E&E Engineering
Conventional Solved Questions

Paper-I

Also useful for
State Engineering Services Examinations

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During the last few decades of engineering academics, India has witnessed geometric growth in engineering graduates. It is noticeable that the level of engineering knowledge has degraded gradually, while on the other hand competition has increased in each competitive examination including GATE and UPSC examinations. Under such scenario higher level efforts are required to take an edge over other competitors.

The objective of MADE EASY books is to introduce a simplified approach to the overall concepts of related stream in a single book with specific presentation. The topic-wise presentation will help the readers to study & practice the concepts and questions simultaneously.

The efforts have been made to provide close and illustrative solutions in lucid style to facilitate understanding and quick tricks are introduced to save time.

Following tips during the study may increase efficiency and may help in order to achieve success.

- Thorough coverage of syllabus of all subjects
- Adopting right source of knowledge, i.e. standard reading text materials
- Develop speed and accuracy in solving questions
- Balanced preparation of Paper-I and Paper-II subjects with focus on key subjects
- Practice online and offline modes of tests
- Appear on self assessment tests
- Good examination management
- Maintain self motivation
- Avoid jumbo and vague approach, which is time consuming in solving the questions
- Good planning and time management of daily routine
- Group study and discussions on a regular basis
- Extra emphasis on solving the questions
- Self introspection to find your weaknesses and strengths
- Analyze the exam pattern to understand the level of questions
- Apply shortcuts and learn standard results and formulae to save time

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Revised Syllabus of ESE: Basics of semiconductors; Diode/Transistor basics and characteristics; Diodes for different uses; Junction and Field Effect Transistors (BJTs, JFETs, MOSFETs); Optical sources/detectors; Basics of Opto electronics and its applications.

1. Semiconductor Physics

Q.1 Show that a semiconductor has minimum conductivity at a given temperature when

\[ n = n_i \sqrt{\mu_n/\mu_e} \]

and

\[ p = n_i \sqrt{\mu_p/\mu_n} \]

[8 marks : 1998]

Solution:

Conductivity of semi-conductor

\[ \sigma = nq\mu_e + pq\mu_h \]

by Mass action law

\[ np = n_i^2; \quad p = \frac{n_i^2}{n} \]

so

\[ \sigma = nq\mu_e + \frac{n_i^2}{n} q\mu_h \]

for maximum conductivity

\[ \frac{d\sigma}{dn} = 0 \]

\[ \frac{d\sigma}{dn} = q\mu_e - \frac{n_i^2}{n^2} q\mu_h = 0 \]

\[ q\mu_e = \frac{n_i^2}{n^2} q\mu_h \]

\[ n_i^2 \frac{\mu_h}{\mu_e} = r^2 \]

\[ n = n_i \sqrt{\frac{\mu_h}{\mu_e}} \]

similarly

\[ p = n_i \sqrt{\frac{\mu_e}{\mu_h}} \]
Q.2 Discuss "Hall Effect" in materials. [10 marks : 2000]

Solution:

- Hall Effect:
  - If a specimen (metal or semiconductor) carrying a current \( I \) is placed in a transverse magnetic field \( B \), an electric field \( E \) is induced in the direction perpendicular to both \( I \) and \( B \). This phenomenon, known as the Hall effect, is used to determine whether a semiconductor is n-type or p-type and to find the carrier concentration.

\[ Y \quad l \quad B \quad E \quad l \quad d \quad X \]

Semiconductor bar

\[ 1 \quad 2 \]

\[ \Rightarrow \] Hall effect is used in many applications as following:
- (a) measurement of magnetic flux density
- (b) measurement of displacement
- (c) measurement of current
- (d) measurement of power in Electromagnetic waves
- (e) determination of carrier concentration
- (f) determination of mobility of semiconductor material.

Q.3 Explain how the phenomenon of Hall effect can be used to determine whether a semiconductor is ‘n’ type or ‘p’ type. [10 marks : 2000]

Solution:

Consider the figure shown here:

- **Statements of Hall effect** "If a specimen (metal or semiconductor) carrying a current \( I \) is placed in a transverse magnetic field \( B \), an electric field \( E \) is induced in the direction perpendicular to both \( I \) and \( B \). This phenomenon, known as the Hall effect, is used to determine whether a semiconductor is n-type or p-type and to find the carrier concentration”.

\[ Y \quad l \quad B \quad E \quad l \quad d \quad X \]

Semiconductor bar

\[ 1 \quad 2 \]

\[ \Rightarrow \] If the semiconductor is n-type material, so that the current is carried by electrons, these electrons will accumulate on side 1 and this surface becomes negatively charged with respect to side 2. Hence, a potential, called the Hall voltage \( (V_h) \), appears between surfaces 1 and 2. If the polarity of \( V_h \) is positive at terminal 2, then as explained above, the carriers must be electrons.

\[ \Rightarrow \] If on the other hand, terminal 1 becomes charged positively with respect to terminal 2, the semiconductor must be p-type.

Q.4 Define Hall Coefficient \( R_h \). Obtain an expression for \( R_h \) in terms of Hall Voltage \( V_h \). [20 marks : 2000]

Solution:

Hall Coefficient \( R_h \) is defined as

\[ R_h \equiv \frac{1}{\rho} \]

where \( \rho \) = charge density
Revised Syllabus of ESE: Electrical Engineering materials; Crystal structure & defects; Ceramic materials-structures, composites, processing and uses; Insulating laminates for electronics, structures, properties and uses; Magnetic materials, basics, classification, ferrites, ferro/para-magnetic materials and components; Nano materials-basics, preparation, purification, sintering, nano particles and uses; Nano-optical/magnetic/electronic materials and uses; Superconductivity, uses.

1. Crystalline Structures

Q.1 Draw sketches illustrating a (100) plane, a (110) plane, and a (111) plane in a cubic unit cell. How many equivalent (100) planes are there in a cubic crystal? A material has a face-centred cubic structure with an ionic radius of 1.06 Å. Calculate the inter planar separation for (111) planes.

[15 marks : 2004]

Solution:

![Sketches of (100), (110), and (111) planes in a cubic unit cell.]

There are six equivalent (100) planes in a cubic crystal.

⇒ In a face-centred cubic structure,

\[ a\sqrt{2} = 4r \]

where

- \(a\) = side of cube
- \(r\) = ionic radius

Given: \(r = 1.06 \text{ Å}\)

\[ a = \frac{4r}{\sqrt{2}} = \frac{4 \times 1.06}{\sqrt{2}} = 2.998 \text{ Å} \]

Inter planar separation for (111) planes is

\[ d = \frac{a}{\sqrt{3}} = \frac{2.998}{\sqrt{3}} = 1.731 \text{ Å} \]

Q.2 Discuss the difference in covalent bonding in carbon as

(i) diamond

(ii) graphite

[10 marks : 2012]
Solution:

(i) **Covalent bonding of Carbon in diamond:**

In diamond, every carbon atom bonds with four other adjoining atoms in a continuous network. No electrons are left unbonded. This results in very strong bonds between carbon atoms and is responsible for the great hardness of diamonds and their clear colorless appearance. Their great density bend light more than other crystals do making their appearance so spectacular.

Valence electrons of carbon atoms in diamonds are bond to 4 electrons in *Tetrahedral arrangement*. The covalent bond is very strong, this makes diamonds have high melting points, the covalent bond in three dimensional structure causes diamond to become the hardest material.

The bonding of electrons, diamonds have dome shaped structures. Dome is one of the strongest structures. Diamond forcing more carbon atoms into a smaller dense package. Since there are no free electrons to wander through the structure, diamonds are excellent insulators. The brilliance and fire of cut diamonds is due to a very high index of refraction (2.42) and the strong dispersion of light, properties which are related to the structure of diamonds.

(ii) **Covalent bonding of Carbon in Graphite:**

In graphite, each carbon atoms shares electrons with only three neighbouring carbon atoms, leaving the fourth electron relatively free to roam around from one carbon atom to another, in much the same way as metals do. The carbon atoms form a network consisting of layers of interconnected carbons able to slide against each other making in a pencil. Unlike diamond, graphite is soft, pitch black in color, and conducts electricity due to the free roaming valence electrons.

Valence electrons of graphite are only bonded to 3 valence electrons, so the covalent bond in hexagonal ring. Graphite is softer than diamond because they are held by weak intermolecular force. Graphite sheet like array of carbon atoms joined with minimal pressure.

Q.3 **Find the relation between unit cell edge length ‘a’ and atomic radius ‘r’ for a body-centred cubic crystal.**

[5 marks : 2018]

Solution:

In a BCC structure, eight atoms are present at the corners of the cube and one atom is present at the centre of the cube.
The corner atoms are shared by 8 unit cells.

The direction from the corner of a cube to the farthest corner is cube body diagonal \( (d_b) \). The face diagonal \( (d_f) \) is a line drawn from one corner to another corner of the same face.

\[
d_f^2 = a^2 + a^2 = 2a^2 \quad \text{and} \quad d_b^2 = a^2 + a^2 + a^2 = 3a^2
\]

Atoms along the body diagonal touch each other. Thus, the body diagonal has a length that is four times the radius of the atom, \( R \).

\[
d_b = 4R
\]

\[
3a^2 = 16R^2
\]

\[
R = \frac{a\sqrt{3}}{4}
\]

### 2. Dielectric and Ceramic Materials

**Q.4** A certain homogeneous slab of lossless dielectric material is characterized by an electric susceptibility of 0.12 and carries a uniform flux density with it of 1.6 nC/m². Find the electric field intensity, the polarization, the average dipole moment if there are \( 2 \times 10^{19} \) dipoles per cubic meter and the voltage between two equipotential 2.54 cm apart. [17 marks : 1998]

**Solution:**

Given,

- Electric susceptibility \( \chi_e = 0.12 \)
- Flux density \( \rho = 1.6 \text{ nC/m}^2 = 1.6 \times 10^{-9} \text{ C/m}^2 \)
- No. of dipoles/m³ \( N = 2 \times 10^{19} \)
- \( d = 2.54 \text{ cm} \)
- \( \chi_e = \varepsilon_r^{-1} \)
- 0.12 = \( \varepsilon_r^{-1} \)
- \( \varepsilon_r = 1.12 \)

So

\( D = \rho = 1.6 \times 10^{-9} \text{ C/m}^2 \)

1. Electric field

\[
E = \frac{D}{\varepsilon_0 \varepsilon_r} = \frac{1.6 \times 10^{-9}}{8.85 \times 10^{-12} \times 1.12}
\]

\( E = 161.4 \text{ V/m} \)

2. Dipole moment

\( \rho = Qd = 1.6 \times 10^{-19} \times 2.54 \times 10^{-2} \)

\( \rho = 4.1 \times 10^{-21} \text{ C-m} \)

3. Polarization

\( P = N\rho = 2 \times 10^{19} \times 4.1 \times 10^{-21} \)

\( P = 8.2 \times 10^{-2} \text{ C/m}^2 \)
Q.5 Draw the electrical equivalent circuit of a Quartz Crystal explaining the significance of the various components of the circuit.

Solution:
The electrical equivalent circuit of a quartz crystal is shown here.
⇒ The inductor \( L \), capacitor \( C \) and resistor \( R \) are analogous to the mass, the compliance (the reciprocal of the spring constant) and the viscous-damping factor of the mechanical system. The shunt capacitance \( C' \) represents the electrostatic capacitance between electrodes with the crystal as a dielectric and its magnitude is very much larger than \( C \). Because the crystal losses, represented by \( R \), are small, the equivalent quality factor of the crystal is high—typically \( 20,000 \).
⇒ This crystal can be used for the Radio frequency oscillation.

Q.6 Draw neat sketches of Impedance versus Frequency, Reactance versus Frequency of the Quartz resonator indicating the critical frequencies and their values.

Solution:

- Crystal impedance versus frequency curve:

- Reactance versus frequency curve (if \( R = 0 \)):

If we neglect the resistance \( R \), the impedance of the crystal is a reactance \( jX \) whose dependence upon frequency is given by

\[
jX = -\frac{j}{\omega C_p} \cdot \frac{\omega^2 - \omega^2_s}{\omega^2 - \omega^2_p}
\]

where \( \omega_s^2 = \frac{1}{L_s C_s} \) is the series resonant frequency (the zero impedance frequency), and

\( \omega_p^2 = \frac{1}{L_s} \left( \frac{1}{C_s} + \frac{1}{C_p} \right) \) is the parallel resonant frequency (the infinite impedance frequency).

Since \( C_p \gg C_s \), then \( \omega_p = \omega_s \).
For \( \omega_s < \omega < \omega_p \), the reactance is inductive and outside this range it is capacitive.
Revised Syllabus of ESE: Principles of measurement, accuracy, precision and standards; Analog and Digital systems for measurement, measuring instruments for different applications; Static/dynamic characteristics of measurement systems, errors, statistical analysis and curve fitting; Measurement systems for non-electrical quantities; Basics of telemetry; Different types of transducers and displays; Data acquisition system basics.

1. Basics of Measurement and Error Analysis

Q.1 A voltmeter with an internal resistance of 4750 Ω issued to measure the voltage across a resistance of 600 Ω connected in series with a DC series of internal resistance 400 Ω. What is the error in measurement? [17 marks : 1998]

Solution:

Equivalent resistance of 600 Ω resistor and voltmeter internal resistance

\[ R_{eq} = \frac{4750 \times 600}{4750 + 600} \]

\[ R_{eq} = 532.7 \, \Omega \]

So voltage measured by voltmeter

\[ V_m = \frac{532.7 \times V}{532.7 + 400} \]

\[ V_m = 0.57 \, V \]

\[ V_f = \frac{600V}{600 + 400} \]

\[ V_f = 0.6 \, V \]

\[ \%\varepsilon_r = \frac{V_m - V_f \times 100}{V_f} = \frac{0.57 - 0.6}{0.6} \times 100 \]

\[ \%\varepsilon_r = -5\% \]

Q.2 Explain briefly the following terms as applied to characterisation of measurement systems:
(i) accuracy, (ii) precision, (iii) resolution, (iv) sensitivity and (v) linearity. [10 marks : 2002]

Solution:

- **Accuracy**: It is the closeness with which an instrument reading approaches the true value of the quantity being measured. Thus accuracy of a measurement means conformity to truth.

- **Precision**: It is a measure of the reproducibility of the measurements, i.e., given a fixed value of a quantity, precision is a measure of the degree of agreement within a group of measurements.
- **Resolution:** The smallest increment in the quantity being measured which can be detected with certainty by an instrument is its resolution.

- **Sensitivity:** The sensitivity of an instrument is the ratio of the magnitude of the output signal or response to the magnitude of input signal or the quantity being measured.

- **Linearity:** The linearity is simply a measure of maximum deviation of any of the calibration points from this straight line.

![Diagram](image)

Q.3 A freshman student of electrical engineering wanted to calibrate a power meter. He recorded the current flowing through a resistor (value marked as 0.0105 Ω), as 30.4 A. Later on, a second year student discovered that the ammeter reading taken by the freshman was lower by 1.2% and the value marked on the resistor was 0.3% lower. Find the true value of the power as a percentage of the power calculated by the freshman. [10 marks : 2005]

Solution:

\[ R = 0.0105 \, \Omega \]

\[ \therefore \text{ True value of resistor is 0.3\% lower than 0.0105 } \Omega \]

\[ \therefore \text{ True value of resistance, } \]

\[ R' = R \left( 1 - \frac{0.3}{100} \right) = 0.0105 \left( 1 - \frac{0.3}{100} \right) = 0.0104685 \, \Omega \]

Current,

\[ I = 30.4 \, \text{A} \]

\[ \therefore \text{ True current is 1.2\% lower than } I. \]

\[ \therefore \text{ True current, } \]

\[ I' = 30.4 \left( 1 - \frac{1.2}{100} \right) = 30.0352 \, \text{A} \]

True power,

\[ P' = I'^2 R' = (30.0352)^2 \times 0.0104685 = 9.44377 \, \text{Watt} \]

But power calculated by freshman,

\[ P = I^2 R = (30.4)^2 \times 0.0105 = 9.70368 \, \text{Watt} \]

\[ \frac{P'}{P} \times 100 = \frac{9.44377}{9.70368} \times 100 = 97.32\% \]

Q.4 What is the difference between accuracy and precision of a measuring instrument? Define sensitivity of a voltmeter.

When a voltmeter is connected across either of the two 100 kΩ resistors in figure, it shows a reading of 90 V when it should have shown 100 V. Explain clearly why this is happening. Also calculate the internal resistance of the voltmeter being used. [15 marks : 2007]
Solution:

- **Accuracy:**
  - It is the closeness with which an instrument reading approaches the true value of the quantity being measured. Thus accuracy of a measurement means conformity to truth.

- **Precision:**
  - It is a measure of the reproducibility of the measurements, i.e., given a fixed value of a quantity, precision is a measure of the degree of agreement within a group of measurements.
  
  A precise instrument may not give accurate measurements.

- **Sensitivity of a voltmeter:**
  - The sensitivity of a voltmeter is defined as
    \[ S_v = \frac{1}{I_{fs}} = \frac{1}{I_m} \ \Omega/V \]
    
    where \( I_{fs} \) is current required for full scale deflection.

  - In the given figure, voltmeter shows the reading of 90 V in place of 100 V because of its loading effect.

  - A voltmeter, when connected across two points in a highly resistive circuit, acts as a shunt for that portion of the circuit. The meter will then give a lower voltage drop than actually existed before the meter was connected. This effect is called loading effect of an instrument and is caused principally by low sensitivity instruments.

Let the internal resistance of the voltmeter be \( R_m \).

\[
\frac{100 \times R_m}{100 + R_m} = R_{eq}
\]

By voltage division Rule

\[
\frac{200 \times R_{eq}}{100 + R_{eq}} = 90 \ V
\]

\[
200 \cdot R_{eq} = 9000 + 90 \cdot R_{eq}
\]

\[
R_{eq} = \frac{900}{11} \ k\Omega
\]

\[
\frac{100 \cdot R_m}{100 + R_m} = \frac{900}{11}
\]

\[
11 \cdot R_m = 900 + 9 \cdot R_m
\]

\[
2 \cdot R_m = 900
\]

\[
R_m = 450 \ k\Omega
\]

Internal resistance of voltmeter is 450 kΩ.
Revised Syllabus of ESE: Network graphs & matrices; Wye-Delta transformation; DC circuits-Ohm's & Kirchoff's laws, mesh and nodal analysis, circuit theorems; Linear constant coefficient differential equations- time domain analysis of RLC circuits; Solution of network equations using Laplace transforms- frequency domain analysis of RLC circuits; 2-port network parameters-driving point & transfer functions; State equations for networks; Single-phase AC circuits, Steady state sinusoidal analysis.

1. Basics of Network Analysis

Q.1 Find $i_1$, $i_2$ and $V$ in the circuit shown in figure. [8 marks: 1998]

Solution:

Applying KCL at node (1),

$$i_2 + 2A = 0 + 8$$

$$i_2 = 6\text{ A}$$

By applying KVL in mesh

$$-V + (3 \times 6) - (4 \times 2) = 0$$

$$V = 10\text{ V}$$

at node (2) by applying KCL

$$5 = i_x + 2$$

$$i_x = 3\text{ A}$$

By applying KCL at node (3)

$$i_1 + i_x = i_2$$

$$i_1 = 6 - 3$$

$$i_1 = 3\text{ A}$$
Q.2 In the circuit given in the below figure find the potential difference between A and C and B and C, under steady state conditions.

Solution:
Let all the capacitors have the same value \( C_1 \).
The given circuit can be redrawn as:

Further the circuit can be redrawn as below:

There will be no current in the vertical \( 3C_1 \) capacitor, so the circuit can be redrawn as below:
(because of balanced bridge)

Under steady state, there will be no current in the circuit. The circuit can be reduced as below:
(because all the capacitors will be open circuited under steady state condition.)
Since the circuit being symmetrical,

So \[ V_{AC} = V_{CB} \]

\[ V_{AB} = V_{AC} + V_{CB} = 100 \]

\[ \Rightarrow 2V_{AC} = 100 \]

\[ \Rightarrow V_{AC} = 50 \text{ V} \]

\[ \Rightarrow V_{CB} = 50 \text{ V} \]

\[ \Rightarrow V_{BC} = -50 \text{ V} \]

Q.3 Find the current through the 5-ohm resistor in the circuit shown in figure. [15 marks : 2007]

Solution:

The given circuit can be rearranged as follows:

On rearranging again

Since, \[ \frac{R_{AD}}{R_{AB}} = \frac{R_{CD}}{R_{BC}} \]

i.e. \[ \frac{5}{10} = \frac{15}{30} \]

\[ \therefore \text{The above circuit is a balanced Wheatstone's bridge. Hence, the current through 5 \Omega resistor i.e. between B and D is 0.} \]
Revised Syllabus of ESE: Small signal equivalent circuits of diodes, BJTs and FETs; Diode circuits for different uses; Biasing & stability of BJT & JFET amplifier circuits; Analysis/design of amplifier—single/multi-stage; Feedback & uses; Active filters, timers, multipliers, wave shaping, oscillators and other circuits; Basics of linear ICs, operational amplifiers and their applications—linear/non-linear.

1. Diode Circuits

Q.1 A power supply using half-wave rectifier is to have an output dc voltage of 30 V, with a load resistance of 500 Ω. The ripple factor should not exceed 0.01. Find a suitable value for C. Determine the peak diode current. Assume 50 Hz supply frequency. [8 marks : 1999]

Solution:
For Half-wave rectifier,

Ripple Factor \[ r = \frac{1}{2\sqrt{3}CR_t f} \]

\[ C = \frac{1}{2\sqrt{3}R_t \times f} = \frac{1}{2\sqrt{3} \times 0.01 \times 500 \times 50} = 1.15 \text{ mF} \]

\[ V_r = rV_{dc} = 0.01 \times 30 = 0.3 \text{ V} \]

\[ V_r = \frac{I_{dc}}{Cf} \]

\[ \Rightarrow I_{dc} = fCV_r = 50 \times 1.15 \times 10^{-3} \times 0.3 = 0.01725 \text{ A} \]

2nd part: Peak diode current

\[ i_{D_{max}} = I_{dc} \left( 1 + 2\pi \sqrt{\frac{2V_m}{V_r(p-p)}} \right) \]

\[ \therefore V_m = V_{dc} \]

\[ i_{D_{max}} = 0.01725 \left( 1 + 2\pi \sqrt{\frac{2 \times 30}{0.3}} \right) = 1.55 \text{ A} \]

Q.2 A simple full wave bridge rectifier circuit has an input voltage of 240 V AC r.m.s. Assume the diodes to be ideal. Find the output DC current, DC voltage, r.m.s. values of output currents and voltages and the peak inverse voltage that appears across the non-conducting diode. Assume load resistance to be 10 kΩ. [8 marks : 2001]
Solution:

Given that \( V_{(\text{rms})} = 240 \text{ V} = \frac{V_m}{\sqrt{2}} \)

\[ \Rightarrow \quad V_m = 240\sqrt{2} \text{ V} \]

Output DC current

\[ I_{\text{DC}} = \frac{2I_m}{\pi} \]

where

\[ I_m = \frac{V_m}{R_L + 2R_f} \]

where \( R_f \) = Forward resistance of each diode

Since diodes are ideal, so \( R_f = 0 \)

\[ \therefore \quad I_m = \frac{V_m}{R_L} = \frac{240\sqrt{2}}{10} = 24\sqrt{2} \text{ mA} \]

So output DC current,

\[ I_{\text{DC}} = \frac{2 \times 24\sqrt{2}}{\pi} \text{ mA} = 21.6 \text{ mA} \]

Output DC voltage,

\[ V_0 = I_{\text{DC}} R_L = 21.6 \times 10 = 216 \text{ V} \]

RMS value of output current,

\[ I_{\text{rms}} = \frac{I_m}{\sqrt{2}} = \frac{24\sqrt{2}}{\sqrt{2}} = 24 \text{ mA} \]

RMS value of output voltage,

\[ V_{0(\text{rms})} = \frac{V_m}{\sqrt{2}} = V_{(\text{rms})} = 240 \text{ V} \]

Peak inverse voltage for bridge rectifier is,

\[ \text{PIV} = V_m = 240\sqrt{2} \Rightarrow \text{PIV} = 339.41 \text{ V} \]

Q.3 For the circuits shown in the figure 1 and 2, sketch and explain the output waveforms. Assume the diodes to be ideal.

Solution:

For figure 1, the output waveform is shown below:

when \( V_i \) is +ve going:

\[ \Rightarrow \quad V_i > 2 \text{ V} \text{ then, } D \text{ is forward biased and short circuit.} \]

\[ \therefore \quad V_o = 2 \text{ V} \]

\[ \Rightarrow \quad V_i < 2 \text{ V} \text{ then } D \text{ is reverse biased and open circuit.} \]

\[ \therefore \quad V_o \text{ follows } V_i \]

For time \( 0 < t < t_1 \) and \( t_2 < t < 2\pi/\omega \), the diode \( D \) is OFF. So, \( V_o = V_i \).

For time \( t_1 < t < t_2 \), the diode \( D \) in ON. So \( V_o = 2 \text{ V} \)
For figure-2, the output waveform is shown below:

For the time period 0 → T/2, diode is in short-circuit state.
So,
\[ V_0 = -V_t \text{ and } V_c = V + V_t. \]

For the time period T/2 → T, diode is in OFF state.
So,
\[ V + V_c + V_0 = 0 \]
\[ \Rightarrow V_0 = -(V + V_c) = -(2V + V_t) \]

Q.4 For a full wave rectifier with a capacitor filter, show that ripple voltage \( V_r \) is inversely proportional to the capacitor \( C \) and is proportional to the load current \( I_{dc} \). Calculate the value of ‘\( V_r \)’ when \( C = 100 \mu F \) and \( I_{dc} = 10 \text{ mA} \). The a.c. input voltage to the rectifier is given by \( V = V_m \sin 314t \).

[8 marks : 2009]

Solution:

Consider a full wave rectifier (FWR) with a capacitor filter as shown in figure below:

\[ V_0 = iR_L \]
\[ = (i_1 + i_2)R_L \text{ ...(i)} \]

\[ I_{dc} = \frac{2I_m}{\pi} \text{ (For a FWR)} \]

\[ I_{rms} = \frac{I_m}{\sqrt{2}} \text{ and } V_{dc} = \frac{2I_mR_L}{\pi} \]

where,
\[ I_m = \frac{V_m}{R_f + R_L} \text{ (} R_f = \text{diode forward resistance)} \]

\[ \Rightarrow \text{ For each rectifier circuit there is a maximum voltage to which the diode can be subjected. This potential is called the Peak Inverse Voltage (PIV) because it occurs during that part of cycle when the diode is in non-conducting mode. The approximated load-voltage waveform } V_0 \text{ in a FW. Capacitor-filtered rectifier is given as:} \]
1. Number Systems, Boolean Algebra and Logic Gates

Q.1 Verify the following equations by using Boolean algebra:

(i) \( AB + AC + BC = AC + BC \)
(ii) \( \overline{AB} + BC + CA = \overline{A}B + \overline{B}C + \overline{C}\overline{A} \)  \[4 + 4 = 8 \text{ marks : 2000}\]

Solution:

(i) \( AB + AC + BC = AB(C + \overline{C}) + AC + BC = ABC + AC + AB\overline{C} + BC \)

\( = (B + 1)AC + (A + 1)BC \) \( \therefore A + 1 = 1 \)

\( = AC + BC \)

(ii) \( \overline{AB} + BC + CA = (\overline{AB})(\overline{BC})(\overline{CA}) \)

\( = (\overline{A} + \overline{B})(\overline{B} + C)(\overline{C} + \overline{A}) \)

\( = (\overline{AB} + \overline{AC} + \overline{B} + BC)(C + A) \)

\( = \overline{ABC} + \overline{AB} + \overline{AC} + \overline{B}C + \overline{AB} + \overline{B}C + \overline{ABC} \)

\( = \overline{AB} + BC + CA + ABC \)

\( = \overline{AB} + B\overline{C} + \overline{C}(1 + B) \)

\( = \overline{AB} + B\overline{C} + \overline{C} \) \( \therefore 1 + \overline{B} = 1 \)

Q.2 In a 4-input NAND gate, two inputs are to be used. What are the options available for the unused inputs and which one is the best and why?  \[4 \text{ marks : 2002}\]

Solution:

There are the three options available for the unused inputs:

(i) The unused inputs are connected to +5 V through a 1 k\(\Omega\) resistor so that the logic level is a 1.

(ii) The unused inputs are tied to a used input.

(iii) If the NAND gate is constructed using TTL logic, the unused inputs can be left unconnected (open/floating). This is because in TTL logic, open/floating input behaves as if a logic 1 is applied to it.
⇒ It is highly undesirable to leave an input disconnected because it will act like an antenna which is liable to pick up stray radiated signals that could cause the gate to operate improperly. When inputs are tied together, it increases the number of driving inputs so the effective fanout decreases so best option is to connect these inputs to +5 V through 1 kΩ resistor.

Q.3 Solve the following expression by mapping:

\[ f = \Sigma m(0, 2, 3, 6, 7, 8, 9, 10, 13) \]

Write the steps involved in solving this problem using Quine-McClusky method. [10 marks : 2003]

Solution:

Given that,

\[ f = \Sigma m(0, 2, 3, 6, 7, 8, 9, 10, 13) \]

The Karnaugh map for the above function is shown below:

\[ f = \overline{A}C + \overline{B}D + ACD \]

⇒ Steps involved in solving the problem using Quine-McClusky method are given below:

(i) Group binary representation of the minterms is done according to the number of 1’s contained.

(ii) Any two minterms that differ from each other by only one variable can be combined, and the unmatched variable removed. Two minterm numbers fit into this category if they both have the same bit value in all positions except one.

(iii) This process is repeated for every minterm until the exhaustive search is completed. The matching-process cycle is repeated for those new terms just found.

(iv) Further cycles are continued until a single pass through a cycle yields no further elimination of literals.

(v) The remaining terms and all the terms that did not match during the process comprise the prime implicates.

Q.4 A 4-bit number is represented by ABCD with D as LSB. Design a logic circuit that will produce a 1 whenever the input is greater than 0010 but less than 1000. Use minimum number of gates. [10 marks : 2003]

Solution:

i.e. when ABCD is between 3 and 7, output = 1

\[ f = \Sigma m(3, 4, 5, 6, 7) \]

Using Karnaugh map:

\[ f = \overline{AB} + \overline{ACD} \]

The logic circuit is shown below:
Q.1 Discuss the power loss in the magnetic core of a transformer. [15 marks : 2003]

Solution:

There are two types of power losses in the magnetic core of a transformer:

**Eddy current loss:** When a magnetic core carries a time-varying flux, voltages are induced in all possible paths enclosing the flux. The result is the production of circulating currents in the core. These currents are called eddy currents and have power loss \((i^2R)\) associated with them is called eddy–current loss.

**Hysteresis loss:**

\[ \Rightarrow \text{When mmf is increased from zero to its maximum value, the energy stored in the field per unit volume is} \]

\[ \int_{-B_f}^{B_m} HdB = \text{area of abgo} \]

When \(H\) is reduced to zero, the energy is given out by the magnetic field and has a value

\[ \int_{B_m}^{B_f} HdB = \text{area cbgc} \]

The net energy unrecovered in the process of abco which is lost irrespectively in the form of heat and is called hysteresis loss.

Q.2 A certain 5-hp three-phase induction motor operates from a 440 V-rms (line-to-line) three-phase source and draws a line current of 6.8 A rms at a power factor of 78 percent lagging under rated full load conditions. The full load speed is 1150 rpm. Under no-load conditions, the speed is 1195 rpm, and the line current is 1.2 A rms at a power factor of 30 percent lagging. Find the power loss and efficiency with full load, the input power with no load, and the speed regulation. [20 marks : 2017]

Solution:

- The rated output power of the motor is,

\[ P_{out} = 5 \text{ hp} = 5 \times 746 \text{ W} = 3730 \text{ W} \]

- The input power under full load condition is,

\[ P_{in(\text{full-load})} = \sqrt{3} V_{rms} I_{rms} \cos \phi \]

\[ = \sqrt{3} (440)(6.8)(0.78) = 4042.2 \text{ W} \]
The power loss under full load condition is,
\[ P_{\text{loss}} = P_{\text{in (full-load)}} - P_{\text{out}} = 312.2 \text{ W} \]

The full load efficiency is,
\[ \eta = \frac{P_{\text{out}}}{P_{\text{in (full-load)}}} \times 100\% = 92.28\% \]

The input power under no load condition is,
\[ P_{\text{in (no-load)}} = \sqrt{3} V_{\text{rms}} I_{\text{rms}} \cos \phi = \sqrt{3} (440)(1.2)(0.30) = 274.4 \text{ W} \]

The speed regulation of the motor is,
\[ \text{Speed regulation} = \frac{n_{\text{no-load}} - n_{\text{full-load}}}{n_{\text{full-load}}} \times 100\% = \frac{1195 - 1150}{1150} \times 100\% = 3.91\% \]

Q.3 Two coils are wound on a toroidal core as illustrated in the figure below. The reluctance of the core is \(10^7\) (ampere-turns)/Wb. Determine the self-inductances and mutual inductance of the coils. Assume that the flux is confined to the core so that all of flux links both the coils.

Solution:
Let flux be \(\phi\)
Given: Reluctance = \(10^7\) (A-turn/Wb), \(N_1 = 100\), \(N_2 = 200\)
∴ Flux produced due to current \(i\) is always proportional to current \(i\).
\[ \phi = K i \quad \text{\(K\rightarrow\) proportionality constant} \]
\[ -\frac{N d\phi}{dt} = e \]
\[ e = -\frac{NKdi}{dt} \quad \text{and} \quad e = -\frac{Ldi}{dt} \]
∴
\[ \frac{L di}{dt} = \frac{N d\phi}{dt} \]
\[ L i = N \phi \]

and
\[ \phi = \frac{Ni \times \mu_0 \mu_r A}{l} \]
∴
\[ L = \frac{N_i^2 \mu_0 \mu_r A}{l} = \frac{N_i^2}{\text{Reluctance}} \]
∴
\[ L_1 = \frac{N_1^2}{\text{Reluctance}} \]
\[ L_1 = \frac{(100)^2}{10^7} = 10^{-3} \text{ H} = 1 \text{ mH} \]
\[ L_2 = \frac{N_2^2}{\text{Reluctance}} = \frac{(200)^2}{10^7} = 4 \times 10^{-3} \text{ H} = 4 \text{ mH} \]

Mutual inductance = \(K\sqrt{L_1L_2}\)
As flux is confined to core, so all of the flux links both the coils,
\[ K = 1 \]
∴
\[ M = \sqrt{L_1L_2} = \sqrt{4 \times 10^{-3} \times 10^{-3}} = 2 \times 10^{-3} \text{ H} = 2 \text{ mH} \]