiver, however, is connected through an induction coil, which also improves the matching between the receiver impedance and the line impedance.

The signal sent to line depends upon the sensitivity of the transmitter which, in turn, depends upon the feeding current, and thus upon the resistance of the local line. On short lines, if the resistance is low, the transmitter output may be uncomfortably high, and some modern telephones have a regulating device to prevent this, while ballast resistors can be fitted in the battery feed to regulate the feeding current to the exchange transmission-bridge. In practice, the upper limit of line resistance is determined by the requirements of the signalling system, rather than by the transmission needs. The present value is 1000 Ω.

The loudness of the received signal depends mainly upon the sensitivity of the receiver and the arrangement of the induction coils. In modern telephones, it is possible to make the sending efficiency of the telephone set equal to the receiving efficiency.

The attenuation of the local line affects both sending and receiving efficiency and the present limit is 10 dB at 1·6 kHz.

The sketch shows the basic elements of a central-battery telephone.



(*b*) Side tone is a desirable feature of the telephone set because, when the telephone is in use, the faint sound of the speaker's own voice suggests that the system is working correctly. If the level of side tone is too high, he thinks he is speaking too loudly and lowers his voice to the possible detriment of the listener at the other end.

Q9 (*a*) *Sketch the cabling layout of a typical rack of mains-operated transmission equipment in a repeater station.*

(*b*) *Show how power can be maintained in the event of a mains failure.*

(*c*) *Explain how interference between power and transmission circuits can be kept to an acceptably low level.*

Q10 (*a*) *Draw block diagrams to show the essential features of a transmission system over a coaxial cable.*

(*b*) *Explain the function of each block.*

(*c*) *Show how power can be fed over the cable to a buried repeater.*

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