SUPPLEMENT

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## TEC: REVISION GUIDANCE
## CGLI: MODEL ANSWERS, 1976–77

## Contents



# TECHNICIAN EDUCATION COUNCIL

## Revision Guidance for Level-1 Units

The organization and structure of Technician Education Council (TEC) courses are described in the January 1978 issue of the *POEEJ* (p. 219). At the end of the academic year 1977–78, a number of students will sit examinations at level 1 of the TEC's Certificate Programme in Telecommunications. As an aid to revision, details of the content of 3 standard level-1 units are given below, together with references to model answers to past City and Guilds of London Institute (CGLI) examination questions that most closely match the TEC syllabi.

For Physical Science 1 and Telecommunication Systems 1, two tables of references are given. In each case, the first table lists the topics covered by the unit (and allocates a number to each topic), and gives references to model answers in past issues of the *Supplement;* the second relates the topic numbers to questions in the *POEEJ*'s series of model-answer books. For Mathematics 1, only references to answers in past *Supplements* are given; no suitable model-answer book is available. The abbreviations used are explained on p. 83.

Back numbers of the *POEEJ* and *Supplement*, and the various model-answer books, can be ordered using the form on p. 96 of this *Supplement*. The order form shows in which issues the references made below appear. The 1977 papers referred to are in this issue of the *Supplement*.

### MATHEMATICS 1

**The coverage and standard of this unit are similar to those of the CGLI subject Practical Mathematics**

| | Topic | *Supplement* References |
|---|---|---|
| 1 | Arithmetic operations. Rules of precedence. Integers and fractions. Ratio and proportion. Decimals. Percentages | PM: A4(*c*) 1973, A1(*c*) 1974, A1(*c*) 1975, A6(*a*) 1975, A1(*b*) 1977, A5(*c*) 1977 |
| 2 | Indices. Mantissa and exponent. Standard form. Binary form. Binary arithmetic. ON/OFF characteristic of binary digits | PM: A6(*a*) 1972, A2(*a*) 1974, A4(*b*) 1974, A6(*b*) 1975, A2(*c*) 1976, A3(*a*)(*ii*)(*iii*)(*b*) 1977<br>MA: A4(*d*) 1972, A4(*b*) 1974, A1(*c*) 1975, A9(*c*)(*d*)(*i*) 1975, A10(*e*)(*i*) 1976 |
| 3 | Accuracy and validity. Approximate evaluation | PM: A2(*a*)(*i*) 1973, A2(*b*) 1976, A4(*c*) 1977<br>MA: A7(*b*) 1972, A9(*a*) 1974, A9(*e*) 1975, A10(*b*) 1976 |
| 4 | Use of tables. Principle and use of logarithms. Principle and use of slide rule. Use of calculating machines. Relative merits of tables, slide rule and machines | PM: A3 1972, A7 1972, A2(*a*)(*ii*) 1973, A3 1973, A2(*b*) 1974, A3 1975, A4 1975, A8(*b*)(*iii*)(*iv*) 1975, A4 1976, A5(*a*)(*b*) 1976, A1(*a*)(*i*)–(*iii*) 1977, A3(*c*) 1977<br>MA: A10(*a*) 1976 |
| 5 | Algebraic representation. Manipulation of algebraic expressions. Factorizing. Solution of simple and simultaneous linear equations. Transposition and evaluation of formulae | PM: A6(*b*)(*c*) 1972, A1 1973, A2(*b*) 1973, A5(*a*)(*b*) 1973, A7 1973, A1(*a*)(*b*) 1974, A5 1974, A8(*b*) 1974, A1(*a*)(*b*) 1975, A5 1975, A6(*c*) 1975, A8(*a*) 1975, A1 1976, A2(*a*) 1976, A3 1976, A5(*c*) 1976, A6(*b*)(*i*) 1976, A8 1976, A2 1977, A3(*a*)(*i*) 1977, A5(*a*)(*b*)(*d*) 1977, A10(*c*) 1977<br>MA: A2(*a*) 1972, A4(*c*) 1972, A1(*b*) 1975, A7(*a*) 1976 |
| 6 | Graphical representation and interpretation. Axes, scales and co-ordinates. Linear graphs. Gradients | PM: A6 1973, A3 1974, A9 1974, A2 1975, A6(*a*)(*b*)(*ii*) 1976, A7 1976, A6 1977, A9 1977 |
| 7 | Collection and tabulation of data. Pictograms, bar charts and pie diagrams. Histograms | — |

| | | |
|---|---|---|
| 8 | Geometry of angles. Geometry of triangles. Theorem of Pythagoras. Similarity and congruency. Geometry of circles. Chords, tangents, sectors, segments and arcs. Radians and angular rotation | PM: A9 1972, A4(*a*)(*b*) 1973, A9 1973, A6(*b*) 1974, A10(*a*) 1974, A9(*a*) 1975, A9(*b*) 1976, A4(*a*)(*b*) 1977, A7(*b*) 1977, A8(*a*)(*c*) 1977<br>MA: A8(*a*) 1972, A10(*a*) 1974, A3(*a*)(*b*) 1976 |
| 9 | Properties of quadrilaterals. Areas of squares, rectangles, parallelograms and circles. Volumes of cylinders, prisms, cones, pyramids and spheres. Surface areas of cylinders and prisms | PM: A5 1972, A8 1973, A4(*a*) 1974, A9(*b*) 1975, A4(*c*) 1977, A7(*a*) 1977, A8(*b*) 1977<br>MA: A10 1973, A10(*b*) 1974, A10(*a*) 1975 |
| 10 | Sine, cosine and tangent ratios. Trigonometrical tables. Fractional form of ratios for common angles. Sine and cosine curves | PM: A10 1972, A10 1973, A6(*a*)(*c*) 1974, A7 1974, A8(*a*)(*i*) 1974, A10(*b*) 1974, A7 1975, A8(*b*)(*i*)(*ii*) 1975, A1(*a*)(*iv*) 1977, A10(*a*)(*b*) 1977<br>MA: A5(*a*) 1972 |

## PHYSICAL SCIENCE 1

**The coverage and standard of this unit are very similar to those of the CGLI subject Engineering Science**

| | Topic | *Supplement* References |
|---|---|---|
| 1 | Components in tension, compression and shear. Elasticity and Hooke's law. Behaviour of brittle and malleable materials. Load/extension graphs for ductile and brittle materials | ES: A3(*a*) 1973, A3(*b*) 1976 |
| 2 | Energy sources, forms of energy and energy conversion. Definitions and units of energy, work, force, efficiency and power. Force/distance graphs | ES: A4(*b*) 1971, A1 1973, A3 1975, A1 1976, A3(*a*)(*c*) 1977<br>TPA: A2 1973 |
| 3 | Temperature and heat. Celsius scale and thermometers. Specific heat. Conduction, convection and radiation. Insulation. Physical effect of heat. Thermal movement | ES: A4(*a*) 1971, A5(*a*) 1973, A3 1975, A8(*a*) 1976<br>ETP: A6 1972 |
| 4 | Waves, wavelength, frequency and velocity. Sound as a pressure wave. Reflection and refraction of waves and sound. Velocity of sound. Production of sound by vibrations | — |
| 5 | SI units and preferred component symbols. Current and potential difference; their relationship for resistors and non-linear components; use of ammeter and voltmeter. Resistance and Ohm's law. Resistors in series and parallel. Simple series and parallel circuits. Dependence of resistance on dimensions, material and temperature of conductor. Lamp circuits. Magnetic, chemical and heating effects of current. Power in electrical circuits | ES: A5(*b*) 1972, A5(*b*) 1973, A5(*a*)(*c*) 1974, A5(*a*) 1975, A5 1976, A5(*a*) 1977, A9 1977<br>ETP: A2(*a*)(*b*) 1973, A10(*a*) 1974, A7(*a*) 1975, A9(*a*) 1976<br>TPA: A1 1974, A4 1974, A5 1976 |
| 6 | (Qualitative treatment only.) Magnetic fields and forces. Field patterns of bar magnet, current-carrying conductor and solenoid. Moving-coil meter, DC motor and AC generator | ES: A7(*a*) 1972, A9(*c*) 1972, A9(*a*)(*b*) 1975, A7 1976, A9(*c*) 1976, A8 1977, A10(*a*) 1977<br>TPA: A5(*a*) 1975 |
| 7 | Speed and distance/time graphs. Velocity, acceleration and speed/time graphs. Acceleration due to gravity. Equations of motion. Force and acceleration. Angular velocity and tangential velocity. Friction (may be omitted) | ES: A3 1971, A2 1972, A2 1973, A4 1973, A2 1974, A3 1974, A2 1975, A4 1975, A2 1976, A4 1976, A2 1977, A3(*b*) 1977 |
| 8 | Scalars and vectors. Force as a vector. Triangle of forces | ES: A4 1972, A1 1974, A1 1977 |
| 9 | Conduction in solids and liquids. Electroplating. Simple cell. Electrochemical series. Corrosion | ES: A6 1972<br>ETP: A2(*a*) 1972, A2(*d*) 1973 |
| 10 | Temperature coefficient of resistance. Resistivity. Conductors and insulators | ES: A5 1971, A7(*a*) 1971, A7(*b*) 1972, A8(*a*) 1972, A6 1973, A5(*b*) 1974, A6 1974, A6 1975, A8(*b*) 1976, A7 1977 |
| 11 | EMF and high-resistance voltmeters. Internal resistance. Primary and secondary cells. Charging and discharging. Cells in series and parallel. Lead-acid, alkaline and mercury cells | ES: A7(*b*) 1971, A5(*a*) 1972, A7 1973, A5(*b*) 1975, A7(*a*)(*b*) 1975, A6 1976, A5(*b*) 1977, A6 1977<br>ETP: A3 1975 |

### MODEL-ANSWER BOOK REFERENCES FOR PHYSICAL SCIENCE 1

| Model-Answer Book References | Topics Covered |
|---|---|
| ETP: Q54 (sketch (*a*)) | 4 |
| Q41, Q42 (first part), Q46 (second part) | 5 |
| Q24, Q25 | 11 |
| LPPA: Q14.2(*a*) | 9 |

## TELECOMMUNICATION SYSTEMS 1

**The topics in this unit cover areas similar, in the main, to parts of the CGLI subjects Elementary Telecommunication Practice, Radio and Line Transmission A, and Telephony and Telegraphy A**

| | Topic | *Supplement* References |
|---|---|---|
| 1 | Methods of transmitting information. Signals. Limitations of DC signals. Characteristics and information-carrying properties of AC signals. Complex waves. The frequency spectrum and its uses | ETP: A8 1972, A7 1973, A3 1974, A9 1975, A3 1976<br>RLTA: A5(*d*) 1976<br>TTA: A10 1969, A4 1974, A2(*a*) 1975, A4 1976<br>TgB: A5 1969, A5(*a*) 1972, A1 1974 |
| 2 | Modulation and demodulation. Carriers. Amplitude, frequency and pulse modulation. Bandwidth and sidebands | RLTA: A1(*a*) 1973, A1(*a*) 1974, A5(*a*)(*b*) 1974, A2(*a*)(*ii*) 1976, A5(*a*)(*b*)(*c*) 1976, A4 1977, A8(*a*) 1977<br>RLTB: A2(*a*) 1975 TPB: A9(*a*)(*b*) 1975<br>BMCC: A6(*b*) 1975 CRC: A7 1969<br>TPC: A7(*a*)(*b*) 1973 |
| 3 | Commercial radio-broadcast system (block diagram with waveforms). Transmission media. Propagation and reflection of radio waves. Propagation paths. Two-way radio-telephony system | RLTA: A10(*a*)(*iii*)(*iv*) 1975<br>RLTB: A6(*a*) 1973 |
| 4 | Television systems and receivers. Cathode-ray tube. Scanning, lines, aspect ratio, fields and interlacing | TPC: A9 1973 |
| 5 | Principles and uses of radar systems. Common navigational systems | — |
| 6 | Telephony and telegraphy networks. Hierarchical structure. Local distribution network. Supervisory signals | ETP: A1(*c*) 1972, A4(*a*) 1973, A10(*b*) 1973, A4(*a*) 1975, A5 1975, A5(*a*)(*iv*)(*v*) 1976<br>LPPA: A10 1976 RLTA: A10(*a*)(*i*)(*ii*) 1975<br>TTA: A3 1969, A8 1969, A8(*b*) 1974, A4(*c*) 1975<br>TpC: A6(*a*)(*b*) 1975 |
| 7 | The matrix switch. Inlets, outlets and crosspoints. Simultaneous calls | TTA: A8 1973, A8 1976<br>TpB: A9 1974 |
| 8 | The step-by-step system. Switching stages. Group and final selection. Trunking diagrams | TTA: A7(*a*)(*b*) 1973, A8(*a*) 1974, A4(*a*) 1975, A6(*a*) 1975 |
| 9 | Principles of carbon-granule transmitter and rocking-armature receiver. Simple local-battery telephone circuit | ETP: A9 1972, A10(*a*) 1973, A6(*a*) 1975, A2 1976<br>RLTA: A3(*a*) 1974 |
| 10 | Noise and signal strength. Attenuation. Amplification | RLTA: A10(*b*) 1975, A2(*a*)(*i*) 1976, A3(*a*) 1977 |
| 11 | Data terminology. Types and uses of computer. Typical data-communication systems. Two-state codes. Input and output devices | CA: A1(*a*) 1971, A7 1971, A1(*a*)(*b*) 1973, A1 1974, A6(*a*) 1976 |

## MODEL-ANSWER BOOK REFERENCES FOR TELECOMMUNICATION SYSTEMS 1

| | Model-Answer Book References | Topics Covered |
|---|---|---|
| ETP: | Q51 | 1 |
| | Q4 | 6 |
| | Q53(*a*), Q54, Q56, Q57, Q59 | 9 |
| RLTA: | Q3.1 (first and second parts), Q3.2(*a*), Q3.3 (first part), Q3.4(*a*), Q3.5(*a*), Q4.1 (first part), Q4.2(*a*), Q4.3 (first part), Q4.4(*a*)(*b*), Q11.1 (second part), Q11.4 (first and second parts) | 2 |
| | Q1.2 | 3, 6 |
| | Q1.1 | 3, 6, 10 |
| | Q1.3, Q1.4 | 3, 10 |
| | Q6.1 (sketch (*a*)), Q6.5 (first part), Q6.7 (sketch (*b*)) | 9 |
| TTA: | Q3.1 (first part), Q4.1, Q4.2, Q4.3 (first part), Q4.4(*a*) | 1 |
| | Q3.2, Q3.3 | 1, 6, 10 |
| | Q5.1 (first part), Q5.2, Q10.2 (third part) | 6 |
| | Q8.1 | 7 |
| | Q10.1 (first part), Q10.2 (first part), Q10.4(*a*)(*b*) | 8 |

BMCC: Basic Microwave Communication C
CA: Computers A
CRC: Communication Radio C
ES: Engineering Science
ETP: Elementary Telecommunication Practice
LPPA: Line Plant Practice A
MA: Mathematics A
PM: Practical Mathematics
RLTA, RLTB: Radio and Line Transmission A, B
TgB: Telegraphy B
TpB, TpC: Telephony B, C
TPA, TPB, TPC: Telecommunication Principles A, B, C
TTA: Telephony and Telegraphy A

# CITY AND GUILDS OF LONDON INSTITUTE

## Questions and Answers

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

### PRACTICAL MATHEMATICS 1977

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

*Q 1* (*a*) *Evaluate the following, using mathematical tables only:*

(*i*) $\sqrt{0\cdot732}$,

(*ii*) $\dfrac{1}{12\cdot3}-\dfrac{1}{18\cdot6}$,

(*iii*) $0\cdot827^2+1\cdot072^2$, *and*

(*iv*) $6\cdot24\sin 72°$.

(*b*) *A television set is sold with a reduction of 16% on its original price for £147, and resold for £189. Calculate*

(*i*) *its original price, and*

(*ii*) *the profit, expressed as a percentage of the price paid.*

**A 1** (*a*) (*i*) From a table of square roots, $\sqrt{0\cdot732}=\underline{0\cdot8556}$.

(*ii*) From a table of reciprocals,

$$\frac{1}{12\cdot3}-\frac{1}{18\cdot6}=0\cdot08130-0\cdot05376=\underline{0\cdot02754}.$$

(*iii*) $0\cdot827^2+1\cdot072^2$

$$\begin{aligned}&=\text{antilog}\,(2\log 0\cdot827)+\text{antilog}\,(2\log 1\cdot072),\\&=\text{antilog}\,(2\times\bar{1}\cdot9175)+\text{antilog}\,(2\times0\cdot0302),\\&=\text{antilog}\,\bar{1}\cdot8350+\text{antilog}\,0\cdot0604,\\&=0\cdot6839+1\cdot1492=\underline{1\cdot8331}.\end{aligned}$$

(*iv*) From a table of sines,

$$\begin{aligned}6\cdot24\sin72°&=6\cdot24\times0\cdot9511,\\&=\underline{5\cdot934}.\end{aligned}$$

| Number | Logarithm |
|---|---|
| 6·24 | 0·7952 |
| 0·9511 | $\bar{1}$·9782 + |
| 5·934 | 0·7734 |

(*b*) (*i*) The price paid (£147) is 100 − 16 = 84% of the original price. Hence, the original price

$$=£147\times\frac{100}{84}=\underline{£175}.$$

(*ii*) The profit $=£189-£147=£42$.

The percentage profit $=\dfrac{£42}{£147}\times100\%=\underline{28\cdot57\%}$.

*Q 2* (*a*) *Using a constant, k, write down formulae which express the following statements:*

(*i*) *the length, L, varies directly as the volume, V, and inversely as the area, A, and*

(*ii*) *the number of swings, N, per minute of a pendulum varies inversely as the square root of its length, d.*

(*b*) *In part (a) (ii), evaluate k if N = 100 and d = 0·81.*

(*c*) *Solve for ω the equation* $\frac{1}{3}(\omega+3)-\frac{1}{6}(3\omega-2)=\frac{1}{2}$.

(*d*) *Solve for s and t:* $3s-2t=0\cdot1$,

$$s+3t=2\cdot6.$$

**A 2** (*a*) (*i*) $\underline{L=\dfrac{kV}{A}}$. (*ii*) $\underline{N=\dfrac{k}{\sqrt{d}}}$.

(*b*) From part (*a*) (*ii*), $k=N\sqrt{d}=100\times\sqrt{0\cdot81}=\underline{90}$.

(*c*) Multiplying the given equation by 6 gives

$$2(\omega+3)-(3\omega-2)=3.$$

$$\therefore\ 2\omega+6-3\omega+2=3.$$

$$\therefore\ -\omega=3-8,\ \text{whence}\ \underline{\omega=5}.$$

(*d*)

$$3s-2t=0\cdot1, \qquad \ldots\ldots (1)$$

$$s+3t=2\cdot6. \qquad \ldots\ldots (2)$$

Multiplying equation (2) by 3 gives $3s+9t=7\cdot8$. ...... (3)

Subtracting equation (1) from equation (3) gives

$$11t=7\cdot7.$$

$$\therefore\ \underline{t=0\cdot7}.$$

Substituting for $t$ in equation (2) gives

$$s+2\cdot1=2\cdot6.$$

$$\therefore\ \underline{s=0\cdot5}.$$

*Q 3* (*a*) *Simplify:*

(*i*) $3a-[4(2a-b)-3a]$,

(*ii*) $(-2t^2)^3$, *and*

(*iii*) $4a^{-3}b^{-2}\div2a^{-4}b$, *expressing the answer in positive indices.*

(*b*) *Express the following in the form* $a\times10^n$, *where a is a number between 1 and 10 and n is a positive or negative whole number:*

(*i*) *0·000793,* (*ii*) *34 000 000, and* (*iii*) $0\cdot72\div12\,000$.

(*c*) *The scale of a slide rule is numbered 1 to 10, and the measured distance between 1 and 10 is 30 cm. Calculate the distance on the slide rule between the digits 2 and 5.*

**A 3** (*a*) (*i*) $3a-[4(2a-b)-3a]=3a-[8a-4b-3a]$,

$$=3a-5a+4b=\underline{4b-2a}.$$

(*ii*) $(-2t^2)^3=(-2)^3t^6=\underline{-8t^6}$. (*iii*) $\dfrac{4a^{-3}b^{-2}}{2a^{-4}b}=\dfrac{4a^4}{2a^3b^2b}=\underline{\dfrac{2a}{b^3}}$.

(*b*) (*i*) $0\cdot000\,793=\underline{7\cdot93\times10^{-4}}$. (*ii*) $34\,000\,000=\underline{3\cdot4\times10^7}$.

(*iii*) $$\frac{0\cdot72}{12\,000}=\frac{72\times10^{-2}}{12\times10^3}=\underline{6\times10^{-5}}.$$

(*c*) The measured distance to a number along a slide-rule scale is proportional to the logarithm of the number. Since $\log_{10}1=0$ and $\log_{10}10=1$, the scale length of 30 cm is proportional to unity.

Now, $\log_{10}2=0\cdot301$ and $\log_{10}5=0\cdot699$. Hence, the logarithmic distance between 2 and 5 $=(0\cdot699-0\cdot301)\times30=\underline{11\cdot94\text{ cm}}$.

*Q 4* *Fig. 1 shows the net of a cube with edges 4 cm in length.*

(*a*) *On the net, calculate*

(*i*) *the length of MF,*

(*ii*) *the distance from the mid-point of AC to the mid-point of IK, and*

(*iii*) *the angle BJK to the nearest minute.*

(*b*) *On the cube, find*

(*i*) *the length of MF,*

(*ii*) *the distance between the mid-points of AC and IK, and*

(*iii*) *the length of the longest diagonal.*

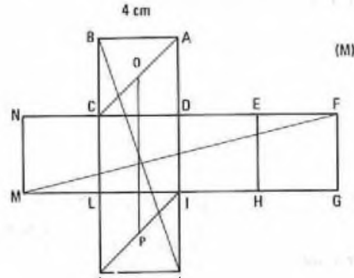
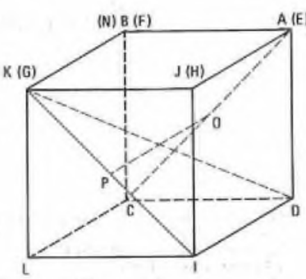



*Fig. 1*




(*a*)

*(c) The diameter, 8·50 cm, of a cylinder was measured as 8·65 cm. Calculate*

*(i) the percentage error in the measurement, and*

*(ii) the percentage error caused by this measurement in the calculation of the volume.*

A 4 (*a*) On Fig. 1, the lines MF, AC, IK and BJ have been drawn (faint lines). Point O, midway between A and C is joined to point P, the mid-point of IK.

(*i*) In triangle MFG, by the theorem of Pythagoras,

$$MF^2 = MG^2 + FG^2 = (4 \times 4)^2 + 4^2 \text{ cm}^2.$$

$$\therefore\ MF = \sqrt{(256 + 16)} = \sqrt{272} = \underline{16{\cdot}49 \text{ cm.}}$$

(*ii*) Because squares ABCD and ILKJ are congruent, CO and KP are equal and parallel. Hence, COPK is a parallelogram.

$$\therefore\ OP = CK = 2 \times 4 = \underline{8 \text{ cm.}}$$

(*iii*) Now,
$$\tan \angle BJK = \frac{BK}{KJ} = \frac{3 \times 4}{4}.$$

$$\therefore\ \angle BJK = \tan^{-1} 3 = \underline{71^\circ\, 34'.}$$

(*b*) The cube is shown in sketch (*a*), drawn with face CDIL at the base, face ABCD at the rear and face IJKL at the front. Face MNCL forms the left-hand side, and faces DEHI and EFGH fold to form the right-hand side and top, giving the coincident letters shown.

(*i*) MF becomes equal to FG, and is therefore $\underline{4 \text{ cm}}$.

(*ii*) The mid-points of AC and IK are the centres of opposite faces, so that OP is $\underline{4 \text{ cm}}$.

(*iii*) The longest diagonal is that between diametrically opposite corners; there are 4 such diagonals (KD, JC, IB and LA) and these are all of equal length. Taking triangle KID, in which $\angle KID = 90^\circ$,

$$KD^2 = KI^2 + ID^2.$$

But, in triangle KLI, in which $\angle KLI = 90^\circ$,

$$KI^2 = KL^2 + LI^2 = 4^2 + 4^2 = 32 \text{ cm}^2.$$

$$\therefore\ KD = \sqrt{(32 + 4^2)} = \sqrt{48} = \underline{6{\cdot}928 \text{ cm.}}$$

(*c*) (*i*) The error $= \dfrac{8{\cdot}65 - 8{\cdot}50}{8{\cdot}50} \times 100 = \underline{1{\cdot}765\%.}$

(*ii*) The volume of a cylinder is $\pi d^2 h/4$, where $d$ is the diameter and $h$ the height. As the height does not alter in this case, the volume can be expressed as $kd^2$, where $k$ is a constant. Thus, the true volume is $k8{\cdot}5^2$ centimetres³ and the calculated volume is $k8{\cdot}65^2$ centimetres³. Hence, the error

$$= \frac{k8{\cdot}65^2 - k8{\cdot}5^2}{k8{\cdot}5^2} \times 100 = \frac{74{\cdot}82 - 72{\cdot}25}{72{\cdot}25} \times 100 = \underline{3{\cdot}56\%.}$$

*Q 5 (a) Evaluate P using the formula* $P = \dfrac{E^2R}{(R + r)^2}$, *when* $E = 5{\cdot}0$, $r = 0{\cdot}09$ *and* $R = 9{\cdot}1$.

*(b) Make E the subject of the formula in part (a).*

*(c) If E is doubled and R and r are increased by 50%, by what proportion does P change?*

*(d) If R = 5r, find a formula for r in terms of P and E.*

A 5 (*a*)
$$P = \frac{E^2R}{(R + r)^2} = \frac{25 \times 9{\cdot}1}{9{\cdot}19^2} = \underline{2{\cdot}694.}$$

(*b*)
$$E^2R = P(R + r)^2.$$

$$\therefore\ E = \sqrt{\left\{\frac{P}{R}(R + r)^2\right\}} = \underline{(R + r) \times \sqrt{\frac{P}{R}}}.$$

(*c*) The new value of $R$ is $1{\cdot}5R$, and the new value of $r$ is $1{\cdot}5r$. If $P'$ is the new value of $P$,

$$P' = \frac{(2E)^2 \times 1{\cdot}5R}{(1{\cdot}5R + 1{\cdot}5r)^2} = \frac{4 \times 1{\cdot}5 \times E^2R}{1{\cdot}5^2 \times (R + r)^2} = \frac{4}{1{\cdot}5} \times P = 2\tfrac{2}{3}P.$$

Therefore, $P$ increases in the ratio $\underline{2\tfrac{2}{3} : 1}$.

(*d*) When $R = 5r$, $P = \dfrac{E^2 \times 5r}{(5r + r)^2} = \dfrac{5E^2r}{36r^2}$, whence $\underline{r = \dfrac{5E^2}{36P}}$.

*Q 6 In an experiment, a load exerting a force of N newtons was suspended by a wire L metres long. The readings of L for various values of N were recorded as follows.*

| *N* | *400* | *450* | *500* | *550* | *600* | *650* | *700* |
|---|---|---|---|---|---|---|---|
| *L* | *0·200* | *0·206* | *0·213* | *0·220* | *0·230* | *0·234* | *0·240* |

*The variation should show the relationship* $N = aL + b$.

*(a) Use appropriate scales to plot a graph to show the relationship.*

*(b) (i) Indicate and determine the major experimental error.*

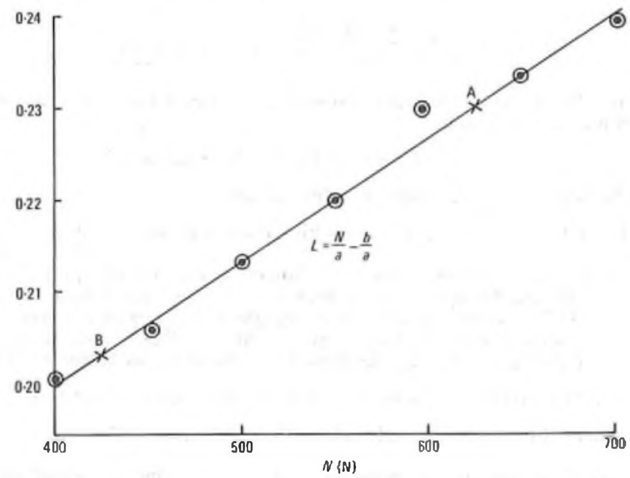
*(ii) Ignoring the error, verify that the relationship is otherwise true.*

*(iii) Estimate from the graph values of a and b.*

*(c) (i) Use the values of a and b to rewrite the relationship.*

*(ii) What would be the correct value for L in part (b)(i), assuming N was always correct?*

A 6 (*a*) The graph is shown in the sketch. With the exception of one point (600, 0·230), a straight line passes through or very close to the plotted points.




(*b*) (*i*) The major experimental error occurs at point (600, 0·230), at which the value of $L$ is approximately $\underline{0{\cdot}003 \text{ m}}$ too high.

(*ii*) The straight line passes through or very close to all the other points, indicating that the linear relationship $N = aL + b$ is true.

(*iii*) The values of $a$ and $b$ are obtained by substituting into the equation $N = aL + b$ the co-ordinates of 2 convenient and widely separated points actually lying on the graph. Taking points **A** and **B** respectively,

$$625 = 0{\cdot}23a + b, \qquad \ldots\ldots (1)$$

and
$$425 = 0{\cdot}203a + b. \qquad \ldots\ldots (2)$$

Subtracting equation (2) from equation (1) gives

$$200 = 0{\cdot}027a, \text{ whence } \underline{a = 7407.}$$

Substituting for $a$ in equation (1) gives

$$625 = 0{\cdot}23 \times 7407 + b, \text{ whence } b = 625 - 1704 = \underline{-1079.}$$

(*c*) (*i*) From part (*b*) (*iii*), $N = 7407L - 1079$.

$$\therefore\ L = \frac{N}{7407} + \frac{1079}{7407} = 0{\cdot}000135N + 0{\cdot}1456.$$

$$\therefore\ \underline{L \approx 0{\cdot}000135N + 0{\cdot}146.}$$

(*ii*) The correct value of $L$ in part (*b*) (*i*)

$$= 0{\cdot}000135 \times 600 + 0{\cdot}1456 = 0{\cdot}2266 \approx \underline{0{\cdot}227 \text{ m.}}$$

*Q 7 (a) Fig. 2 shows the cross-section of a piece of moulding (which has a mass of 1 kg) formed by 3 quadrants of a circle, of centre 0, and a square of side 8 cm. Using* $\pi = 3{\cdot}142$,

*(i) calculate the cross-sectional area of the moulding, and*

*(ii) find the length of moulding which has a mass of 1 kg if the material of the moulding has a density of 62·7 kg/m³.*

(*b*) *An isosceles triangle has sides of 12 cm, 12 cm and 16 cm. Calculate*
(*i*) *its area, and*
(*ii*) *its non-equal angle.*

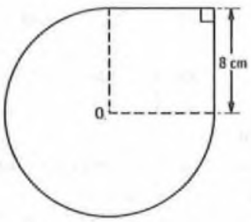
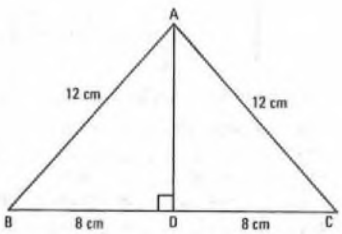



*Fig. 2*




(*a*)

A 7 (*a*) (*i*) The cross-sectional area, $A$, of the moulding is three-quarters of the area of a circle plus the area of a square, where the radius of the circle and the side length of the square are both equal to 8 cm.

$$\therefore A = \frac{3 \times 3\cdot142 \times 8^2}{4} + 8^2 = \underline{214\cdot8 \text{ cm}^2.}$$

(*ii*) Let $L$ be the length of moulding having a mass of 1 kg. The volume of this length

$$= LA = L \times 214\cdot8 \times 10^{-4} \text{ metres}^3.$$

But mass is density multiplied by volume, or

$1 = 62\cdot7 \times L \times 214\cdot8 \times 10^{-4}$ kilograms, whence $\underline{L = 0\cdot7425 \text{ m}.}$

(*b*) (*i*) The isosceles triangle is illustrated in sketch (*a*); AD is the perpendicular through A to the base BC, and bisects the base so that BD = DC = 8 cm. The area of a triangle is half the base multiplied by the perpendicular height; thus, the area is BD × AD, which is 8AD centimetres². By the theorem of Pythagoras, in triangle ABD,

$$\text{AD} = \sqrt{(\text{AB}^2 - \text{BD}^2)} = \sqrt{(144 - 64)} = \sqrt{80} = 8\cdot944 \text{ cm}.$$

Hence, the area of triangle ABC is $8 \times 8\cdot944 = \underline{71\cdot55 \text{ cm}^2.}$

(*ii*) Since the triangle is isosceles, AD bisects the non-equal angle BAC. Hence, ∠BAC = 2 × ∠BAD. In triangle BAD,

$$\sin \angle\text{BAD} = \frac{\text{BD}}{\text{AB}} = \frac{8}{12} = 0\cdot\dot{6}.$$

$$\therefore \angle\text{BAC} = 2\sin^{-1} 0\cdot\dot{6} = 2 \times 41° \, 49' = \underline{83° \, 38'.}$$

*Q 8* (*a*) *Fig. 3 shows a triangle, ABC, in which a point D on AB divides AB such that* $\frac{AD}{DB} = \frac{1}{2}$. *Lines DF and DE are drawn parallel to AC and BC respectively.*
(*i*) *Name the similar triangles in the figure.*
(*ii*) *State the ratio of the area of triangle BDF to that of triangle ABC.*
(*iii*) *If AC = 12 cm, find the length of DF.*

(*b*) *A sphere of radius R metres just fits into a cylinder, touching simultaneously at each end and along the curved surface area of the cylinder. Find the ratio of the volume of the sphere to that of the cylinder.*

(*c*) *A car travelling at 100 km/h has wheels whose overall diameter is 0·4 m. Calculate*
(*i*) *its speed in metres/second, and*
(*ii*) *the number of complete turns made by the wheels each second.*

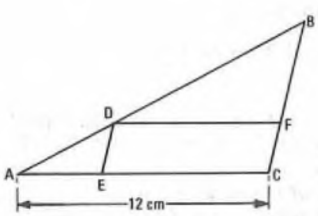
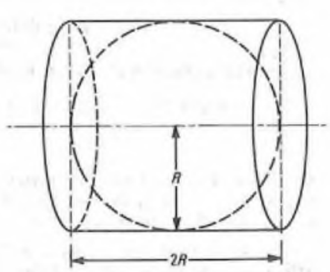



*Fig. 3*




(*a*)

A 8 (*a*) (*i*) The similar triangles are ADE, DBF and ABC.

(*ii*) The ratio of the areas of similar triangles is that of the squares of similar sides. Since DB = 2AD, AB = 3AD. Hence, the ratio of the area of triangle BDF to that of triangle ABC

$$= \text{DB}^2 : \text{AB}^2 = 4\text{AD}^2 : 9\text{AD}^2 = \underline{4 : 9.}$$

(*iii*) In the similar triangles DBF and ABC,

$$\frac{\text{DF}}{\text{AC}} = \frac{\text{DB}}{\text{AB}} = \frac{2}{3}, \text{ whence DF} = \frac{2}{3} \times 12 = \underline{8 \text{ cm}.}$$

(*b*) The sphere and cylinder are shown in sketch (*a*). Since the sphere touches each end of the cylinder, the length of the latter is $2R$. Hence, the ratio of the volume of the sphere to that of the cylinder

$$= \frac{\frac{4}{3}\pi R^3}{\pi R^2 \times 2R} = \frac{4}{3 \times 2} = \underline{\frac{2}{3}}.$$

(*c*) (*i*) The speed of the car $= \dfrac{100 \times 10^3}{60 \times 60} = \underline{27\cdot\dot{7} \text{ m/s.}}$

(*ii*) In one complete turn, a wheel travels a distance equal to its circumference; that is, $\pi \times 0\cdot4 = 1\cdot2568$ m. In 1 s, the car travels $27\cdot\dot{7}$ m. Hence, the number of turns made per second by the wheels is $27\cdot\dot{7}/1\cdot2568 = 22\cdot1$. Therefore, the number of complete turns made by the wheels each second is $\underline{22.}$

*Q 9* (*a*) *The potential difference across the ends of a conductor remains constant. The table of values below shows the variation between the current, i amperes, and the resistance, R ohms.*

| *i* | 2·0 | 2·5 | 3·0 | 3·5 | 4·0 | 4·5 | 5·0 | 5·5 | 6·0 |
|---|---|---|---|---|---|---|---|---|---|
| *R* | 12·5 | 10·0 | | | | | 5·0 | 4·54 | |

(*i*) *From the table above, find a value for k if iR = k.*
(*ii*) *Hence copy and complete the table of values.*

(*b*) *Choose suitable scales and plot a graph for values of i from 2·0 A to 6·0 A.*

(*c*) *From the graph, find the value of*
(*i*) *R when i = 3·7 A, and*
(*ii*) *i when R = 6·5 Ω.*

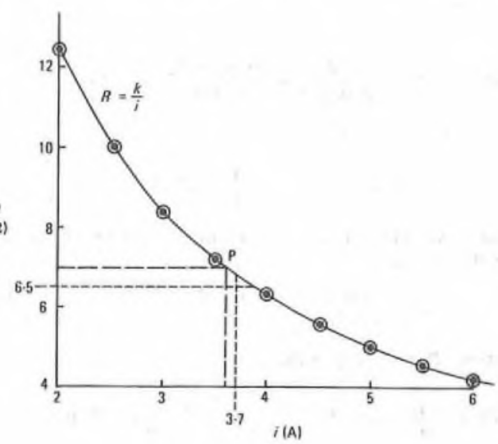
(*d*) *Calculate the numerical value of i when it is half that of R, and show your result on the graph.*

A 9 (*a*) (*i*) At $i = 2\cdot0$ A, $k = 2 \times 12\cdot5 = 25$; at $i = 2\cdot5$ A, $k = 25$; at $i = 5\cdot0$ A, $k = 25$; and at $i = 5\cdot5$ A, $k = 24\cdot97$. Hence, it is reasonable to state that $\underline{k = 25.}$

(*ii*) The complete table of values is shown below, using the relationship $R = 25/i$.

| *i* | 2·0 | 2·5 | 3·0 | 3·5 | 4·0 | 4·5 | 5·0 | 5·5 | 6·0 |
|---|---|---|---|---|---|---|---|---|---|
| *R* | 12·5 | 10 | $8\cdot\dot{2}$ | 7·143 | 6·25 | $5\cdot\dot{5}$ | 5 | $4\cdot\dot{5}\dot{4}$ | $4\cdot1\dot{6}$ |

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



(*c*) (*i*) When $i = 3{\cdot}7$ A, $R = 6{\cdot}7\ \Omega$.

(*ii*) When $R = 6{\cdot}5\ \Omega$, $i = 3{\cdot}85$ A.

(*d*) When $R = 2i$, $i = k/2i$. Therefore, $i^2 = 25/2 = 12{\cdot}5$. Hence, $i = \sqrt{12{\cdot}5} = 3{\cdot}536$ A.

This is shown on the graph as point P. From the graph, it can be verified that $R \approx 2i$.

**Q 10** (*a*) *Using only the numbers 1, 2, $\sqrt{3}$ and $\sqrt{2}$, write down the values of*

(*i*) *tan 60°*, (*ii*) *cos 30°*, (*iii*) *sin 45°, and* (*iv*) *sin 30°.*

(*b*) *Fig. 4 represents the cross-section of a lean-to garage. CD is a horizontal floor, and AD and BC are vertical walls; AD = 2 m, angle ACD = 30°, and angle CDB = 45°. Without the aid of tables, calculate, expressing the answers in terms of 1, 2, $\sqrt{3}$ and $\sqrt{2}$:*

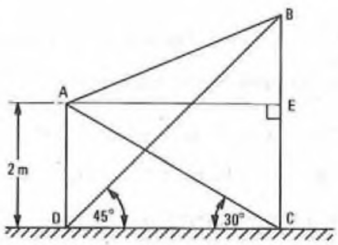



*Fig. 4*

(*i*) *the width of the floor,*
(*ii*) *the height of B above A, and*
(*iii*) *the gradient of the roof expressed as a tangent.*

(*c*) *Factorize completely* (*i*) $2x^2 - 8$, *and* (*ii*) $8xy - 16y$.

*Hence, simplify as far as possible* $\dfrac{2x^2 - 8}{8xy - 16y}$.

**A 10** (*a*) (*i*) $\tan 60° = \sqrt{3}$. (*ii*) $\cos 30° = \sqrt{(3)}/2$.

(*iii*) $\sin 45° = 1/\sqrt{2}$. (*iv*) $\sin 30° = 1/2$.

(*b*) The line AE (shown faint) has been drawn on Fig. 4, parallel to DC.

(*i*) In triangle ADC, $\angle$ADC = 90° and, hence, $\angle$DAC = 60°.

$\therefore$ DC = AD tan 60° = $2\sqrt{3}$ m.

(*ii*) The height of B above A = BE = BC − EC = BC − AD. But, in triangle DBC, BC = DC tan 45° = DC × 1. Hence, BC = DC = $2\sqrt{3}$ m.

$\therefore$ BE = $2\sqrt{3} - 2 = 2(\sqrt{3} - 1)$ m.

(*iii*) The gradient of the roof

$$= \frac{\text{BE}}{\text{AE}} = \frac{\text{BE}}{\text{DC}} = \frac{2(\sqrt{3} - 1)}{2\sqrt{3}} = 1 - \frac{1}{\sqrt{3}}.$$

(*c*) (*i*) $2x^2 - 8 = 2(x^2 - 4) = 2(x - 2)(x + 2)$.

(*ii*) $8xy - 16y = 8y(x - 2) = 2^3y(x - 2)$.

Hence,
$$\frac{2x^2 - 8}{8xy - 16y} = \frac{2(x - 2)(x + 2)}{2^3y(x - 2)} = \frac{x + 2}{4y}.$$

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## ENGINEERING SCIENCE 1977

**Students were expected to answer 2 questions from Q1–4 and 4 questions from Q5–10.**
**The use of electronic calculators was permitted**

**Q 1** (*a*) *State the principle of the triangle of forces.*

(*b*) *A cable-car of mass 500 kg is suspended between 2 pylons on an overhead-cable railway, as shown in Fig. 1.*

(*i*) *Find the tension in the section of cable AB.*

(*ii*) *Calculate the tensile stress in the cable if it has a diameter of 30 mm.*

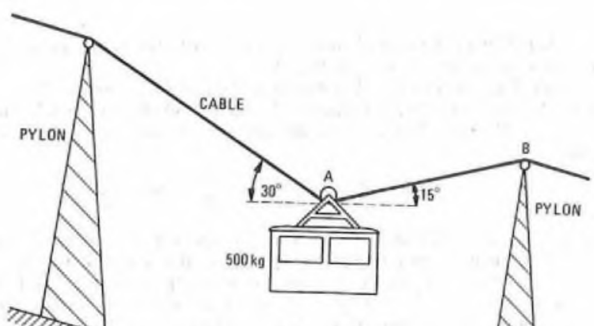
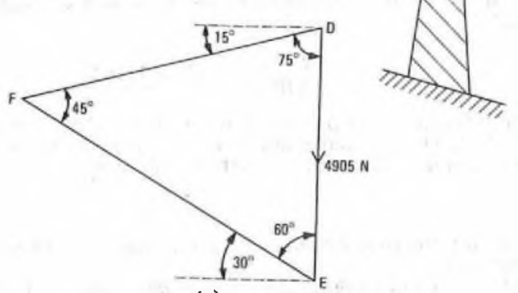



*Fig. 1*




(*a*)

**A 1** (*a*) The principle of the triangle of forces states that, if 3 forces acting at a point are in equilibrium, they can be represented in magnitude and direction by the 3 sides of a triangle if each of the 3 sides is drawn parallel to the force it represents.

(*b*) (*i*) Since force is given by mass multiplied by acceleration, the mass of the cable-car times the acceleration due to gravity results in a force acting vertically downwards. This force and the tensions (forces) in the 2 sections of cable are in equilibrium, acting at A, and the triangle of forces can be applied as shown in sketch (*a*).

DE is drawn vertically to represent the downward force of 500 × 9·81 = 4905 N. DF is drawn at 15° to the horizontal and EF at 30° to the horizontal to represent the tensions in the 2 sections of cable, DF representing section AB. Applying the sine rule gives

$$\frac{\text{DE}}{\sin \angle \text{DFE}} = \frac{\text{DF}}{\sin \angle \text{DEF}}.$$

$$\therefore\ \text{DF} = \frac{4905 \times \sin 60°}{\sin 45°} = 6007\ \text{N}.$$

(*ii*) Tensile stress is given by the tension divided by the cross-sectional area. Therefore, the tensile stress in the section of cable AB

$$= \frac{6007}{\pi \times 15^2 \times 10^{-6}}\ \text{N/m}^2 = 8{\cdot}5\ \text{MN/m}^2.$$

**Q 2** *A train of mass $1{\cdot}0 \times 10^5$ kg accelerates uniformly at $0{\cdot}25$ m/s² from rest along a level track to a uniform speed of 72 km/h and maintains this speed for a time of 2 min. The train then decelerates uniformly to halt at a station in a time of 20 s.*

(*a*) *Find the time during which the train is accelerating.*

(*b*) *Determine the deceleration of the train.*

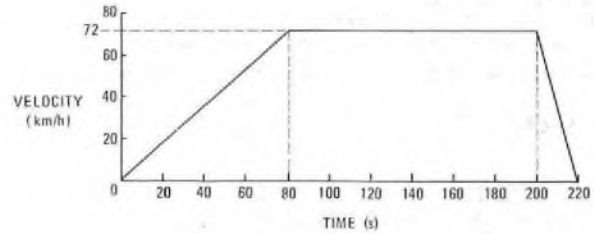
(*c*) *Sketch a velocity/time graph showing the motion of the train, and find the total distance travelled.*

(*d*) *What force must be provided by the engine to give the train an acceleration of 0·25 m/s² if 25% of the applied force is used to overcome friction?*

**A 2** (*a*) The time, *t* seconds, during which the train is accelerating is obtained from the formula $v = u + at$ metres/second, where $v$ is the final velocity (metres/second), $u$ is the initial velocity (metre/s second), and $a$ is the acceleration (metres/second²). The final velocity of the train is 72 km/h = 72 × 10³/3600 = 20 m/s.

$\therefore$ 20 = 0 + 0·25$t$ metres/second, whence $t$ = 80 s.

(*b*) Deceleration is the change in velocity divided by the time taken. Hence, the deceleration of the train = (20 − 0)/20 = 1 m/s².




(*c*) A velocity/time graph of the motion of the train is shown in the sketch.

The distance, $s$ metres, is given by $s = ut + at^2/2$ metres.

During acceleration, $s = 0 + (0{\cdot}25 \times 80^2)/2 = 800$ m.

The train then maintains a constant speed of 20 m/s for 120 s, covering $20 \times 120 = 2400$ m.

During deceleration, $s = 20 \times 20 - (1 \times 20^2)/2 = 200$ m.

The total distance travelled $= 800 + 2400 + 200$ m $= \underline{3{\cdot}4 \text{ km}}$.

(*d*) Force is given by mass multiplied by acceleration. Therefore, the force required to give the train an acceleration of $0{\cdot}25$ m/s$^2$

$$= 1{\cdot}0 \times 10^5 \times 0{\cdot}25 \text{ N}.$$

But 25% of the force actually applied is required to overcome friction. Therefore, the total force applied

$$= \frac{0{\cdot}25 \times 10^5}{0{\cdot}75} \text{ N} = \underline{33{\cdot}3 \text{ kN}}.$$

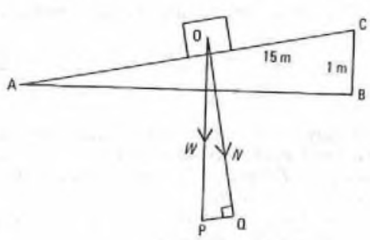
Q 3 (*a*) *Find the increase in potential energy of a boat and its contents of total mass $4{\cdot}0 \times 10^3$ kg when it is raised, by means of a lock, through a vertical distance of $3{\cdot}0$ m.*

(*b*) *A box of mass 20 kg is pulled with uniform speed up a ramp $1{\cdot}0$ m high and 15 m long in a time of 2 min. If the coefficient of friction between the box and the ramp is $0{\cdot}2$, find the power expended because of friction.*

(*c*) *A wheel of radius 150 mm is mounted on an axle of radius 30 mm. If the combination of wheel and axle is used as a machine and the efficiency is 60%, calculate the mechanical advantage of the system.*

A 3 (*a*) The increase in potential energy of the boat is the work that would be done if it were allowed to fall freely through the vertical distance through which it has been raised by the lock. Energy is given by force multiplied by distance. Therefore, the increase in potential energy of the boat $= 4 \times 10^3 \times 9{\cdot}81 \times 3$ J $= \underline{117{\cdot}72 \text{ kJ}}$.

(*b*) Power is the rate of doing work. In this case, the work done is the force required to overcome the force of friction multiplied by the distance through which the force acts. In the sketch, OP represents the gravitational force on the box, $W$, acting vertically downwards. OQ represents a force, $N$, which is equal and opposite to the normal reaction between the box and the ramp. Triangles ABC and OPQ are similar.




Now, $\quad AB = \sqrt{(AC^2 - BC^2)} = \sqrt{(225 - 1)} = 14{\cdot}97$ m.

Also $\quad \dfrac{OP}{OQ} = \dfrac{AC}{AB}$,

whence $\quad OQ = N = \dfrac{20 \times 9{\cdot}81 \times 14{\cdot}97}{15} = 195{\cdot}8$ N.

The coefficient of friction, $\mu$, is the ratio of the frictional force to the normal reaction. Hence, the frictional force

$$= \mu N = 0{\cdot}2 \times 195{\cdot}8 = 39{\cdot}16 \text{ N}.$$

The work done in overcoming friction $= 39{\cdot}16 \times 15 = 587{\cdot}4$ J, and the power expended $= 587{\cdot}4/2 \times 60 = \underline{4{\cdot}9 \text{ W}}$.

(*c*) The efficiency of a wheel and axle is given by the ratio of its mechanical advantage to its speed ratio, where the speed ratio is the ratio of the radius of the wheel to the radius of the axle. The speed ratio is $150/30 = 5$. Hence, the mechanical advantage $= 0{\cdot}6 \times 5 = \underline{3}$.

Q 4 *Answer 2 only of the following.*

(*a*) *Describe the construction and the action of a thermostat.*

(*b*) *Sketch a typical stress/strain graph for a mild-steel wire, labelling the various stress regions, and explain what is meant by the ultimate tensile strength.*

(*c*) *Describe the function of a simple gear train and state 2 factors which affect its efficiency.*

A 4 See A3, Engineering Science 1976, *Supplement*, Vol. 70, p. 2, Apr. 1977.

Q 5 (*a*) *Sketch the positive and negative current/voltage characteristics of a linear resistor.*

(*b*) *The EMF of each cell in Fig. 2 is $2{\cdot}0$ V and the internal resistance of each cell is $0{\cdot}20$ Ω. Calculate*

(*i*) *the total effective resistance of the complete circuit when switch S is closed,*

(*ii*) *the power dissipated by the 8 Ω resistor when switch S is closed, and*

(*iii*) *the current flowing through the 8 Ω resistor when switch S is open.*

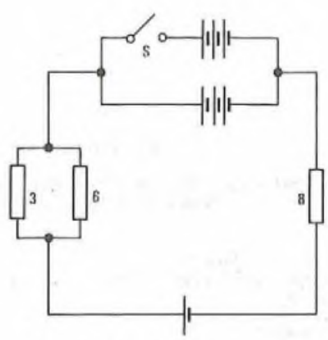
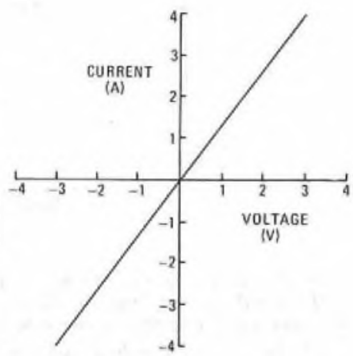



*Fig. 2*




(*a*)

A 5 (*a*) The positive and negative current/voltage characteristics of a linear resistor are shown in sketch (*a*).

(*b*) (*i*) The total internal resistance of each 3-cell battery is $3 \times 0{\cdot}2 = 0{\cdot}6$ Ω. The effective resistance of the two 3-cell batteries in parallel is $0{\cdot}6/2 = 0{\cdot}3$ Ω. Hence, the total effective resistance of the complete circuit

$$= 0{\cdot}3 + 8 + 0{\cdot}2 + \frac{3 \times 6}{3 + 6} = \underline{10{\cdot}5\ \Omega}.$$

(*ii*) A battery of three 2 V cells in series has a total EMF of 6 V. Two such batteries in parallel still give a total EMF of 6 V. The single cell is in opposition to the others, so that the effective EMF in the circuit is $6 - 2 = 4$ V. From Ohm's law, the total current in the circuit, which is the current in the 8 Ω resistor, is $4/10{\cdot}5$ A.

The power dissipated in a resistor is given by the square of the current multiplied by the resistance. Hence, the power dissipated in the 8 Ω resistor

$$= \left(\frac{4}{10{\cdot}5}\right)^2 \times 8 = \underline{1{\cdot}16 \text{ W}}.$$

(*iii*) When switch S is open, the effective EMF remains the same, but the the total effective resistance is increased by $0{\cdot}3$ Ω. Hence, the current in the 8 Ω resistor $= 4/10{\cdot}8 = \underline{0{\cdot}37 \text{ A}}$.

Q 6 (*a*) *Distinguish between the terms electromotive force and potential difference.*

(*b*) *The potential difference between the terminals A and B in Fig. 3 is $2{\cdot}25$ V when switch S is open and $2{\cdot}18$ V when switch S is closed.*

(*i*) *Calculate the charge drawn from the cell in 20 s when S is closed.*

(*ii*) *Find the internal resistance of the cell.*

(*c*) *Describe one test that could be used to assess the state of charge of a lead-acid cell.*

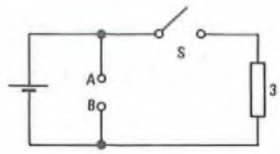



*Fig. 3*

A 6 (*a*) An electromotive force is the total voltage available from an electrical supply to drive a current around a circuit. It is the voltage which exists across the terminals of the supply before current is drawn; when current is drawn, there is a voltage drop due to the internal resistance of the supply. Potential difference is the voltage between 2 points in a circuit. In a closed series circuit, the sum of the potential differences is equal to the electromotive force.

(*b*) (*i*) When switch S is closed, the current drawn from the cell is the same as the current in the 3 Ω resistor. The current in the 3 Ω resistor is 2·18/3 A.

The charge drawn from the cell is given by the current multiplied by the time. Hence, the charge drawn

$$= \frac{2{\cdot}18}{3} \times 20 = \underline{14{\cdot}53\ \text{C.}}$$

(*ii*) The potential difference across the internal resistance of the cell

$$= 2{\cdot}25 - 2{\cdot}18 = 0{\cdot}07\ \text{V}.$$

This must be due to the current of 2·18/3 A being drawn from the cell. Therefore, the internal resistance of the cell

$$= 0{\cdot}07 \times \frac{3}{2{\cdot}18} = \underline{0{\cdot}096\ \Omega.}$$

(*c*) See A7, Engineering Science 1975, *Supplement*, Vol. 68, p. 95, Jan. 1976.

*Q 7* (*a*) *Explain the term temperature coefficient of resistance.*

(*b*) *A platinum resistance thermometer has a resistance of 20·0 Ω at 0°C and a length of 600 mm.*

(*i*) *Find the diameter of the platinum wire if its resistivity is 1·0 × 10⁻⁷ Ω m at 0°C.*

(*ii*) *What is the temperature of the thermometer when it has a resistance of 23·9 Ω and the temperature coefficient of resistance is 3·9 × 10⁻³/°C at 0°C?*

A 7 (*a*) The temperature coefficient of resistance, $\alpha_0$, is the change in resistance of a substance caused by a rise of 1°C in temperature, and is expressed as a fraction of the resistance at 0°C, $R_0$.

(*b*) (*i*) The resistance, $R$, of a conductor is given by $R = \rho l/a$ ohms, where $\rho$ is the resistivity of the material (ohm metres), $l$ is the length (metres), and $a$ is the cross-sectional area (metres$^2$) and is equal to $\pi r^2$ metres$^2$ for a wire of circular cross-section where $r$ is the radius (metres).

$$\therefore\ r = \sqrt{\frac{10^{-7} \times 600 \times 10^{-3}}{20 \times \pi}} = 3{\cdot}09 \times 10^{-5}\ \text{m}.$$

Thus, the diameter of the wire $= 2 \times 3{\cdot}09 \times 10^{-5}$ m $= \underline{0{\cdot}0618\ \text{mm.}}$

(*ii*) The temperature of the thermometer, $t$, is found from the formula $R_t = R_0(1 + \alpha_0 t)$ ohms, where $R_t$ is the resistance (ohms) at $t$ degrees Celsius.

$$\therefore\ 23{\cdot}9 = 20(1 + 3{\cdot}9 \times 10^{-3}t)\ \text{ohms}.$$

$$\therefore\ t = \left(\frac{23{\cdot}9}{20} - 1\right) \times \frac{1}{3{\cdot}9 \times 10^{-3}} = \underline{50°\text{C.}}$$

*Q 8* (*a*) *A straight wire carrying a current, I, of 40 mA is placed in a vertical position in a uniform magnetic field, B, of flux density 5 × 10⁻³ T, as shown in Fig. 4.*

(*i*) *Sketch a diagram from Fig. 4 to show the view in the direction of arrow A of the resultant magnetic field and the force acting on the wire.*

(*ii*) *Calculate the force per unit length on the wire.*

(*iii*) *Show how the force on the wire varies as it is turned through angle θ, where θ varies from 0° to 90°.*

(*b*) *Two parallel wires carry equal currents. Sketch the resultant magnetic fields and indicate the directions of forces between the wires when*

(*i*) *the currents are in the same direction, and*

(*ii*) *the currents are in opposite directions.*

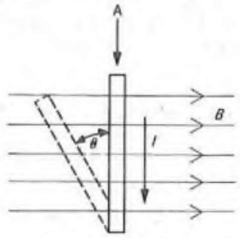
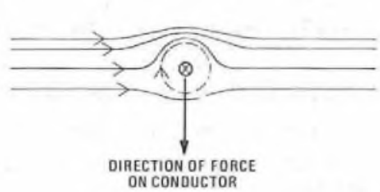



*Fig. 4*



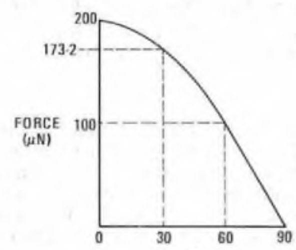

(*a*)

A 8 (*a*) (*i*) The required view is shown in sketch (*a*).

(*ii*) The force per unit length is given by the product of the flux density and the current. Therefore, the force per unit length

$$= 5 \times 10^{-3} \times 40 \times 10^{-3}\ \text{N} = \underline{200\ \mu\text{N.}}$$

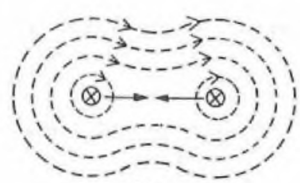
(*iii*) If the wire is turned through angle $\theta$, the force on the wire varies as the cosine of the angle. The variation in force per unit length as $\theta$ varies from 0° to 90° is shown in sketch (*b*).



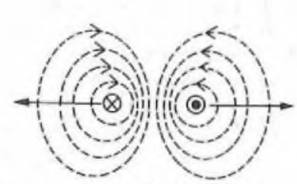

(*b*)

(*b*) (*i*) The resultant magnetic field when the currents in the parallel wires are in the same direction is shown in sketch (*c*).

(*ii*) The resultant magnetic field when the currents are in opposite directions is shown in sketch (*d*).



(*c*)



(*d*)

*Q 9* (*a*) *A voltmeter has a range of 5 V and a resistance of 10 kΩ.*

(*i*) *What is the voltage sensitivity of the meter?*

(*ii*) *What is the current for full-scale deflexion (FSD) of the meter?*

(*b*) *This voltmeter is connected in a circuit as shown in Fig. 5. The internal resistance of the battery and the resistance of the ammeter may be neglected.*

(*i*) *What is the observed voltmeter reading?*

(*ii*) *Find the difference in the current reading on the ammeter when the voltmeter is first connected and then removed.*

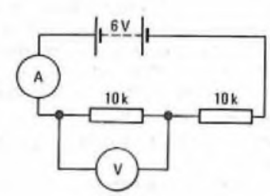



*Fig. 5*

A 9 (*a*) (*i*) The voltage sensitivity of the meter is expressed in ohms per volt, and is given by 10 000/5 = $\underline{2000\ \Omega/\text{V.}}$

(*ii*) If the resistance of the meter is 10 kΩ and the voltage range is 5 V, by Ohm's law, the FSD current is 5/10 000 A = $\underline{0{\cdot}5\ \text{mA.}}$

(*b*) (*i*) As the resistance of the voltmeter is 10 kΩ, the total resistance in the circuit is $10 + 10/2 = 15$ kΩ. Therefore, the voltage drop across the 10 kΩ resistor and the voltmeter in parallel (and thus the voltmeter reading) is $\frac{5}{15} \times 6 = \underline{2 \text{ V}}$.

(*ii*) The current reading on the ammeter with the voltmeter connected is $\frac{6}{15 \times 10^3}$ A $= 0{\cdot}4$ mA.

When the voltmeter is removed, the total resistance in the circuit is 20 kΩ, and the ammeter reading becomes $\frac{6}{20 \times 10^3}$ A $= 0{\cdot}3$ mA.

Therefore, the difference in ammeter readings is a decrease of $\underline{0{\cdot}1 \text{ mA}}$.

*Q 10 (a) A bar magnet is placed on the axis of a circular coil and is moved towards the coil.*

*(i) Sketch a diagram to show the direction of the induced EMF in the coil relative to the polarity of the magnet. Give reasons for your answer.*

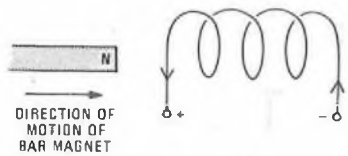
*(ii) What is the effect on the induced EMF of increasing the number of turns on the coil by a factor of 3?*

*(b) A coil of 20 turns, each enclosing an area of $8{\cdot}0 \times 10^{-2}$ m², is in a plane perpendicular to a magnetic field of flux density $3{\cdot}0 \times 10^{-2}$ T. The coil is connected to a circuit which has a total resistance of $2{\cdot}0$ Ω. The coil is then turned to a position parallel to the field in $0{\cdot}50$ s.*

*(i) Find the average EMF induced in the coil.*

*(ii) What is the power expended in the coil?*

A 10 (*a*) (*i*) The sketch shows the direction of motion of the magnet relative to the coil and the polarity of the resulting EMF. The polarity of the induced EMF is obtained by applying Lenz's law, which states that the direction of an induced EMF is such as to set up a current which causes a force opposing the change responsible for inducing the EMF. Assuming an external circuit is connected, the induced EMF causes a current to flow in the direction indicated by




the arrows on the coil. This current produces a magnetic field having a north pole at the end of the coil nearer to the magnet, and thus opposes the movement of the magnet towards the coil.

(*ii*) The induced EMF is directly proportional to the number of turns on the coil cut by the lines of magnetic force. Therefore, if the number of turns is increased by a factor of 3, the induced EMF is 3 times as large.

(*b*) (*i*) The maximum EMF, *E*, induced in a rotating coil is given by $E = 2NBA\pi n$ volts, where *N* is the number of turns on the coil, *B* is the flux density (teslas), *A* is the area swept by the coil as it rotates (metres²), and *n* is the angular velocity (revolutions/second). The coil is turned through 90° in $0{\cdot}50$ s; this is equivalent to an angular velocity of $0{\cdot}5$ revolution/s.

$$\therefore\ E = 2\pi \times 20 \times 3 \times 10^{-2} \times 8 \times 10^{-2} \times 0{\cdot}5 = 0{\cdot}15 \text{ V}.$$

The average value of a quarter of a sine wave is the same as the average value of half a sine wave; that is, $0{\cdot}64 \times$ the maximum value. Therefore, the average value of EMF induced

$$= 0{\cdot}64 \times 0{\cdot}15 \text{ V} = \underline{96 \text{ mV}}.$$

(*ii*) In an electrical circuit, power can be expended only by a current flowing through the resistance of the circuit. As no value of resistance is quoted for the coil, it can be assumed to be negligible, so that no power is expended in the coil.

If, however, the value of resistance quoted for the circuit is taken to include the resistance of the coil, the total power dissipated in the *circuit* is given by the square of the average induced EMF divided by the resistance; that is, $96^2 \times 10^{-6}/2$ W $= \underline{4{\cdot}6 \text{ mW}}$.

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## RADIO AND LINE TRANSMISSION A 1977

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

*Q 1 (a) Define the decibel.*

*(b) Briefly explain how logarithmic units may be used in radio and line transmission work to simplify*

*(i) calculations, and*

*(ii) the presentation of data.*

*(c) Express the following powers in decibels relative to 1 mW (dBm):*

*(i) 20 μW, (ii) 1 mW, and (iii) 15 W.*

*(d) An amplifier has a power gain of 23 dB and an output load resistance of 40 Ω. If the input power is 17 dBm, calculate the output voltage.*

A 1 (*a*) If the ratio of 2 powers, $P_1$ and $P_2$, is to be expressed in decibels, the number of decibels, *N*, is given by

$$N = 10 \log_{10} \frac{P_1}{P_2} \text{ decibels.}$$

(*b*) (*i*) The use of logarithmic units can simplify calculations because the enormous ranges of powers, voltages and currents involved in communications work can be expressed in simple numbers. Also, in complicated systems involving several sections in tandem, it is a relatively simple matter to determine the overall output-to-input ratios of the powers, voltages and currents by taking the sum of the logarithmic ratios for the different parts of the system.

(*ii*) The ability to express values in simple numbers is useful when presenting data. In graphical presentations, the use of logarithmic units can assist by effectively compressing scales, or by changing many common relationships into linear form.

(*c*) (*i*) Now, 20 μW $= 20 \times 10^{-3}$ mW $= 0{\cdot}02$ mW.

$$\therefore\ 10 \log_{10} \frac{0{\cdot}02}{1} = 10 \times \bar{2}{\cdot}3010 \approx \underline{-17 \text{ dBm}}.$$

$$(ii)\ 10 \log_{10} \frac{1}{1} = 10 \times 0 = \underline{0 \text{ dBm}}.$$

(*iii*) Now, 15 W = 15 000 mW.

$$\therefore\ 10 \log_{10} \frac{15\,000}{1} = 10 \times 4{\cdot}1761 \approx \underline{41{\cdot}8 \text{ dBm}}.$$

(*d*) The amplifier has a gain of 23 dB and an input power of 17 dBm. Therefore, the output power is $23 + 17 = 40$ dBm. If the output power is *P* watts, then

$$40 = 10 \log_{10} \frac{P}{1 \times 10^{-3}} \text{ decibels.}$$

$$\therefore\ P = 10^{-3} \text{ antilog}_{10} 4 = 10 \text{ W}.$$

By Ohm's law, the power must equal $V^2/R$ watts, where *V* is the output voltage and *R* is the load resistance (ohms).

$$\therefore\ V = \sqrt{(10 \times 40)} = \underline{20 \text{ V}}.$$

*Q 2 (a) Explain briefly the principles of operation of any 2 of the following types of receiver:*

*(i) moving-coil,*

*(ii) balanced-armature, and*

*(iii) moving-iron.*

*(b) State one application, giving one reason for its suitability, of each of the following types of microphone:*

*(i) carbon-granule,*

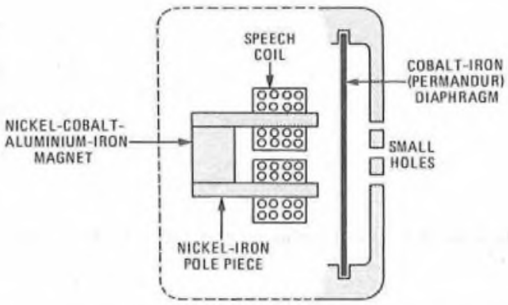
*(ii) crystal, and*

*(iii) moving-coil.*

A 2 (*a*) (*i*) and (*ii*) See A3, Radio and Line Transmission A 1974, *Supplement*, Vol. 68, p. 2, Apr. 1975.

(*iii*) The sketch shows the essential features of a moving-iron telephone receiver. It consists of a circular cobalt-iron diaphragm supported at its rim and held close to 2 pole pieces of a permanent-magnet system; speech coils are wound on the pole pieces. When no current flows in the coils, the permanent magnet exerts a steady pull on the diaphragm. When the speech coils are energized by, say, an audio tone, the action of the current flowing through the coils creates a varying magnetic field which alternately strengthens and weakens the permanent magnetic field. Hence, the pull on the diaphragm is varied in accordance with the applied electric signal, and the resulting flexing of the diaphragm causes sound waves to be produced.

(*b*) Typical applications for each of the 3 types of microphone, together with reasons for their suitability, are given in the table.




| Type of Microphone | Application | Reason for Suitability |
|---|---|---|
| Carbon-Granule | Telephone instrument | Low cost and robustness |
| Crystal | Domestic tape-recorder | Reasonable frequency response at moderate cost |
| Moving-Coil | Broadcasting studio | Very good frequency response |

*Q 3 (a) Briefly explain the purpose of 2-wire-to-4-wire terminating sets.*

*(b) Draw labelled block diagrams of*

*(i) a simple line-communication system, and*
*(ii) a simple radio-communication system,*
*involving the use of 2-wire-to-4-wire terminating sets.*

*(c) State a suitable carrier frequency for use on the radio system.*

A 3 (*a*) On long-distance telephone lines, it is often necessary to introduce amplifiers to compensate for losses due to the attenuation of the line. Amplifiers are unidirectional devices, and it is therefore necessary to separate the GO and RETURN directions of transmission (thus changing the system to 4-wire operation). This separation is effected by a 2-wire-to-4-wire terminating set, which also maintains the matched condition of the individual lines, and isolates the GO and RETURN signals to prevent oscillation around the circuit.

On many radio systems, it is necessary to separate the 2 directions of transmission (for example, when the transmitting and receiving stations are at different locations), and 2-wire-to-4-wire terminating sets are again used.

(*b*) See A5, Radio and Line Transmission A 1972, *Supplement*, Vol. 65, p. 93, Jan. 1973.

(*c*) For a radio circuit providing a long-distance overseas telephony link, a suitable carrier frequency would be in the range 3–30 MHz.

*Q 4 (a) The envelope of an amplitude-modulated carrier wave varies sinusoidally between a maximum value of ±14 V and a minimum value of ±6 V. Sketch the waveform and label the axes.*

*(b) Determine for the above*

*(i) the amplitude of the unmodulated carrier,*
*(ii) the amplitude of the modulating signal, and*
*(iii) the modulation factor expressed as a percentage.*

*(c) Draw the diagram of a circuit suitable for demodulating the signal, and sketch the output waveform.*

A 4 (*a*) The amplitude-modulated carrier is shown in sketch (*a*).

(*b*) Let $V_C$ be the amplitude of the unmodulated carrier and $V_M$ be the amplitude of the modulating signal. Then, for the waveform in sketch (*a*),

$$V_C + V_M = 14 \text{ V}, \qquad \ldots\ldots (1)$$

and

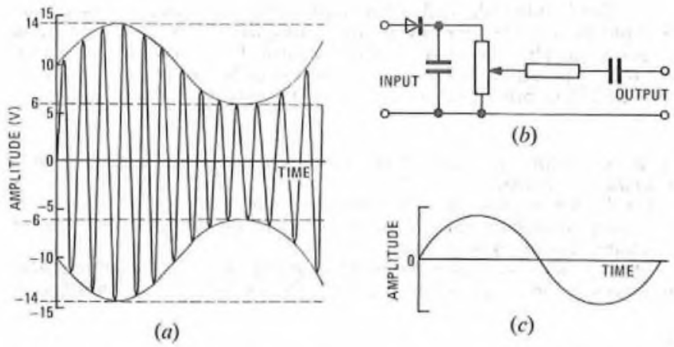
$$V_C - V_M = 6 \text{ V}. \qquad \ldots\ldots (2)$$

(*i*) Adding equations (1) and (2) gives

$$2V_C = 20 \text{ V, whence } \underline{V_C = 10 \text{ V.}}$$

(*ii*) Subtracting equation (2) from equation (1) gives

$$2V_M = 8 \text{ V, whence } \underline{V_M = 4 \text{ V.}}$$




(*iii*) The modulation factor

$$= \frac{V_M}{V_C} \times 100\% = \frac{4}{10} \times 100\% = \underline{40\%}.$$

(*c*) A circuit suitable for demodulating the amplitude-modulated signal is shown in sketch (*b*), and the output waveform is shown in sketch (*c*).

*Q 5 (a) Explain how a parallel tuned circuit may be used in an amplifier to provide selectivity.*

*(b) The measured response of a parallel tuned circuit is shown in the table.*

| *Frequency (kHz)* | *462* | *464* | *466* | *468* | *470* | *472* | *474* | *476* | *478* |
|---|---|---|---|---|---|---|---|---|---|
| *Voltage (V)* | *8·5* | *13* | *16* | *19* | *20* | *19* | *16* | *13* | *8·5* |

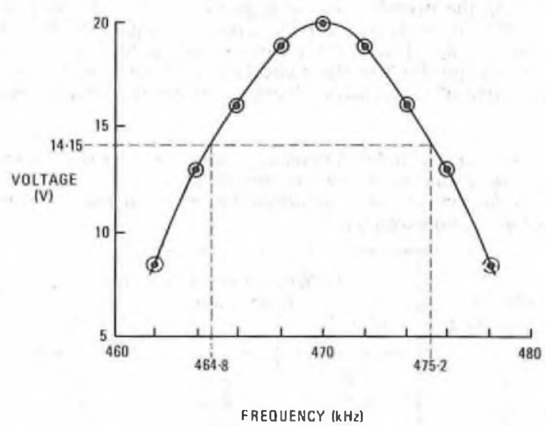
*Plot the response curve and*

*(i) calculate the voltage at the half-power (−3 dB) points, and*
*(ii) determine the bandwidth at the −3 dB points.*

*(c) Briefly comment on the suitability of such a circuit for use in a medium-wave broadcast receiver.*

A 5 (*a*) See A5, Radio and Line Transmission A 1974, *Supplement*, Vol. 68, p. 3, Apr. 1975.

(*b*) The voltage/frequency characteristic is shown in the sketch.




(*i*) The half-power points are the points at which the response is 3 dB below the maximum value. In terms of voltages,

$$20 \log_{10} \frac{20}{V} = 3 \text{ dB},$$

where $V$ is the voltage at the −3 dB points.

$$\therefore \frac{20}{V} = \text{antilog}_{10} \frac{3}{20} = 1 \cdot 413, \text{ whence } V = \frac{20}{1 \cdot 413} = \underline{14 \cdot 15 \text{ V.}}$$

(*ii*) From the graph, this voltage is obtained at frequencies of about 464·8 kHz and 475·2 kHz. Therefore, the bandwidth at the half-power points = 475·2 − 464·8 = 10·4 kHz.

(*c*) The bandwidth used for medium-wave broadcast transmissions is typically 10 kHz, permitting audio frequencies up to 5 kHz to be transmitted. Thus, the bandwidth of the tuned circuit makes it suitable for use in a medium-wave receiver, although further selectivity would be required in practice to reject adjacent-channel interference.

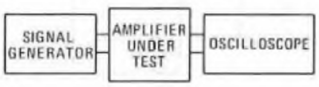
*Q 6* (*a*) *Draw a circuit diagram to show what is meant by R-C interstage coupling.*

(*b*) *Briefly explain how the gain/frequency response of a 2-stage R-C coupled audio-frequency amplifier can be determined using a signal generator and an oscilloscope.*

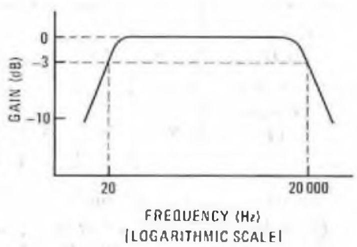
(*c*) *Sketch a typical gain/frequency response curve for such an amplifier and explain the factors which limit the high and low-frequency response.*

A 6 (*a*) See A2, Radio and Line Transmission A 1973, *Supplement* Vol. 67, p. 18, Apr. 1974.

(*b*) The gain/frequency response of a 2-stage audio amplifier can be determined using the arrangement shown in sketch (*a*). An audio-signal generator is coupled to the input of the amplifier and an oscilloscope is connected to the output. The signal generator is adjusted to a suitable frequency (say, 1 kHz) and the amplitude of its output adjusted to produce the maximum undistorted amplifier output. The output voltage of the amplifier, $V_{out}$, is measured using the calibrated display on the oscilloscope. The oscilloscope is then connected across the amplifier input to measure the input voltage, $V_{in}$. The voltage gain at this particular test frequency is given by $V_{out}/V_{in}$. The procedure is repeated for other frequencies covering the range 20 Hz to 20 kHz, and a gain/frequency graph is plotted.




(*a*)




(*b*)

(*c*) A typical gain/frequency response for a 2-stage R-C coupled transistor amplifier is shown in sketch (*b*). The frequency response at low frequencies is limited by the reactance of the coupling capacitor which, together with the input impedance of the second stage, forms a potential-divider network. At low frequencies, a significant proportion of the output voltage from the first stage is developed across the coupling capacitor, thus reducing the input to the second stage and hence reducing the overall gain. At high frequencies, the stray capacitances in the circuit (for example, across the input of the second stage) shunt the signal, and the output of the amplifier is reduced. With careful design, both of these effects can be made negligible over the middle range of frequencies, giving a substantially flat response.

*Q 7* (*a*) *Draw a circuit for determining the output characteristics of a transistor in the common-emitter configuration.*

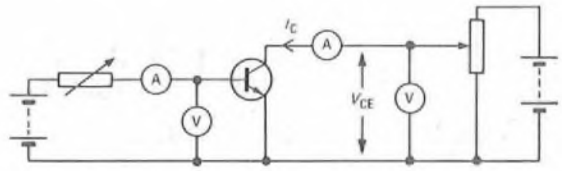
(*b*) *The following data were obtained for an n p n transistor in the common-emitter configuration.*

| *Collector Voltage (V)* | *Collector Current (mA) for Base Currents of* 60 $\mu A$ | 90 $\mu A$ | 120 $\mu A$ |
|---|---|---|---|
| 1 | 2·6 | 4·1 | 5·5 |
| 3 | 3·0 | 4·6 | 6·1 |
| 5 | 3·4 | 5·1 | 6·7 |
| 7 | 3·8 | 5·6 | 7·3 |
| 9 | 4·2 | 6·1 | 7·9 |

*Plot the collector-current/collector-voltage characteristic for each of the base currents shown.*

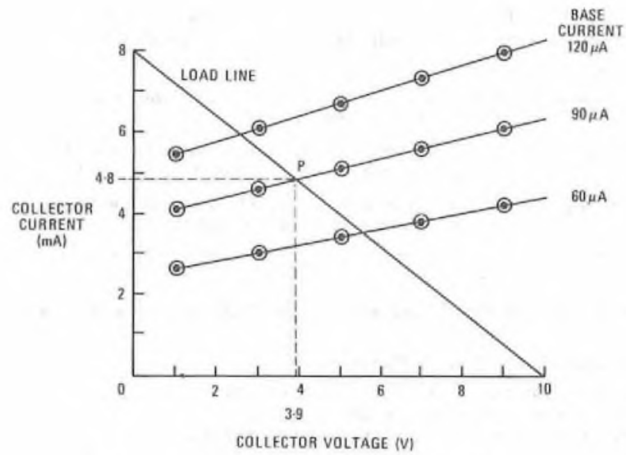
(*c*) *Draw the load line for a collector load resistance of 1·25 kΩ and a supply voltage of 10 V, and determine the power dissipated at the collector when the base current is 90 μA.*

A 7 (*a*) The diagram of a circuit suitable for determining the output characteristics of a common-emitter n p n transistor is shown in sketch (*a*).




(*a*)

(*b*) The collector-current/collector-voltage characteristics are shown in sketch (*b*).




(*c*) For a load resistance, $R_L$, equal to 1·25 kΩ, and a supply voltage, $V_S$, of 10 V, then when $I_C$ is zero, $V_{CE} = V_S = 10$ V, and when $V_{CE}$ is zero, $I_C = V_S/R_L = 10/1250$ A $= 8$ mA, where $I_C$ is the collector current, and $V_{CE}$ is the collector voltage.

Therefore, the load line passes through the points ($V_{CE} = 0$, $I_C = 8$ mA) and ($V_{CE} = 10$ V, $I_C = 0$). The constructed load line is shown on the graph.

For a base current of 90 μA, the operating point is at the intersection of the load line and the appropriate characteristic, and is shown as point P on the graph. At point P, $I_C = 4·8$ mA and $V_{CE} = 3·9$ V. The power dissipated at the collector

$$= I_C V_{CE} = 4·8 \times 3·9 = \underline{18·7 \text{ mW}}.$$

*Q 8* (*a*) *Briefly explain why the bandwidth normally used for commercial speech is restricted to the range 300-3400 Hz.*

(*b*) *The frequency assigned to a radio transmitter is 15·01 MHz. If its measured wavelength is 20 m, determine the percentage error in the transmitted frequency. (Take the velocity of propagation to be $3 \times 10^8$ m/s.)*

(*c*) *Sketch, using the same axes, waveforms of the following:*

(*i*) *a sinusoidal tone of amplitude 3·5 V,*

(*ii*) *the third harmonic of this tone with an amplitude of 1·5 V, and*

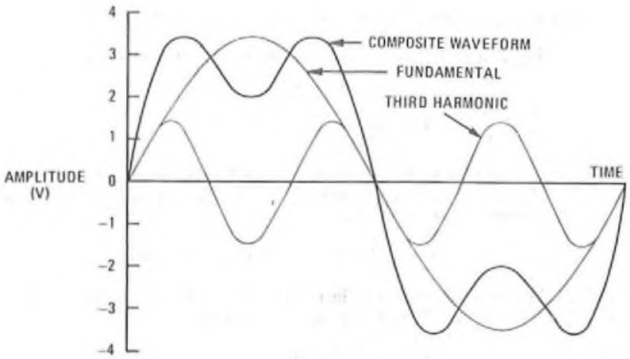
(*iii*) *the composite wave formed by adding waveforms (i) and (ii).*

A 8 (*a*) The full range of frequencies contained in human speech extends from a few tens of hertz to 10 kHz or more. However, it is possible to restrict considerably this range and yet retain the intelligibility of the speech. In commercial communication systems, the narrower the bandwidth of each telephone circuit, the more channels a particular system can transmit. Furthermore, cheaper amplifiers and other items of equipment can be designed if the telephony bandwidth is restricted. The choice of a suitable bandwidth for commercial speech is thus a compromise between quality of speech and economy of the communication system. An acceptable compromise is obtained by selecting a range of 300-3400 Hz, and this has been adopted as an international standard.

(*b*) The relationship between frequency, $f$ hertz, wavelength, $\lambda$ metres, and velocity of propagation, $v$ metres/second, is given by $f = v/\lambda$. Thus, the transmitted frequency

$$= \frac{3 \times 10^8}{20} \text{ Hz} = 15 \times 10^6 \text{ Hz} = 15 \text{ MHz}.$$

Therefore, the error in the transmitted frequency is $15·01 - 15 = 0·01$ MHz.




Expressed as a percentage of the assigned frequency, the error

$$= \frac{0 \cdot 01}{15 \cdot 01} \times 100\% = \underline{0 \cdot 067\%}.$$

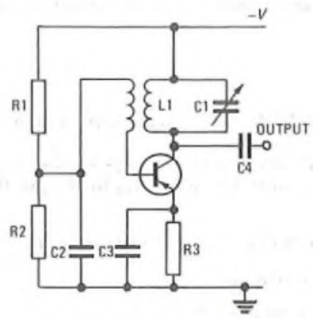
(*c*) The required waveforms are shown in the sketch. The composite waveform is constructed by adding the amplitudes of the fundamental and third-harmonic waveforms at selected points.

*Q 9* (*a*) *State 2 applications of electrolytic capacitors.*
(*b*) *State 2 functions of a transformer, and give an example of an application to illustrate each function.*
(*c*) *State 2 main causes of loss in mains power transformers.*

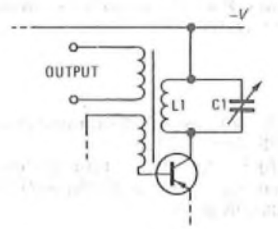
*Q 10* (*a*) *State the 2 requirements for the maintenance of oscillation in an oscillator.*
(*b*) *Draw the circuit diagram of a mutual-inductance-coupled transistor oscillator.*
(*c*) *Draw simple sketches to show 2 methods of coupling the output.*
(*d*) *If the oscillator's tuned circuit has a capacitance of 490 pF and an inductance of 160 μH, calculate the frequency of resonance.*

**A 10** (*a*) To maintain oscillation in an oscillator, there must be some form of feedback of energy in the correct phase from the output to the input, and there must be sufficient amplification in the circuit to overcome the losses around the feedback loop.

(*b*) The circuit diagram of a simple tuned-collector mutual-inductance-coupled transistor oscillator is shown in sketch (*a*). (For a description of its operation, see A9, Radio and Line Transmission A 1975, *Supplement*, Vol. 69, p. 12, Apr. 1976.




(*a*)




(*b*)

(*c*) The output from the oscillator can be obtained by capacitor coupling from the collector as shown in sketch (*a*), or by transformer coupling from the tuned circuit as shown in sketch (*b*).

(*d*) The frequency of resonance, $f_0$, of a tuned circuit having capacitance $C$ farads and inductance $L$ henrys is given approximately by $f_0 = 1/2\pi\sqrt{(LC)}$ hertz.

$$\therefore f_0 = \frac{1}{2\pi\sqrt{(160 \times 10^{-6} \times 490 \times 10^{-12})}} \text{ Hz},$$

$$\approx \underline{568 \text{ kHz}}.$$

## COMMUNICATION RADIO C 1976

**Students were expected to answer any 6 questions**

*Q 1* (*a*) *What is the meaning of the following terms:*
(*i*) *maximum usable frequency, and*
(*ii*) *optimum traffic frequency?*
(*b*) *How are* (*i*) *and* (*ii*) *related?*
(*c*) *Explain how a radio wave incident on an ionized region is returned to earth by refraction.*
(*d*) *How does the refraction vary with*
(*i*) *frequency,*
(*ii*) *electron density in the ionized region, and*
(*iii*) *angle of incidence?*

**A 1** (*a*), (*b*) and (*c*) See A1, Communication Radio C 1973, *Supplement*, Vol. 67, p. 63, Oct. 1974.

*Note* Students are advised also to refer to the correspondence on p. 275 of the January 1978 issue of the *POEEJ*.

(*d*) Now, $\sin r = \dfrac{\sin i}{\sqrt{(1 - 81N/f^2)}}$ and $\dfrac{\sin i}{\sin r} = \mu$,

where $i$ is the angle of incidence, $r$ is the angle of refraction, $N$ is the number of electrons per cubic metre in the ionized region, $f$ is the frequency of transmission (hertz), and $\mu$ is the refractive index, which is a constant for a given medium.

(*i*) As $f$ increases, $1 - 81N/f^2$ increases, and hence $r$ decreases.
(*ii*) As $N$ increases, $1 - 81N/f^2$ decreases, and hence $r$ increases.
(*iii*) As $i$ increases, so does $r$, since $\mu$ is constant.

*Q 2* *The available noise power for an aerial is given by* $N = kTB$ *watts, where* $k = 1 \cdot 374 \times 10^{-23}$ *J/K, T is the absolute temperature (kelvins), and B is the noise bandwidth of the aerial (hertz).*

*An aerial is connected to a matched amplifier having a gain of 27 dB and a noise factor of 3 dB. The aerial and the amplifier both have a temperature of 300 K and the same noise bandwidth. The signal level at the input to the amplifier is 1 μW. If the available noise power from the aerial is −120 dB relative to 1 mW, what is*

(*a*) *the signal-to-noise ratio at the input,*
(*b*) *the noise power at the output,*
(*c*) *the signal-to-noise ratio at the output, and*
(*d*) *the noise bandwidth of the amplifier?*

**A 2** (*a*) A signal level of 1 μW has a logarithmic value of $10 \log_{10} (1 \times 10^{-6}/1 \times 10^{-3}) = -30$ dBm. Since the aerial is matched to the amplifier input, all the noise from the aerial is developed at the input to the amplifier. Hence, using logarithmic units, the signal-to-noise ratio at the input is the input signal level minus the input noise power; that is, $-30 - (-120) = \underline{90 \text{ dB}}$.

*Note* The signal-to-noise ratio can also be expressed as the unitless ratio of the powers in watts. In that case, the logarithmic noise power available from the aerial must be converted to watts [$1 \times 10^{-3} \times \text{antilog}_{10}(-120/10) = 10^{-15}$ W], and calculated as $1 \times 10^{-6}/1 \times 10^{-15} = \underline{10^9}$.

(*b*) The noise power at the output (using logarithmic units) is the input noise to the amplifier plus the amplifier gain plus the noise contributed by the amplifier

$$= -120 + 27 + 3 = \underline{-90 \text{ dBm}}.$$

*Note* This illustrates the simplicity of using logarithmic units; the same calculation using unitless ratios of the powers in watts is far more complicated.

(*c*) The signal-to-noise ratio at the output (using logarithmic units) is the output signal level (which is the input signal level plus the amplifier gain) minus the output noise power

$$= -30 + 27 - (-90) = \underline{87 \text{ dB}}.$$

(*d*) The equation given for the aerial also applies to the amplifier, so that

$$B = \frac{N}{kT} = \frac{10^{-15}}{1 \cdot 374 \times 10^{-23} \times 300} \text{ Hz} \approx \underline{243 \text{ kHz}}.$$

*Q 3 (a) With the aid of a circuit diagram, explain the operation of the mixer and local oscillator of a transistor superheterodyne amplitude-modulation sound receiver.*

*(b) The symbols $f_1$ and $f_2$ represent the frequencies of the wanted input signal and the local oscillator of a superheterodyne receiver. The output voltage of the mixer ($v_{out}$) is related to the input voltage ($v_{in}$) by the equation $v_{out} = av_{in} + bv_{in}^2$, where a and b are constants.*

*(i) At what frequencies do the components of the output occur?*
*(ii) Which of the output components represent the wanted signal?*
*(iii) Why do the other components not appear at the audio output of the receiver?*

A 3 (*a*) See A3, Communication Radio C 1971, *Supplement*, Vol. 65, p. 78, Jan. 1973.

(*b*) (*i*) Let $f_1$ be represented by $E_1 \sin \omega_1 t$ and $f_2$ by $E_2 \sin \omega_2 t$. Then, $v_{in} = (E_1 + E_2 \sin \omega_2 t) \sin \omega_1 t$. Substituting for $v_{in}$ in the given equation gives

$$v_{out} = a(E_1 + E_2 \sin \omega_2 t) \sin \omega_1 t + b\{(E_1 + E_2 \sin \omega_2 t) \sin \omega_1 t\}^2,$$

$$= aE_1 \sin \omega_1 t + aE_2 \sin \omega_2 t \sin \omega_1 t$$

$$+ bE_1^2 \sin^2 \omega_1 t + 2bE_1E_2 \sin^2 \omega_1 t \sin \omega_2 t$$

$$+ bE_2^2 \sin^2 \omega_2 t \sin^2 \omega_1 t.$$

Expanding the terms individually:

$aE_1 \sin \omega_1 t$ contains the fundamental of the wanted input signal, $f_1$;

$$aE_2 \sin \omega_2 t \sin \omega_1 t = \frac{aE_2}{2}\{\cos(\omega_2 - \omega_1)t - \cos(\omega_2 + \omega_1)t\},$$

and contains the upper and lower sideband components, $f_2 - f_1$ and $f_2 + f_1$;

$bE_1^2 \sin^2 \omega_1 t = \frac{bE_1^2}{2}(1 - \cos 2\omega_1 t)$ and contains the second harmonic of the wanted input signal, $2f_1$;

$$2bE_1E_2 \sin^2 \omega_1 t \sin \omega_2 t = 2bE_1E_2 \frac{1 - \cos 2\omega_1 t}{2} \sin \omega_2 t,$$

$$= bE_1E_2 \sin \omega_2 t - \ldots,$$

and contains the fundamental component of the local-oscillator frequency, $f_2$; and

$$bE_2^2 \sin^2 \omega_2 t \sin^2 \omega_1 t = \frac{bE_2^2}{4}(1 - \cos 2\omega_2 t)(1 - \cos 2\omega_1 t),$$

$$= \frac{bE_2^2}{4}(1 - \cos 2\omega_2 t + \ldots),$$

and contains the second harmonic of the local-oscillator frequency, $2f_2$.

The output components of the mixer are therefore

$$\underline{f_1, f_2, 2f_1, 2f_2, f_2 + f_1 \text{ and } f_2 - f_1.}$$

(*ii*) Information is contained in the sidebands $f_2 - f_1$ and $f_2 + f_1$. Either can be used, but there are advantages in selecting the lower sideband; that is, $f_2 - f_1$.

(*iii*) The unwanted components ($f_1$, $f_2$, $2f_1$, $2f_2$ and $f_2 + f_1$) must be prevented from being developed across the detector. While an element of suppression is afforded by the tuned output of the mixer, the predominant rejection is provided by the following intermediate-frequency stage.

*Q 4 A superheterodyne receiver has an intermediate frequency of 5·5 MHz, and the local-oscillator frequency is above the radio frequency. The receiver covers the band of frequency-modulation (FM) carriers spaced at 0·3 MHz intervals from 80 MHz to 92 MHz inclusive. Each of these carriers has a modulation index of 5 when the maximum modulating frequency is 15 kHz.*

*(a) (i) What is the number of FM channels in the band?*
*(ii) What is the maximum guard-band between channels?*

*(b) When the receiver is tuned to the carrier at 80 MHz, what is the band covered by the*

*(i) image channel, and*
*(ii) adjacent channel?*

*(c) (i) Which carriers are susceptible to image-channel interference from within the band?*
*(ii) What are the frequencies of the interfering carriers?*

A 4 (*a*) (*i*) By inspection, the number of channels

$$= \frac{\text{highest channel carrier} - \text{lowest channel carrier}}{\text{carrier separation}} + 1,$$

$$= \frac{92 - 80}{0 \cdot 3} + 1 = \underline{41}.$$

(*ii*) The bandwidth, $B$, required for satisfactory transmission is given by $B = 2(f_m + mf_m)$ hertz, where $f_m$ is the frequency of modulation, and $m$ is the modulation index.

$$\therefore \; B = 2(15 + 5 \times 15) = \underline{180 \text{ kHz.}}$$

(*b*) (*i*) When the local-oscillator frequency is above the signal frequency, $f_s$, the image frequency, $f_i$, is given by

$$f_i = f_s + 2f_I \text{ hertz,} \qquad \ldots\ldots(1)$$

where $f_I$ is the intermediate frequency.

$$\therefore \; f_i = 80 + 2 \times 5 \cdot 5 = 91 \text{ MHz.}$$

The receiver responds to all signals in the channel band, which is 180 kHz. Hence, the band covered by the image channel is $\underline{91 \pm 0 \cdot 090 \text{ MHz.}}$

(*ii*) The channel adjacent to the 80 MHz carrier is the next highest allocated carrier. Therefore, the band covered by the adjacent channel is $\underline{80 \cdot 3 \pm 0 \cdot 090 \text{ MHz.}}$

(*c*) (*i*) From equation (1), the following table of image carriers is compiled.

| Signal Carrier (MHz) | Image Carrier (MHz) |
|---|---|
| 80·0 | 91·0 |
| 80·3 | 91·3 |
| 80·6 | 91·6 |
| 80·9 | 91·9 |
| 81·2 | 92·2 |

The table shows that the fifth image carrier is outside the receiver bandwidth, as are all image carriers above 92·2 MHz. Therefore, the signal carriers susceptible to image-channel interference are 80·0, 80·3, 80·6 and 80·9 MHz.

(*ii*) The interfering signals in the table are likely to be generated by carriers having similar frequencies, and the carriers in the range specified that most closely approach the interfering signals are 91·1, 91·4, 91·7 and 92·0 MHz.

*Q 5 (a) Draw the circuit diagram of a push-pull class-B modulator with its associated class-C radio-frequency (RF) amplifier.*

*(b) A push-pull class-B modulator is used to modulate sinusoidally a push-pull class-C RF amplifier. The maximum anode dissipation of the RF amplifier is 250 W and its anode efficiency is 75%. The class-B modulator has an anode efficiency of 60% and a maximum anode dissipation of 200 W.*

*(i) Calculate the maximum modulated RF output from the class-C amplifier.*
*(ii) What is the maximum modulation power that the modulator can supply to the RF amplifier?*
*(iii) What is the maximum depth of modulation?*

A 5 (*a*) The sketch shows the circuit of a push-pull class-B modulator and associated class-C RF amplifier.

(*b*) (*i*) The efficiency, $\eta$, of the class-C stage is given by $\eta = (P_I - P_D)/P_I$, where $P_I$ is the input power, and $P_D$ is the dissipated power.

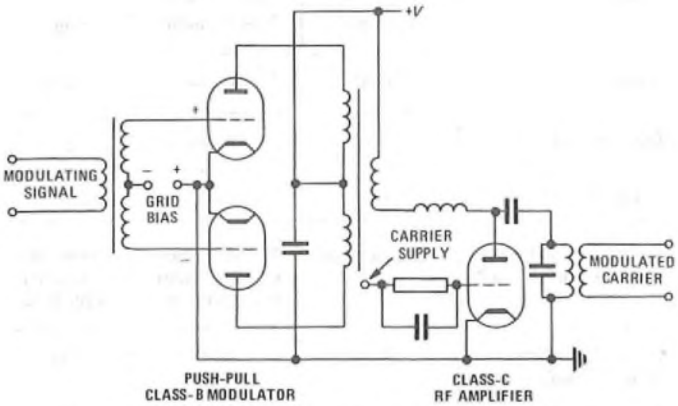
$$\therefore \; P_I = \frac{P_D}{1 - \eta} = \frac{250}{1 - 75/100} = 1000 \text{ W.}$$

The maximum modulated RF output power of the amplifier, $P_{OA}$, is given by $P_{OA} = P_I - P_D = 1000 - 250 = \underline{750 \text{ W.}}$

(*ii*) Similarly, the input power to the class-B stage is given by

$$P_I = \frac{200}{1 - 60/100} = 500 \text{ W.}$$

Hence, the maximum modulation output power delivered by the modulator, $P_{OM}$, is given by $P_{OM} = 500 - 200 = \underline{300 \text{ W.}}$




(*iii*) Now, $P_{OA} = P_C(1 + m^2/2)$ watts, where $P_C$ is the unmodulated carrier power, and $m$ is the modulation index.

$$\therefore\ P_C + \frac{P_C m^2}{2} = 750\ \text{W}. \qquad \ldots\ldots(1)$$

Also, the maximum modulation power at the output of the class-C stage is $P_C m^2/2$ watts which, in this case, is 75% of $P_{OM}$. Substituting for $P_C m^2/2$ in equation (1) gives

$$P_C = 750 - \frac{300 \times 75}{100} = 525\ \text{W}.$$

$$\therefore\ m = \sqrt{\frac{2\eta P_{OM}}{P_C}} = \sqrt{\frac{2 \times 300 \times 75}{525 \times 100}} = \underline{0{\cdot}926.}$$

*Q 6 (a) Draw the block diagram of a LINCOMPEX equipment.*

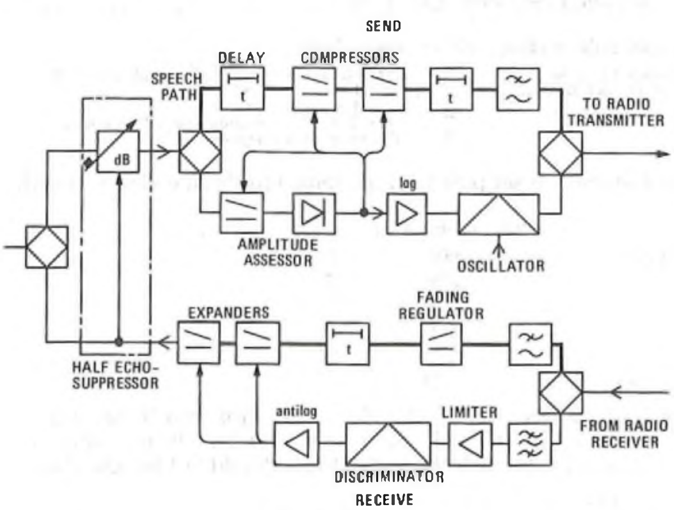
*(b) Briefly describe the general principles of the LINCOMPEX system.*

*(c) What factors affect the time constant of the gain-variation circuits?*

A 6 (*a*) The sketch shows a block diagram of LINCOMPEX equipment.

(*b*) In line transmission, the effects of noise between transmitter and receiver can be reduced by the use of a compressor and an expander. The compressor, located at the sending end, compresses the volume range of signals; at the receiver, the expander restores the original volume range. However, the system is only effective if the path loss between the compressor and expander is constant. In radio applications, this is unfortunately not the case. The technique can be used, however, if information concerning the degree of compression introduced at the compressor is conveyed accurately to the expander. The LINked COMPressor and EXpander (LINCOMPEX) provides this facility.

Speech is compressed to a constant amplitude by the compressor at syllabic rate, and the compressor-control current also frequency modulates an oscillator operating in a separate channel. The compressed speech and frequency-modulated control signal are combined and transmitted over a single 3 kHz channel. At the receiver, the speech and control signals are separated, the latter being used to control the expander which restores the original amplitude variations in the speech channel. The use of frequency modulation of the control signal makes it essentially independent of fluctuations in path loss, thereby satisfying the constant-loss requirements.



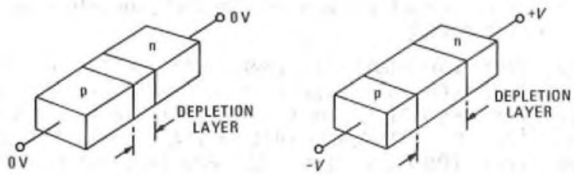

(*c*) The time constant of the control-current circuitry needs to follow syllabic variations, so that a relatively low time constant is desirable. However, the lower the time constant, the wider is the bandwidth required by the frequency-modulated control signal. Since an increase in control-signal bandwidth in the composite 3 kHz channel can only be provided at the expense of speech bandwidth, some compromise must be reached. Subjective tests show that time constants in the range 18–20 ms are optimum. Lower values require too large a control-signal bandwidth; higher values cause sluggish operation of the expander.

*Q 7 (a) Use a diagram to explain the characteristic of a varactor diode.*

*(b) Describe, with the aid of a simple circuit diagram, the operation of a varactor-diode frequency modulator.*

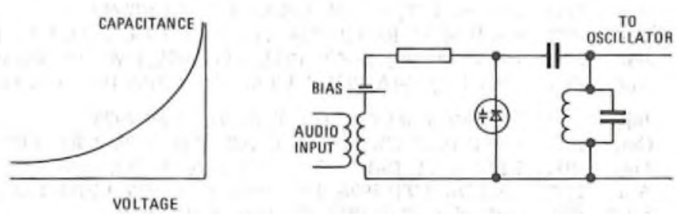
*(c) An oscillator operating at 9 MHz has a 64 pF capacitor in its tuning circuit. What total capacitance swing must the varactor supply to allow the modulator to have a 100 kHz peak deviation?*

A 7 (*a*) A varactor diode is fundamentally a p n junction diode. When a junction is formed between p-type and n-type materials, electrons cross from the n-region into the p-region and neutralize positive carriers. Also, positive carriers (holes) cross from the p to the n-region and neutralize excess electrons. The result is the formation of a narrow region near the junction which is free from charged particles, and which is termed the *depletion layer* (see sketch (*a*)). If an external reverse bias is applied to the p n junction, the width of the depletion layer increases (sketch (*b*)).




(*a*) (*b*)

The depletion layer introduces capacitance between the p and n-type materials, so that variation of the depletion layer produces variations in capacitance. It can be shown that the capacitance, $C_D$ of the diode is related to the potential applied, $V$, by the expression $C_D = 1/\sqrt{|V|}$. A typical capacitance/voltage characteristic is shown in sketch (*c*).




(*c*) (*d*)

(*b*) Since the reactance of a varactor diode is controlled by the potential developed between the p and n-type materials of its structure, it is possible to modulate a signal. Sketch (*d*) illustrates this application. The varactor is biased to a convenient point on its characteristic such that the resultant diode capacitance, together with that of the tuned circuit of the oscillator, resonates with the inductance of the tuned circuit at the nominal carrier frequency. When an audio signal is connected across the diode, the potential across the diode varies in sympathy with the audio signal, producing capacitance variations. These are transferred to the tuned circuit, thereby changing the frequency. Thus, audio-signal amplitude variations are transformed into frequency variations; that is, the oscillator is frequency modulated.

(*c*) Resonance occurs at a frequency, $f$, defined by the expression $f = 1/2\pi\sqrt{(LC)}$ hertz, where $L$ is the inductance (henrys), and $C$ is the capacitance (farads). Hence, $f = kC^{-1/2}$. Differentiating with respect to $C$ gives

$$\delta f = -\frac{k}{2}C^{-3/2}\,\delta C = -\frac{f\delta C}{2C}.$$

The minus sign indicates that the frequency decreases as the capacitance increases.

Assuming the varactor to be part of the tuning-circuit capacitance,

$$\delta C = \frac{2C\delta f}{f} = \frac{2 \times 0{\cdot}1 \times 64}{9} = \underline{\pm\ 1{\cdot}42\ \text{pF.}}$$

*Q 8 (a) With the aid of a block diagram, describe the operation of a very-high-frequency communication receiver unit suitable for both amplitude-modulated and frequency-modulated signals.*
*(b) List the controls you would expect on such a receiver.*

**A 8** See A6, Communication Radio C 1972, *Supplement*, Vol. 66, p. 52, Oct. 1973.

*Q 9 Complete the table of comparison for the Yagi, rhombic and log-periodic aerials, as applied to a typical aerial of each type.*

| | *Rhombic* | *Log-Periodic* | *Yagi* |
|---|---|---|---|
| *Operating-Frequency Range* | High-frequency | High-frequency | Very-high frequency |
| *Bandwidth* | 4 MHz | 10 MHz | 2% of resonant frequency |
| *Gain* | 15 dB | 10 dB | 8 dB |
| *Input Impedance* | 600 Ω | 100 Ω | 75 Ω |
| *Dimensions* | 6λ | 3λ/4 | λ/2 |
| *For What Service is it Commonly Used?* | Point-to-point | Fixed service to more than one receiver | Domestic broadcast reception |
| *Is it a Travelling-Wave Aerial?* | Yes | No | No |

**A 9** The table is shown completed; λ is the wavelength.

*Q 10 (a) Describe how to measure the sensitivity of a superheterodyne sound-broadcast receiver, listing the equipment required.*
*(b) Describe the procedure to be followed in aligning the intermediate-frequency stages of a superheterodyne sound-broadcast receiver.*

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