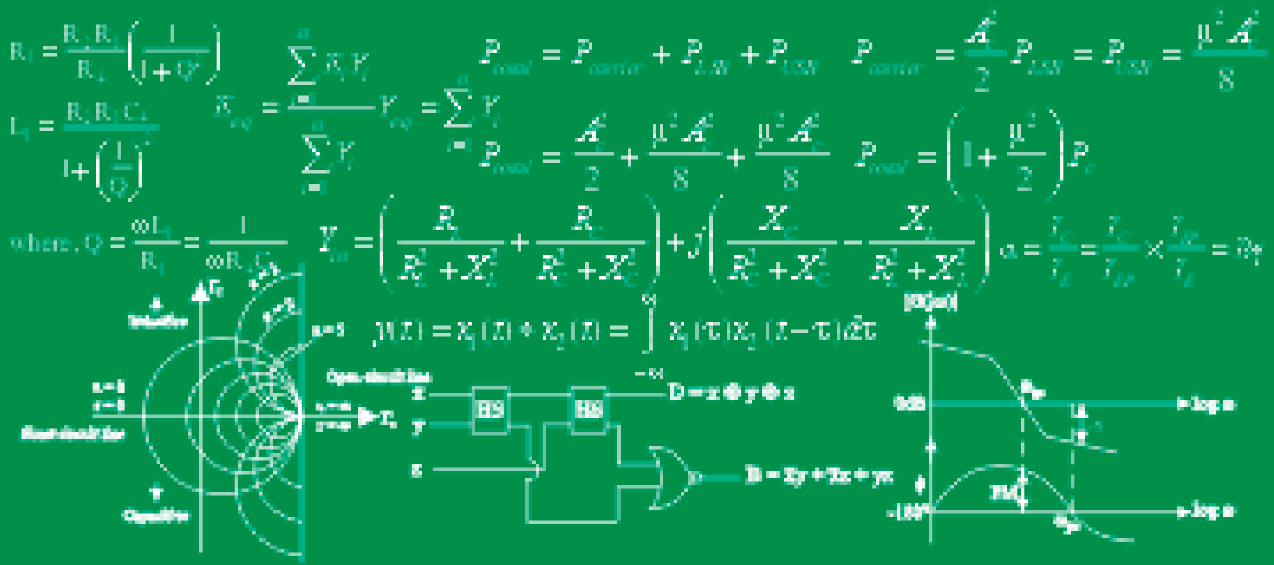
FORMULA BOOK
for
GATE, IES & PSU's

ELECTRONICS ENGINEERING

NETWORK THEORY | CONTROL SYSTEM | DIGITAL ELECTRONICS | MICROPROCESSOR | COMPUTER ORGANIZATION | ELECTRONIC DEVICES & CIRCUITS | ANALOG ELECTRONICS | SIGNAL AND SYSTEM | COMMUNICATION SYSTEM | MICROWAVES | ELECTROMAGNETIC THEORY | MEASUREMENT & INSTRUMENTATION | MATERIAL SCIENCE



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ELECTRONICS FORMULA BOOK for GATE, IES & PSU's

HANDBOOK
&
FORMULA BOOK

for

GATE, IES, JTO, PSU's & SSC

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A WORD TO THE STUDENTS

Er. R.K. Rajesh
(DIRECTOR)

GATE and Engineering Services Examinations are the most prestigious competitive examinations conducted for graduate engineers. Over the past few years, they have become more competitive as more and more numbers of aspirants are increasingly becoming interested in post graduate qualifications & government jobs for a secured and bright career.

This Formula Book consists of well-illustrated concepts, important formulae and diagrams, which will be highly beneficial at the last leg of candidate's preparation.

It includes all the subjects of Electronics Engineering, which are required for all type of competitive examinations. Adequate emphasis has been laid down to all the major topics in the form of Tips / Notes, which will be highly lucrative for objective and short answer type questions.
Proper strategy and revision is a mandatory requirement for clearing any competitive examination. This book covers short notes and formulae for Electronics Engineering. This book will help in quick revision before the GATE, IES & all other PSUs.
This book has been designed after considering the current demand of examinations.

It would be very fruitful if the students go through this book every day.
We are presenting this book by considering all the facts which is required to get success in the competition.

With best wishes for future career

R. K. Rajesh
Director
Engineers Institute of India
eii.rkrajesh@gmail.com

This book is dedicated to all

Electronics Engineers

Preparing for GATE, IES, JTO, SSC

& Public sector examinations.

CONTENTS

Why IES?

Indian Engineering Services (IES) constitute of engineers that work under the govt. of India to manage a large segment of public sector economy which constitutes of Railroads, Public works, Power, Telecommunications, etc. IES remain the most sought-after careers for the engineering graduates in India. A combined competitive examination is conducted by UPSC for recruitment to the Indian Engineering Services. The exam constitutes of a written exam followed by an interview for personality test.

Why GATE?

In the present competitive scenario, where there is mushrooming of universities and engineering colleges, the only yardstick to measure and test the calibre of engineering students is the GATE.

The GATE Advantage

Many public sector undertakings such as BHEL, IOCL, NTPC, BPCL, HPCL, BARC and many more PSUs are using the GATE score for selecting candidates for their organizations. Students who qualify in GATE are entitled to a stipend of Rs 8,000 per month during their M.Tech. course. Better remuneration is being offered for students of M.Tech./ME as compared to those pursuing B.Tech/B.E. A good rank assures a good job. After joining M.Tech. at IITs and IISc, one can look at a salary package ranging from Rs 7lakh to 30lakh per annum depending upon specialization and performance. Qualifying GATE with good marks is also an eligibility clause for the award of JRF in CSIR Laboratories.

1

NETWORK THEORY

CONTENTS

1. NETWORK BASICS

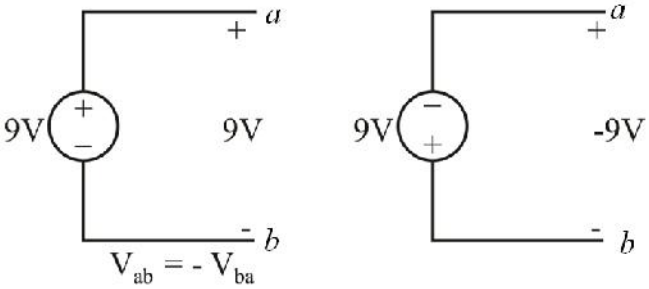
Current: Electric current is the time rate of change of charge flow.

$$i = \frac{dq}{dt} \quad \text{(Ampere)}$$

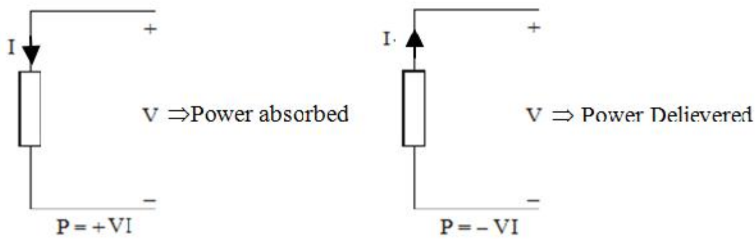
Charge transferred between time t_o and t $\quad q = \int_{t_o}^{t} i\,dt$

Sign Convention: A negative current of –5A flowing in one direction is same as a current of +5A in opposite direction.

Voltage: Voltage or potential difference is the energy required to move a unit charge through an element, measured in volts.



Power: It is time rate of expending or absorbing energy.



- Law of conservation of energy must be obeyed in any electric circuit.
- Algebraic sum of power in a circuit, at any instant of time, must be zero.

i.e. $\sum P = 0$

Circuit Elements:

Resistor: Linear and bilateral (conduct from both direction)

In time domain V(t) = I(t)R

In s domain V(s) = RI(s)

$$\boxed{R = \frac{\rho l}{A} \text{ ohm}}$$

l = length of conductor, ρ = resistivity, A = area of cross section

- Extension of wire to n times results in increase in resistance: $\boxed{R' = n^2 R}$

- Compression of wire results in decrease in resistance: $\boxed{R' = \dfrac{R}{n^2}}$

Capacitor: All capacitors are linear and bilateral, except electrolytic capacitor which is unilateral.

Time Domain: $i(t) = \dfrac{Cdv(t)}{dt}$ $\qquad v(t) = \dfrac{1}{C}\int_{-\infty}^{t} i(t)dt$

In s-domain: $I(s) = sCV(s)$ $\qquad V(s) = \dfrac{1}{sC} I(s)$

- Capacitor doesn't allow sudden change of voltage, until impulse of current is applied.
- It stores energy in the form of electric field and power dissipation in ideal capacitor is zero.
- Impedance $Z_c = -jX_c\Omega$ & $X_c = \dfrac{1}{\omega C}$; $X_c \rightarrow$ Capacitive reactance ; $\omega = 2\pi f$

Inductor: Linear and Bilateral element

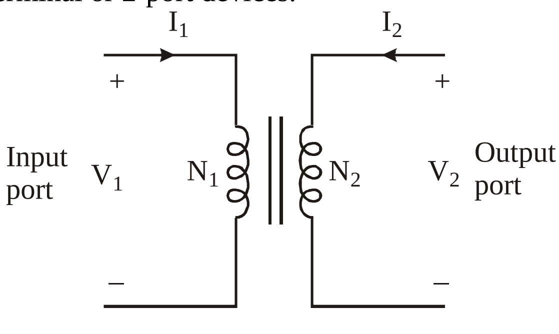
Time Domain: $v(t) = L\dfrac{di(t)}{dt}$ $\qquad i(t) = \dfrac{1}{L}\int_{\infty}^{t} v(t)dt$

Impedance $Z_L = jX_L\,\Omega$ & $X_L = \omega L\,\Omega$

In s-domain $V(s) = sL\,I(s)$ $\qquad I(s) = \dfrac{1}{sL} V(s)$

- Inductor doesn't allowed sudden change of current, until impulse of voltage is applied.
- It stores energy in the form of magnetic field.
- Power dissipation in ideal inductor is zero.

Transformer: 4 terminal or 2-port devices.



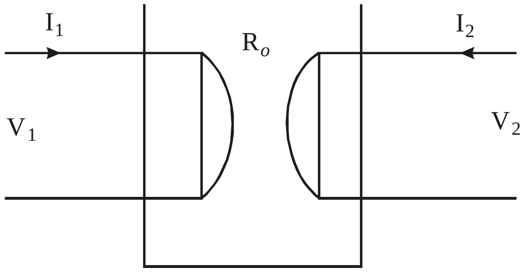
$N_1 > N_2$: Step down transformer $\qquad$ $N_2 > N_1$ **:** Step up transformer

$$\boxed{\frac{V_1}{V_2} = \frac{N_1}{N_2}} \qquad \boxed{\frac{I_1}{I_2} = \frac{N_2}{N_1}}$$

Where $\dfrac{N_1}{N_2} = K \rightarrow$ *Turns ratio.*

Transformer doesn't work as amplifier because current decreases in same amount power remain constant.

Gyrator:

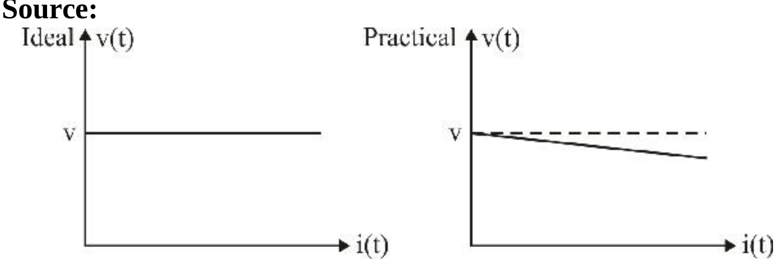


$R_o \rightarrow$ Coefficient of Gyrator

$V_1 = R_o\ I_2$ $\qquad\qquad$ $V_2 = -R_o\ I_1$

- If load is capacitive then input impedance will be inductive and vice versa.
- If load is inductive then input impedance will be capacitive.
- It is used for simulation of equivalent value of inductance.

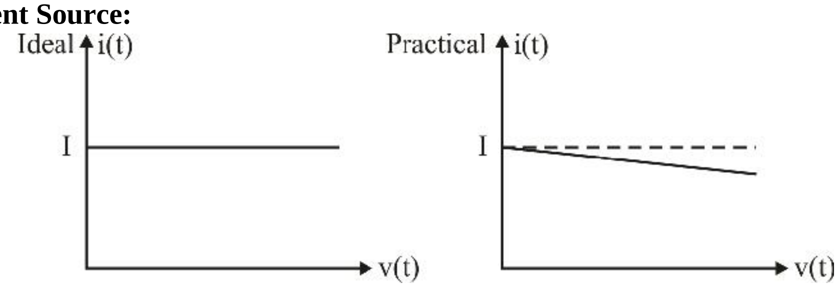
Voltage Source:



In practical voltage source, there is small internal resistance, so voltage across the element varies with respect to current.

- **Ideal voltmeter, R_V ì ã (Internal resistance)**

Current Source:



In practical current source, there is small internal resistance, so current varies with respect to the voltage across element.

- **Ideal Ammeter, $R_a \to 0$ (Internal resistance)**

Dependent and Independent Source:

Independent Source: Voltage or current source whose values doesn't depend on any other parameters. E.g. Generator etc.

Dependent Source: Voltage or current source whose values depend upon other parameters like current, voltage.

The handling of independent and dependent voltage source is identical except.

(*i*) In **Thevenin** and **Norton Theorem** (*ii*) **Superposition Theorem**

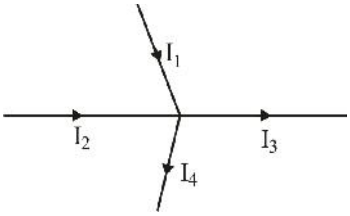
Where, (*i*) All **independent** voltage sources are short circuited.
(*ii*) All **independent** current sources are open circuited.
(*iii*) All **dependent** voltage and current sources are left as they are.

- A network in which all network elements are physically **separable** is known as **lumped network.**
- A network in which the circuit elements like resistance, inductance etc, are not physically separate for analysis purpose, is called **distributed network**. E.g. Transmission line.
- If an element is capable of delivering energy independently, then it is called active element.
  Example: Voltage source, Current source
- If it is not capable of delivering energy, then it is **passive element.**
  Example: Resistor, Inductor, Capacitor
- If voltage and current across an element are related to each other through a constant coefficient then the element is called as **linear element** otherwise it is called as **non-linear.**
- When elements characteristics are independent of direction of current then element is called **bi-directional** element otherwise it is called as **unidirectional**. Ex: R, L & C.
- Diode is a unidirectional element.
- Voltage and current sources are also **unidirectional** elements.
- Every linear element should obey the **bi-directional** property but vice versa as is not necessary.
- Internal resistance of **voltage source** is in series with the source. Internal resistance of ideal **voltage source** is zero.
- Internal resistance of **current source** is in parellel with the source. Internal resistance of ideal **current source** is infinite.

2. METHODS OF ANALYSIS AND THEOREMS

(*i*) **Kirchoff's Points Law** or **Current Law (KCL):** In any electrical network, the algebric sum of the currents meeting at point (or junction) is zero.

Incoming current = Outgoing current



$$I_1+I_2 = I_3+I_4$$

It is based on conservation of charge.

(*ii*) **Kirchoff's Mesh Law** or **Voltage Law (KVL):** The algebraic sum of products of currents and resistance in each of conductor in any closed path in a network plus the algebraic sum of emf in that path is zero.

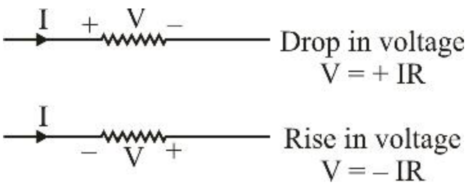
i.e. $\Sigma IR + \Sigma emf = 0$

It is based on conservation of energy.

Determination of Voltage Sign

(*a*) **Sign of Battery E.M.F.:**

(*b*) **Sign of IR Drop:**



Resistors in Series: $R_{eq} = R_1 + R_2 + R_3 + ... + R_n$

Resistors in Parallel: $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} .....+ \frac{1}{R_n}$

Inductors in Series: $L_{eq} = L_1 + L_2 + L_3 + ... + L_n$

Inductors in Parallel: $\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + ... + \frac{1}{L_n}$

Capacitors in Series: $\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ... + \frac{1}{C_n}$

Capacitor in Parallel: $C_{eq} = C_1 + C_2 + C_3 + ... + C_n$

2

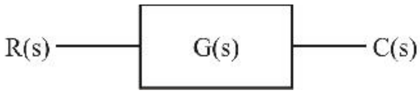
CONTROL SYSTEMS

CONTENTS

1. BLOCK DIAGRAM

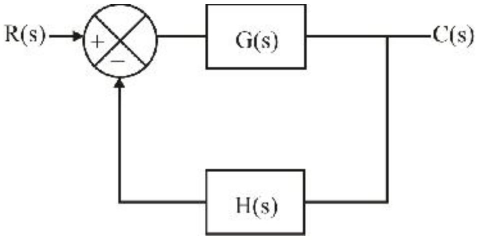
Open Loop Control System:

- In this system the output is not fedback for comparison with the input.
- Open loop system faithfulness depends upon the accuracy of input calibration.



Transfer function $G(s) = \frac{C(s)}{R(s)}$

When a designer designs, he simply design open loop system.
Closed Loop Control System: It is also termed as feedback control system. Here the output has an effect on control action through a feedback. Ex. Human being
Transfer Function:



$$\text{Transfer function} = \frac{C(s)}{R(s)} = \frac{G(s)}{1 + G(s)H(s)}$$

Comparison of Open Loop and Closed Loop control systems:
Open Loop:

1. Accuracy of an open loop system is defined by the calibration of input.
2. Open loop system is simple to construct and cheap.
3. Open loop systems are generally stable.
4. Operation of this system is affected due to presence of non-linearity in its elements.

Closed Loop:

1. As the error between the reference input and the output is continuously measured through feedback. The closed system works more accurately.
2. Closed loop systems is complicated to construct and it is costly.
3. It becomes unstable under certain conditions.
4. In terms of performance the closed loop system adjusts to the effects of non-linearity present.

Transfer Function: The transfer function of an LTI system may be defined as the ratio of Laplace transform of output to Laplace transform of input under the assumption

$$G(s) = \frac{Y(s)}{X(s)}$$

- The transfer function is completely specified in terms of its poles and zeros and the gain factor.

- The T.F. function of a system depends on its elements, assuming initial conditions as zero and is independent of the input function.
- To find a gain of system through transfer function put $s = 0$

Example: $G(s) = \dfrac{s+4}{s^2+6s+9}$ Gain $= \dfrac{4}{9}$

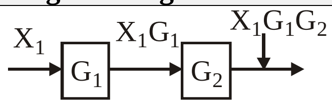
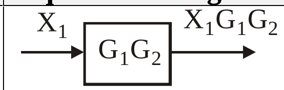
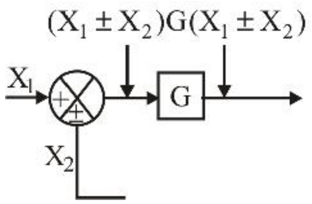
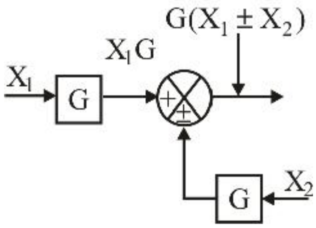
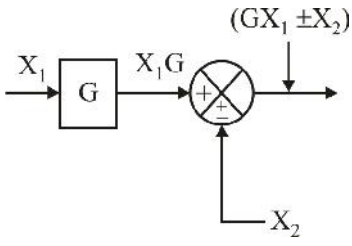
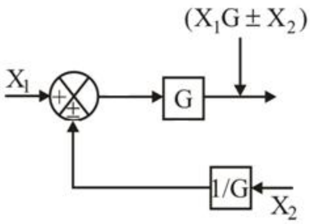
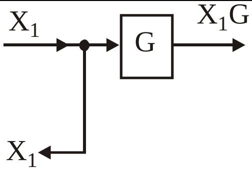
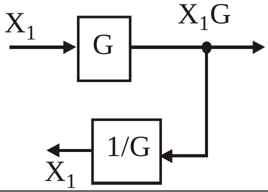
If a step, ramp or parabolic response of T.F. is given, then we can find Impulse Response directly through differentiation of that T.F.

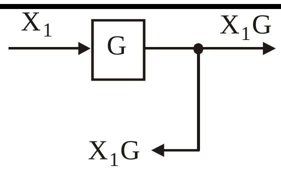
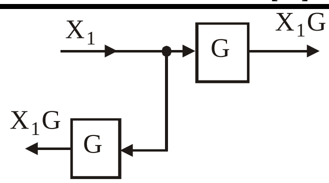
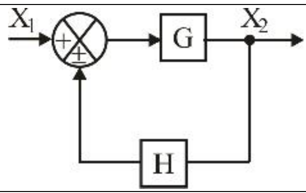
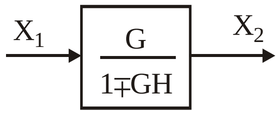
$$\frac{d}{dt}\text{(Parabolic Response)} = \text{Ramp Response}$$

$$\frac{d}{dt}\text{(Ramp Response)} = \text{Step Response}$$

$$\frac{d}{dt}\text{(Step Response)} = \text{Impulse Response}$$

Block Diagram Reduction:

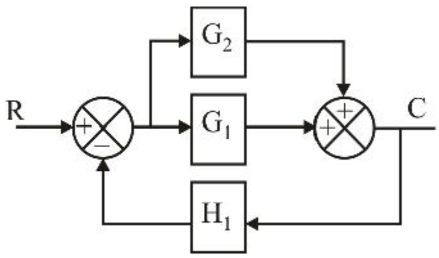
Rule	**Original Diagram**	**Equivalent Diagram**
1. Combining blocks in cascade		
2. Moving a summing point after a block		
3. Moving a summing point ahead of block		
4. Moving a take off point after a block		

5. Moving a take off point ahead of a block		
6. Eliminating a feedback loop		

$(GX_1 \pm X_2)$

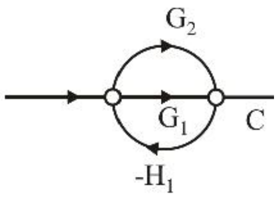
Signal Flow Graphs:

- It is a graphical representation of control system.
- Signal Flow Graph of Block Diagram:



Block diagram

$\Rightarrow$



Signal Flow Graph

Mason's Gain Formula: Transfer function = $\dfrac{\Sigma\, p_k\, \Delta_k}{\Delta}$

$p_k \rightarrow$ Path gain of k^{th} forward path

Δ = 1 – [Sum of all individual loops] + [Sum of gain products of two non-touching loops] – [Sum of gain products of 3 non-touching loops] + ………..

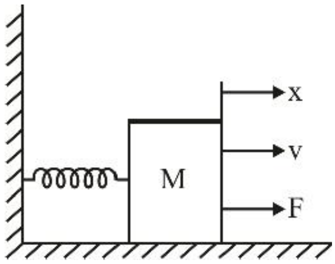
$\Delta_k \rightarrow$ Value of Δ obtained by removing all the loops touching k^{th} forward path as well as non-touching to each other

2. MATHEMATICAL MODELLING

Mechanical System:

Translational System:

Mass:

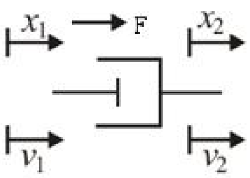


$$F = m\frac{d^2x}{dt^2} = m\frac{dv}{dt}$$

F = Force on block m — x = Displacement of block

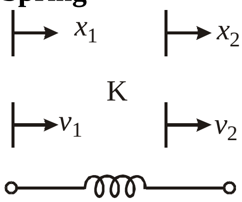
V = Velocity of Block — m = Mass of block

Damper



$$F = f\frac{d}{dt}(x_1 - x_2)$$

Spring



by hooke's law

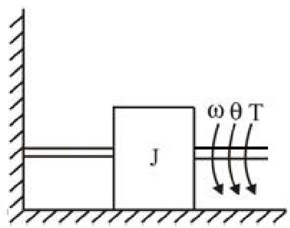
$$F = k(x_1 - x_2) = k\int (v_1 - v_2)\, dt$$

$k \rightarrow$ Spring constant

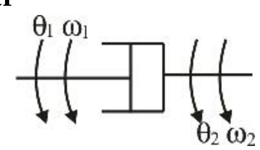
Rotational System

Inertia

$$T = J\frac{d^2\theta}{dt^2} = J\frac{d\omega}{dt}$$

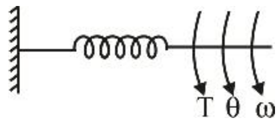


Damper



$$T = f\frac{d^2\theta}{dt^2} = f(\omega_1 - \omega_2)$$

Spring twisted:



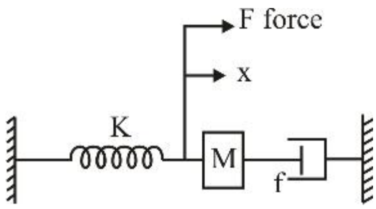
$$T = k\theta = k\int \omega\, dt$$

Force Voltage and Force Current Analogy:

Voltage (Series RLC)	**Current (Parallel RLC)**	**Force (Translational)**	**Torque (Rotational)**
V	I	F	T
q	ϕ	x	θ
R	$\frac{1}{R}$	f (Damper)	f (Damper)
$\frac{1}{C}$	$\frac{1}{L}$	k	k
L	C	M	J
I	V	Linear velocity	Angular velocity

Conversion of Translational System to other Systems:

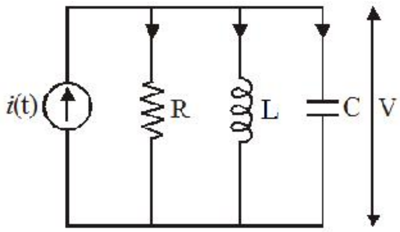
$$F = M\frac{d^2x}{dt^2} + f\frac{dx}{dt} + kx$$



Force–Current Analogy:

$$i = C\frac{d^2\phi}{dt^2} + \frac{1}{R}\frac{d\phi}{dt} + \frac{\phi}{L}$$

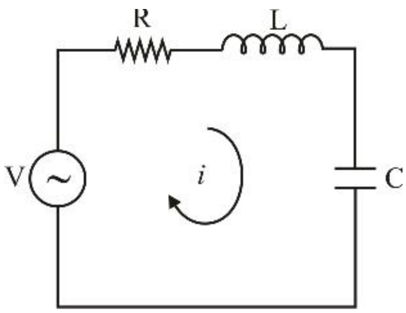
$$i = C\frac{dv}{dt} + \frac{v}{R} + \frac{1}{L}\int vdt$$



Force–Voltage Analogy:

$$V = L\frac{d^2q}{dt^2} + R + \frac{dq}{dt} + \frac{q}{C}$$

$$V = L\frac{di}{dt} + iR + \frac{1}{C}\int idt$$



3

DIGITAL ELECTRONICS AND CIRCUITS

CONTENTS

1. NUMBER SYSTEM & CODES

Number System and Codes:

Number System

- Weighted Number System
  e.g. : Binary, Octal, BCD
- Unweighted Number System
  e.g. : Gray code Excess-3 code

A number system with base '*r*', contents '*r*' different digits and they are from 0 to *r* – 1.

Decimal to other codes conversions: To convert decimal number into other system with base '*r*', divide integer part by r and multiply fractional part with *r*.

Other codes to Decimal Conversions: $(x_2 x_1 x_0 \,.\, y_1 y_2)_r \rightarrow (\mathrm{A})_{10}$

$$\mathrm{A} = x_2 r^2 + x_1\, r + x_0 + y_1\, r^{-1} + y_2\, r^{-2}$$

Hexadecimal to Binary: Convert each Hexadecimal digit into 4 bit binary.

$$(5AF)_{16} \rightarrow \frac{(0101}{5}\,\frac{1010}{A}\,\frac{1111)_2}{F}$$

Binary to Hexadecimal: Grouping of 4 bits into one hex digit.

$$(110101.11)_2 \rightarrow \underbrace{0011}\,\underbrace{0101}\,.\,\underbrace{1100} \rightarrow (35.\mathrm{C})_{16}$$

Octal to Binary and Binary to Octal: Same procedure as discussed above but here group of 3 bits is made.

Codes:

Binary coded decimal (BCD):

- In BCD code each decimal digit is represented with 4 bit binary format.

$$Eg : (943)_{10} \rightarrow \left(\underbrace{1001}_{9}\ \underbrace{0100}_{4}\ \underbrace{0011}_{9}\right)_{BCD}$$

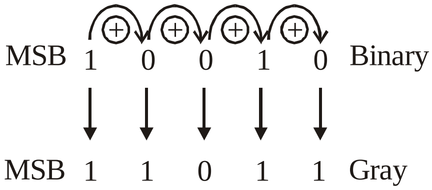
- It is also known as 8421 code
  Invalid BCD codes
  Total Number possible $\rightarrow\ 2^4 \Rightarrow 16$
  Valid BCD codes $\rightarrow 10$
  Invalid BCD codes $16 - 10 \Rightarrow 6$
  These are 1010, 1011, 1100, 1101, 1110, and 1111

Excess-3 code: (BCD + 0011)

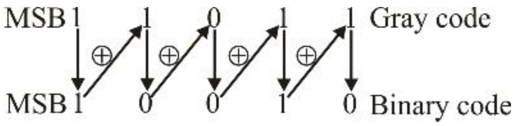
- It can be derived from BCD by adding '3' to each coded number.
- It is unweighted and self-complementing code.

Gray Code:
It is also called minimum change code or unit distance code or reflected code.

Binary code to Gray code:



Gray code to Binary code:



Alpha Numeric codes: EBCDIC (Extended BCD Interchange code)
It is 8 bit code. It can represent 128 possible characters.

- Parity Method is most widely used schemes for error detection.
- Hamming code is most useful error correcting code.
- BCD code is used in calculators, counters.

Complements: If base is **r** then we can have two complements.

(i) (r – 1)'s complement.
(ii) r's complement.

To determine (r–1)'s complement: First write maximum possible number in the given system and subtract the given number.
To determine r's complement: (r–1)'s complement + 1
First write (r–1)'s complement and then add 1 to LSB

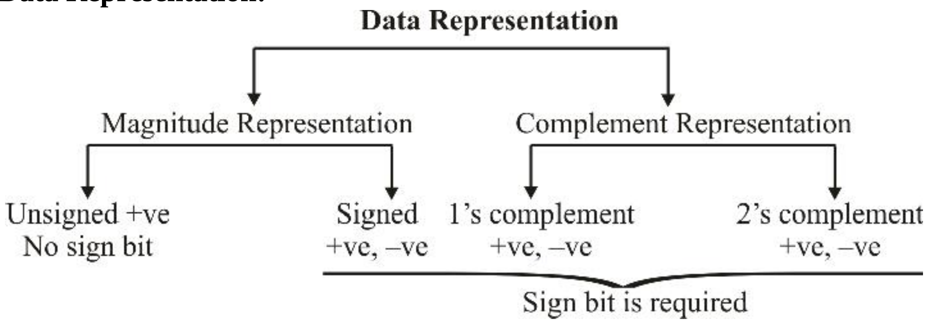
Example: Find 7's and 8's complement of 2456

$$\text{7's complement}\quad \begin{array}{r} 7777 \\ -2456 \\ \hline 5321 \end{array} \qquad \text{8's complement}\quad \begin{array}{r} 5321 \\ +1 \\ \hline 5322 \end{array}$$

Find 2's complement of 101.110
1's complement 010.001
For 2's complement add 1 to the LSB

$$\text{2's complement}\quad \begin{array}{r} 010.001 \\ +1 \\ \hline 010.010 \end{array}$$

Data Representation:



Unsigned Magritude: Range with *n* bit $\rightarrow$ 0 to 2^{n-1} $+5 \Rightarrow 101$

$-5 \Rightarrow$ Not possible

Signed Magritude: Range with *n* bit $\rightarrow -(2^{n-1}-1)$ to $+(2^{n-1}-1)$

$+6 \Rightarrow 0110$ $-6 \Rightarrow \underbrace{\underbrace{1}_{\text{sign bit}}\ 110}_{\text{with 4 bits}}$ $\underbrace{\underbrace{1}_{\text{sign bit}}\ 0000110}_{\text{with 8 bits}}$

1's complement: Range with *n* bit $\rightarrow -(2^{n-1}-1)$ to $+(2^{n-1}-1)$

$+6 \Rightarrow 0110$ $-6 \Rightarrow \underbrace{1}_{\text{sign bit}}\ \underbrace{001}_{\text{1's complement of 6}}$

2' complement: With *n* bits Range -2^{n-1} to $(2^{n-1}-1)$

$+6 \Rightarrow 0110$ $-6 \Rightarrow \underbrace{1}_{\text{sign bit}}\ \underbrace{010}_{\text{2's complement of 6}}$

In any representation
+ve numbers are represented similar to +ve number in sign magnitude.

2. BINARY AIRTHMETIC

When both the numbers have same sign then we add only magnitude and use the sign of MSB.

1' Complement Addition: When the numbers have different signs, keep one number as it is and take 1's complement of the negative number and add them.

If carry occurs:

(*a*) add carry to LSB

(*b*) sign of the result is sign of the complemented number.

If carry does not occur:

(*a*) take 1's complement of the result

(*b*) sign of the result is sign of the complemented number.

2' Complement Addition: When the numbers have different signs, keep the positive number as it is and take 2's complement of the negative number and add them.

If carry occurs:

(*a*) carry is discarded

If carry does not occur:

(*a*) take 2's complement of the result

(*b*) sign of the result is sign of the complemented number

BCD Addition: Add the BCD numbers as regular true binary numbers.

If the sum is 9(1001) or less, it is a valid BCD answer.

If sum is greater than 9 or if there is carryout of MSB, it is an invalid BCD number.

If it is invalid, add 6 (0110) to the result to make it valid. Any carry out of the MSB is added to the next more-significant BCD number.

Repeat steps for each group of BCD bits

$$\begin{array}{r} 76 \\ \underline{+94} \\ 170 \end{array} \qquad \begin{array}{r} 0111\ 0110 \\ \underline{+\ 1001\ 0100} \\ 1\ 0000\ 1010 \end{array} \quad \text{Invalid BCD number}$$

Add 6 (110) in the result, $\begin{array}{r} 1\ \ 0000\ \ 1010 \\ \underline{+\ \ 0110\ \ 0110} \\ \underbrace{1}_{1}\ \ \underbrace{0111}_{7}\ \ \underbrace{0000}_{0} \end{array}$ valid BCD number

Overflow concept: Overflow may occur when two same sign numbers are added.

Overflow condition : If x and y are the MSB's of two numbers and z is resultant MSB after adding two numbers then overflow conditions is

$$\bar{x}\,\bar{y}\,z + x\,y\,\bar{z} = 1$$

BOOLEAN ALGEBRA

Basic Operations:

AND	OR	NOT
A. A=A	A+A=A	
A.0=0	A+0=A	$\bar{\bar{A}}=A$
A.1=A	A+1=1	
$A.\bar{A}=0$	$A+\bar{A}=1$	

Boolean algebra Laws:

Commutative Law: A + B = B + A and A.B = B.A

Associative Law: A + (B + C) = (A + B) + C = A + B + C

A.(B.C) = (A.B).C = A.B.C

Distributive Law: A.(B + C) = A.B + A.C

Theorems: Distribution theorem: (A + B.C) = (A + B).(A + C)

A.(B + C) = A.B + A.C

Example: $\left(\bar{A} + A\bar{B}\right) = (\bar{A} + A)(\bar{A} + \bar{B}) = (\bar{A} + \bar{B})$

$$A+\bar{A}B = (A+\bar{A})(A+B) = A+B$$

Transposition Theorem: (A + B) . (A + C) = A + B.C

De Morgan's Law:

$$\overline{A_1.A_2.A_3......A_n} = \bar{A}_1 + \bar{A}_2 + ... + \bar{A}_n$$

$$\overline{A_1 + A_2 + A_3 ..... + A_n} = \bar{A}_1.\bar{A}_2.....\bar{A}_n$$

Involution Theorem: $\bar{\bar{A}} = \bar{A}$

Absorption Theorem: A + AB = A

Dual Expression: It will convert positive logic into negative and negative logic into positive logic.

Procedure:

1. Change each OR sign by AND and vice-versa.
2. Convert all 1s to 0s and all 0s to 1s.
3. Keep variables as it is.

- If one time dual is as same as function then it is known as **self dual expression**.

4

MICROPROCESSORS

CONTENTS

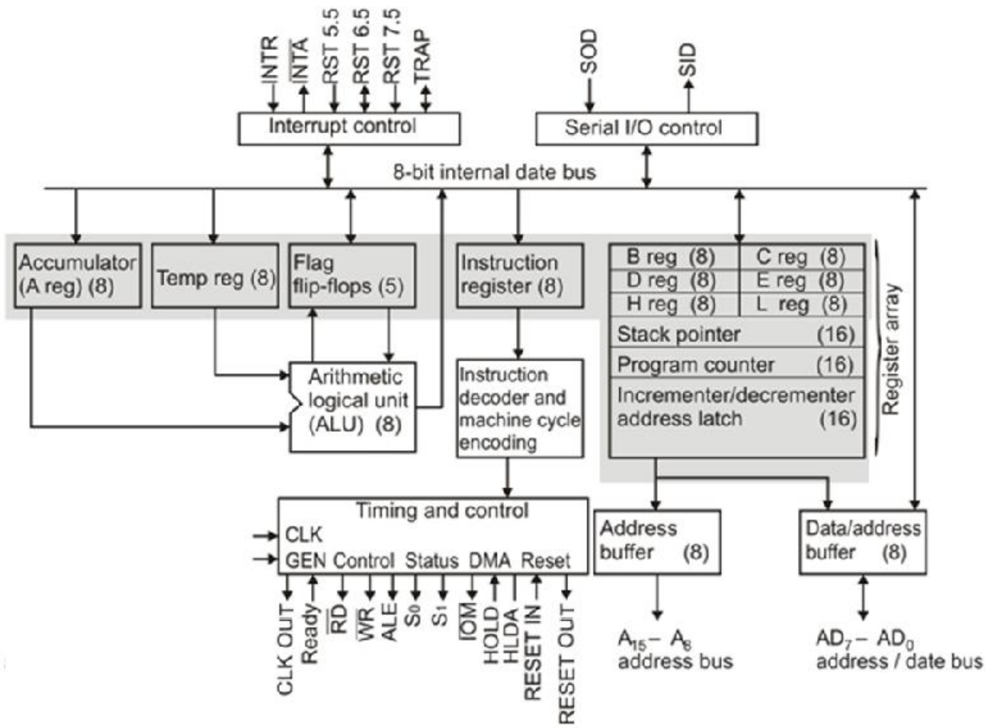
1. MICROPROCESSOR BASICS

A **Microprocessor** includes ALU, register arrays and control circuits on a single chip.

Microcontroller:

A device that includes microprocessor, memory and input and output signal lines on a single chip, fabricated using VLSI technology.

Architecture of 8085 Microprocessor



1. **8085 MPU:**

- 8 bit general – purpose microprocessor capable of addressing 64 K of memory.
- It has 40 pins, requires a +5V single power supply and can operate with 3 – MHz single phase clock.

2. **8085 programming model:**

   It has six general purpose register to store – 8 bit data. These are B, C, D, E, H and L. It can be combined as BC, DE, and HL to perform 16 bit operations.
   B, D, H $\rightarrow$ high order register and C, E, L $\rightarrow$ low order register.

Accumulator: Is an 8 bit register that is used to perform arithmetic and logic functions.

Flags: 5 flags

Flag Register:

D_7	D_6	D_5	D_4	D_3	D_2	D_1	D_0
S	Z		AC		P		CY

Carry Flag (CY): If an arithmetic operation result in a carry or borrow, the CY flag is set, otherwise it is reset.

Parity Flag (P):

If the result has au even number of 1s, the flag is set, otherwise the flag is reset.

Auxiliary Carry (AC): In an arithmetic operation

- If carry is generated by D_3 and passed to D_4 flag is set.
- Otherwise it is reset.

Zero Flag (Z): Zero Flag is set to 1, when the result is zero otherwise it is reset.

Sign Flag (S): Sign Flag is set if bit D_7 of the result is 1. Otherwise it is reset.

Program counter (PC): It is used to store the l6 bit address of the next byte to be fetched from the memory or address of the next instruction to be executed.

Stack Pointer (SP): It is 16 bit register used as a memory pointer. It points to memory location in Read/Write memory which is called as stack.

8085 Signals:

Address lines:

There are l6 address lines $AD_0 - AD_7$ and $A_8 - A_{15}$ to identify the memory locations.

Data lines/ Multiplexed address lines:

Multiplexed address lines: The signal lines $AD_7 - AD_0$ are bi-directional i.e. they serve dual purpose. The $AD_7 - AD_0$ address lines are shared with the data lines. The ALE signal is used to distinguish between address lines and data lines.

Control and Status Signals:

Address Latch Enable (ALE): This is positive going pulse generated every time and indicates that the $AD_7 - AD_0$ bits are address bits.

$\overline{\mathbf{RD}}$**:** This is active low signal indicates that the selected I/O or memory device is to be read.

$\overline{\mathbf{WR}}$**:** Active low signal indicates that data on data bus are to be written into a selected memory or I/O location.

IO/}M:

When this signal is high, it indicates an I/O operation.

When it is low it indicates memory operation.

$\mathbf{S_1}$ **and** $\mathbf{S_0}$ **:** These are status signals.

8085 Machine cycle status and control signals

Machine cycle	Status IO/M	S_1	S_o	Control signals
Opcode Fetch	0	1	1	$\overline{RD} = 0$
Memory Read	0	1	0	$\overline{RD} = 0$
Memory write	0	0	1	$\overline{WR} = 0$
I/O Read	1	1	0	$\overline{RD} = 0$
I/O write	1	0	1	$\overline{WR} = 0$
Interrupt Acknowledge	1	1	1	$\overline{INTA} = 0$
Halt	Z	0	0	
Hold	Z	X	X	
Reset	Z	X	X	$\overline{WR} = Z$ $\overline{INTA} = 1$

Note:
Z = Tri state (High Impedance) X = Unspecified

Externally Initiated Signals Including Interrupts:
The 8085 has five Interrupt signals that can be used to interrupt program execution. (INTR, TRAP, RST 7.5, RST 6.5, RST 5.5).
In addition to the interrupts, three pins – RESET, HOLD & READY accept the externally initiated signals as inputs.
Power supply and clock frequency
V_{CC} : + 5 power supply **V_{SS} :** ground reference
X1, X2: The frequency is internally divided by two. Therefore to operate a system at 3 MHz the crystal should have a frequency of 6 MHz.
CLK (OUT): Can be used as system clock for other devices.

Serial I/O ports:
8085 has two signals to implement the serial transmission: SID (serial input data) and SOD (serial output data).

Interfacing Memory and I/O devices:
It is used so that microprocessor should be able to identify I/O devices with an 8-bit address. It ranges from 00H to FFH.

Input output interfacing: It is used so that microprocessor should be able to identify input output devices with an 8-bit address. It ranges from 00H to FFH.

Size of memory: $2^n \times m$

$n \rightarrow$ address lines $m \rightarrow$ data lines

Absolute and Partial Decoding:
- When all the address lines are decoded to select the memory chip or input device and no other logic levels can select the chip. This is called absolute decoding.

- When some of the address lines may not be decoded, such lines are used as don't care. It results in multiple addresses. This technique reduces hardware and also called fold-back or mirror memory space.
- Instruction cycle is time required to complete the execution of an instruction.
- Machine cycle is the time required to complete one operation of accessing memory.
- T-state is one sub version of the operation performed in one clock period.

Characteristics	Memory-Mapped I/O	Peripheral I/O
Device address	16 bit	8 bit
Control signals for input/output	$\overline{MEMR}$ / $\overline{MEMW}$	$\overline{IOR}$ / $\overline{IOW}$
Instructions Available	Memory Related Instruction STA, LDA	IN and OUT
Data transfer	Between any register and input/output	Only between input/output and the accumulator
Maximum number of input/output possible	The memory map (64 K) is shared between input/output and system memory	The input/output map is independent of the memory map
Execution speed	13 – T states (LDA, STA) 7 – T states (MOV M, R)	10 – T states
Hardware Requirements	More hardware is needed to decoded 16 – bit address	Less hardware is needed to be coded 8 – bit address
Other features	Arithmetic or logical operation can be directly performed with input/output data	Not available

Instruction word size

The 8085 instruction set is classified into the following three groups according to word size

1. One – word or 1 – byte instructions
2. Two – word or 2 – byte instructions
3. Three – word or 3 – byte instructions

One – byte instructions

A 1 – byte instruction includes the op-code and operand in the same byte. Operands are internal registers and are coded into the instruction.

One – byte instructions

Task	Op-code	Operand	Binary – code	Hex code
Copy the contents of the accumulator in the register C.	MOV	C,A	01001111	4FH
Add the contents of the register B to the contents of the accumulator.	ADD	B	10000000	80H
Invert (complement) each bit in the accumulator.	CMA		00101111	2FH

Two – Byte Instructions

In a two – byte instruction, the first byte specifies the op-code and the second byte specifies the operand. Source operand is a data byte immediately following the op code.

Two – Byte Instructions

Task	Op-code	Operand	Binary Code	Hex code	
Load an 8 – bit data in the accumulator	MVI	A, Data	0011 1110	3E	First Byte
			DATA	DATA	Second Byte

Assume that the data byte is 32H. The assembly language instruction is written as

Mnemonics	Hex Code
MVI A, 32H	3E 32H

Three – byte Instructions

In a three byte instruction, the first byte specifies the op-code and the following two bytes specify the 16 – bits address. Note that, the second byte is the low – order address and the third byte is the high – order address.

Opcode + data byte + data byte

Three – byte Instructions

Task	Op-code	Operand	Binary Code	Hex Code	Instruction Type
Transfer the program sequence to the memory location 2085H.	JMP	2085H	1100 0011 1000 0101 0010 0000	C3 85 20	First byte Second byte Third byte

5

ELECTRONIC DEVICES & CIRCUITS

CONTENTS

1. SEMICONDUCTOR BASICS & ENERGY BANDS

Thermal Voltage: V_T (Voltage Equivalent of Temperature)

$$\boxed{V_T = \frac{T}{11600}\text{volt}}$$

Standard room temperature (300 K) $V_T = 0.0256$ volt $\boxed{V_T = 26mV}$

The standard room temperature corresponds to a voltage of 26 mV.

Leakage Current (I_o)

- Also called minority carrier current or thermally generated current.
- In silicon it is in nano ampere range and in germanium it is in micro ampere range.
- I_o doubles for every 10ºC. For 1ºC, I_o increases by 7%.
- I_o is proportional to the area of the device.
- **Advantages of smaller I_o:**

(i) Suitable for high temperature applications
(*ii*) Good Thermal stability
(*iii*) No false triggering

Energy Gap: Difference between the lower energy level of conduction band (CB) E_C and upper energy level of valance band (VB) E_v is called as energy gap.

Metals: VB and CB are overlap to each other.

- This overlapping increases with temperature.
- e^- is both in CB and VB.

Insulators: Conduction band is always empty. Hence no current passes. Band gap: 5 eV – 15 eV.

Semiconductor: Energy gap is small and it is in range of 1 eV.

- At room temperature current can pass through a semi conductor.

Energy Gap	Ge	Si	Ga As
$Eg_{T=0}$	7.85 eV	1.21 eV	X X
$Eg_{T=300\,K}$	0.72 eV	1.1 eV	1.47 eV

Energy gap at temperature T

For Ge $Eg_{(T)} = 0.785 - 7.2\times10^{-4}\,T$

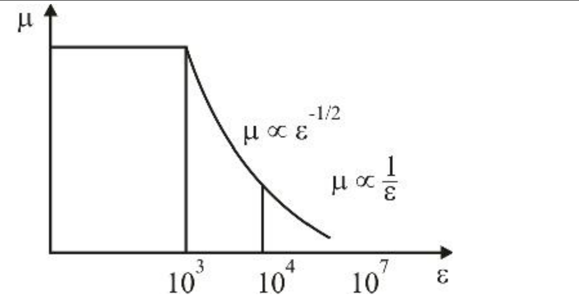
For Si $Eg_{(T)} = 1.21 - 3.6\times10^{-4}\,T$

Energy gap decreases with temperature.

Electric Field Intensity $£ = \frac{-dv}{dx}\frac{volt}{meter}$

Mobility of charge carriers $\mu = \frac{\text{drift velocity}}{\text{electric field intensity}} = \frac{v}{\varepsilon} \quad \frac{m^2}{sec}$

Mobility V_s £ curve

	$\varepsilon < 10^3$ $\mu = \text{constant}$ $10^3 < \varepsilon < 10^4$ « ∝ £ $^{-1/2}$ $\varepsilon > 10^4$ « ∝ $\frac{1}{£}$

So drift velocity: $V_d \propto$ £ $V_d \propto$ £$^{1/2}$ $V_d = \text{constant}$

- Mobility indicates how quick is the e^- or hole moving from one place to another.
- Electron mobility > hole mobility
- Mobility of charge carriers decreases with the temperature.

$$\boxed{« \propto T^{-m}}$$

Mass Action Law: In a semi conductor under thermal equilibrium (at constant temperature) the product of electrons and holes in a semiconductor is always constant and equal to the square of intrinsic concentration.

$$[n_o p_o = n_i^2]$$

$n_o \rightarrow$ Concentration of e^- in conduction band

$P_o \rightarrow$ Concentration of holes in valance band

$n_i \rightarrow$ Intrinsic concentration at given temperature

$$\text{Majority carrier concentration} = \frac{n_i^2}{\text{Minority carrier concentration}}$$

Intrinsic concentration $\boxed{n_i^2 = A_o T^3 e^{-\frac{Eg}{2KT}}}$

n_i is a function of temperature and energy gap.

Einstein's Equation: Relation between diffusion constant, mobility and thermal voltage.

$$\boxed{\frac{D_n}{«_n} = \frac{D_P}{«_P} = V_T = KT}$$

The unit of $\frac{D}{\mu}$ is volts. Where, $D_n \rightarrow e^-$ diffusion constant

$D_p \rightarrow$ Hole diffusion constant

Diffusion and Drift Current:

Diffusion Current: It is defined as migration of charge carriers from higher concentration to lower concentration due to concentration gradient.

Drift Current: It is flow of current through the material or device under the influence of voltage or electric field intensity.

Total current density in a semi conductor

$$\underset{\text{(Total current)}}{J} = \underset{\text{(Current carried by } e^-\text{)}}{J_n} + \underset{\text{(Current carried by holes)}}{J_p}$$

$$\underset{\text{current due to } e^-}{J_n} = \underset{e^- \text{ drift current density}}{J_n'} + \underset{e^- \text{ diffusion current density}}{J_n''}$$

For e^- $\boxed{J_n = nq«_n£ + qD_n \frac{dn}{dx} A/cm^2}$

For holes $\boxed{J_p = pq«_p£ - qD_p \frac{dp}{dx} A/cm^2}$

e^- diffusion length $\boxed{L_n = \sqrt{D_n{}^{2}}\ cm}$

Hole diffusion length $\boxed{L_P = \sqrt{D_P{}^{2}}\ cm}$

Conductivity

In Metals: Metals are uni-polar, so current is carried only by e^-

$$± = nq«_n$$

In metal, conductivity decreases with temperature.

In Semi Conductors $\boxed{± = nq«_n + pq«_P}$

$n \rightarrow$ Concentration of e^- in CB

$e \rightarrow$ Concentration of holes in VB

$\mu_n, \mu_p \rightarrow$ Mobility of holes and electrons

- Conductivity of pure semi-conductor increases with temperature

In Extrinsic Semi-conductor

For *n* type $\boxed{± = N_D\, q«_n}$ N_D = donor concentration

For *p* type $\boxed{± = N_A\, q«_p}$ N_A = acceptor concentration

In extrinsic semiconductor (SC) below the room temperature, conductivity increases. But above the room temperature their conductivity decreases.

Direct Band Gap Semiconductor

- During the re-combinations the falling e^- from the conduction band will be releasing energy in the form of light.
- Momentum and direction of e^- will remain same.

  Example: *GaAs*, *InP*, *ZnS*

Indirect Band Gap Material

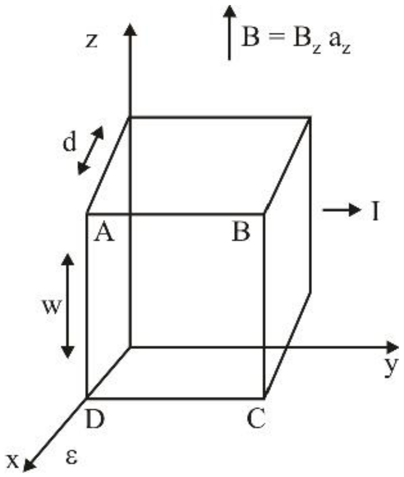
- Most of falling e^- will directly releasing energy in the form of heat

- Moment of e^- will change
- Direction of e^- will change *Example: Ge and Si*
  - Direct band gap materials having higher carrier lifetime and are used for fabrication for LED, laser, tunnel diode, photodiode.

General Properties of Ge and Si

Properties	Ge	Si
Atomic number	32	14
Density of atoms	4.42×10^{22}	5×10^{22}
Intrinsic concentration	2.5×10^{13}	1.5×10^{10}
«$_n$ at 300 K	$3800\,\frac{\text{cm}^2}{\text{V sec}}$	$1300\,\frac{\text{cm}^2}{\text{V sec}}$
«$_p$ at 300 K	1800	500
Leakage current	μA	nA
Temperature range	60º to 75º C	60º to 175º C
Power handling capacity	Less	High
β doubles for	50º C	75º C
For 1º C conductivity	Increases by 6%	Increases by 8%
Cut in voltage	0.2 V	0.7 V
Applications	High conductivity and high frequency	Switching applications
$\frac{\mu_n}{\mu_p}$ ratio	2.1 : 1	2.6 : 1
$D_n\left(\frac{\text{cm}^2}{\text{V sec}}\right)$	99	34
$D_p\left(\frac{\text{cm}^2}{\text{V sec}}\right)$	47	13

Hall Effect



If a specimen (metal or semi conductor) carrying the current I is placed in transverse magnetic field B, an electric field intensity 'ε' is induced in a direction perpendicular to both I and B.

- Force experience by the charge carriers is always same direction irrespective of their polarity.

Force direction $\boxed{\vec{F} = q\left(\vec{v} \times \vec{B}\right)}$

(For e^- from diagram)

$= -e(-V_y a_y \times B_z a_z)e^-$

Direction is in negative y

$$F = eV_yB_z\hat{a}_x$$

Force is in positive $+x$ direction. So for

N Type Material: Plane which is in + x direction should have negative polarity. For P-type material plane which is in + x direction should have positive polarity.

According to Hall Effect

Hall Voltage $\mathbf{V_H} = \dfrac{BI}{\rho W}$

$B \rightarrow$ Magnetic field $\rho \rightarrow$ charge density

$W \rightarrow$ Width of specimen (it is in plane of applied B)

or $\boxed{V_H = \dfrac{BIR_H}{W}}$ where $R_H \rightarrow$ hall coefficient = $\dfrac{1}{\rho}$

Charge density $\boxed{° = nq}$

Field intensity $\boxed{£ = \dfrac{V_H}{D}}$

By hall experiment, **mobility is** given by $\boxed{« = \dfrac{8}{3®} \pm R_H}$

- By polarity of hall voltage we can determine whether the semiconductor is p type or n type.
- By magnitude of hall voltage we can differentiate between metal and semiconductor.
- For metal hall voltage V_H is less as compared to SC.
- Hall voltage is +ve for **N type** SC and metals
- Hall voltage is –ve for **P type** SC.
- Hall voltage is zero for intrinsic SC.
- **In metals,** R_H increases with temperature

- In **pure SC,** R_H decreases with temperature
  - In **extrinsic SC,** R_H increases with temperature
  - It can be used in finding mobility of charge carriers, concentration of charge carriers, magnetic field intensity.

Types of Semi Conductors

Intrinsic Semi Conductor: $n = p = n_i$

At 0K all valance e^- are occupied with covalent bonding and therefore charge carriers are zero and the semiconductor behave as insulator.

Extrinsic Semi Conductor

N Type

- Impurity is penta-valent (phosphorous, arsenic)
- Majority carriers are electrons

$$\Rightarrow \left.\begin{matrix} n > n_i \\ p < n_i \end{matrix}\right] \text{ for } \textbf{N type semiconductor (SC)}$$

P-Type

- Impurity is trivalent (Boron, Aluminium)
- Majority carriers are holes.

$$\Rightarrow \left.\begin{matrix} p > n_i \\ n < n_i \end{matrix}\right] \text{ for } \textbf{P type semiconductor (SC)}$$

Law of Electric Neutrality $N_D + p = N_A + n$

Total positive charges =Total negative charges

Intrinsic SC	$N_D = 0,$	$N_A = 0$	$n = p$	
***N* type SC**	$N_D = 0$	$p = N_A + n$	$p >> n$	$p \approx N_A$
***N* type SC** $\rightarrow$	$N_A = 0$	$n = N_D + p$		
Since	$n >> p$	$n \approx N_D$		

Fermi Level: It is maximum energy possessed by e^- at absolute 0 of temperature. It is energy state having probability **1/2** of being occupied by an electron.

Fermi Dirac Function: It gives the probability that an available energy state E will be occupied by an electron at absolute temperature T.

$$\boxed{f(E) = \frac{1}{1 + \exp\left[\frac{(E - E_F)}{KT}\right]}}$$

$E_F \rightarrow$ Fermi energy level K $\rightarrow$ Boltzman's constant

T $\rightarrow$ Absolute temperature in kelvin

$[1 - f(E)]$ gives the probability that energy state E will be occupied by hole.

Concentration of e^- in conduction band

$$\boxed{n_o = N_c e^{-\frac{(E - E_F)}{KT}}}$$

$n_o \rightarrow$ Concentration of e^- in conduction band

$E_C \rightarrow$ Conduction band energy level

$E_F \rightarrow$ Fermi energy level

6

ANALOG ELECTRONICS

CONTENTS

1. VOLTAGE REGULATOR & RECTIFIERS

Voltage Regulator Circuits:

$$\%\ \text{Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$$

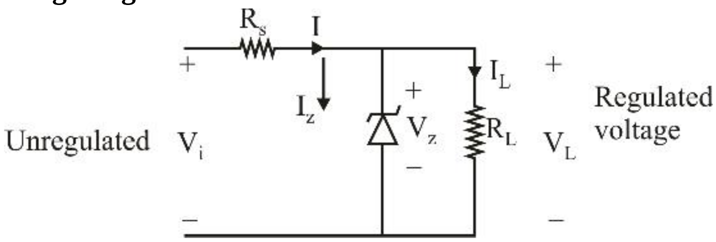
$$\text{Full load current} = I_{FL} = \frac{V_{FL}}{R_L}$$

V_{NL} -No load

V_{FL} -Full load

Smaller the regulation better is the circuit performance.

Zener Voltage Regulator Circuit:



Since Zener diode is conducting

$V_L = V_z = V_{Br}$ $\quad V_L = I_L R_L$ $\quad V_z = I_z R_z$ $\quad I = I_z + I_L$

If Zener current is maximum then load current is minimum and vice versa.

$I = I_{z\,max} + I_{L\,min}$ $\quad I = I_{z\,min} + I_{L\,max}$

For satisfactory operation of circuit $\quad I \geq I_{z\,min} + I_L$ $\quad \boxed{\frac{V_i - V_L}{R_s} \geq I_{z\min} \quad I_L}$

The power dissipated by the Zener diode is $\quad P_z = V_z I_z$

Rectifier: To convert a bi-directional current or voltage into a unidirectional current or voltage

Ripple factor:

$$r = \frac{\text{rms value of AC component}}{\text{DC value}}$$

$$r = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1}$$

Form factor:

$$F = \frac{rms\ value}{dc\ value} = \frac{V_{rms}}{V_{dc}} \qquad r = \sqrt{F^2 - 1}$$

$$\text{Crest factor} = \frac{Peak\ value}{RMS\ value}$$

$$\text{Rectifier Efficiency} = \frac{\text{DC power output}}{\text{AC power input}} \times 100\%$$

TUF (Transformer utilization factor):

$$\text{TUF} = \frac{\text{DC power output}}{\text{AC rating of transformer}}$$

Half Wave Rectifier: Average value of current and voltage

$$I_{dc} = \frac{I_m}{\pi}, \qquad V_{dc} = \frac{V_m}{\pi}$$

RMS value of current and voltage: $I_{rms} = \frac{I_m}{2}, \qquad V_{rms} = \frac{V_m}{2}$

Efficiency $\eta = 40.6\%$ | Ripper factor = 1.21

Frequency of ripple voltage = f | Form factor = 1.57

Peak inverse voltage = V_m | TUF = 0.286

Full Wave Rectifier: Average value of current and voltage:

$$I_{dc} = \frac{2I_m}{\pi}, \; V_{dc} = \frac{2V_m}{\pi}$$

RMS value of current and voltage: $V_{rms} = \frac{V_m}{\sqrt{2}}, \; I_{rms} = \frac{I_m}{\sqrt{2}}$

Efficiency $\eta = 81.2\%$ | Ripper factor = 0.48

From factor = 1.11 | Crest factor = $\sqrt{2}$

TUF = 0.692

Frequency of ripple voltage = $2f$ | Peak inverse voltage = $2V_m$

Bridge Rectifier: All the parameters are same as full wave rectifier except

Peak inverse voltage = V_m | Transformer utilization factor = 0.812

Advantage of Bridge Rectifier:

1. The current in both the primary and secondary of the transformer flows for entire cycle.
2. No center tapping is required in the transformer secondary. Hence it is a cheap device.
3. The current in the secondary winding of transformer is in opposite direction in two half cycles. Hence net DC current flow is zero.
4. As two diode currents are in series, in each of the cycle inverse voltage appear across diode gets shared. Hence the circuit can be used for high voltage application.

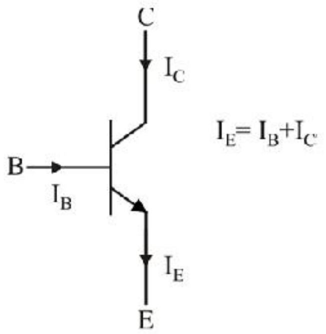
2. BJT & TRANSISTOR BIASING

General Equation of Transistor: **In CE mode** $\rightarrow$ $I_C = \beta I_B + (1+\beta) I_{CO}$

In CB mode $\rightarrow$ $I_C = \alpha I_E + I_{CO}$

$$I_E = I_{C_O} e^{\frac{V_{BE}}{V_T}}$$

Typical values for $V_{BE} =$ 0.2 (Ge Transistor)
0.7 (Si Transistor)
1.3 (GaAs Transistor)



(*a*) Condition to keep transistor in **cut off**: $\boxed{V_{BE} < 0.7V}$

(*b*) Condition for transistor under **active region**:

1. $V_{BE} = 0.7V$ 2. $I_C = \quad I_B = \sim I_E$ 3. $I_B < \frac{I_{c\,sat}}{\beta}$

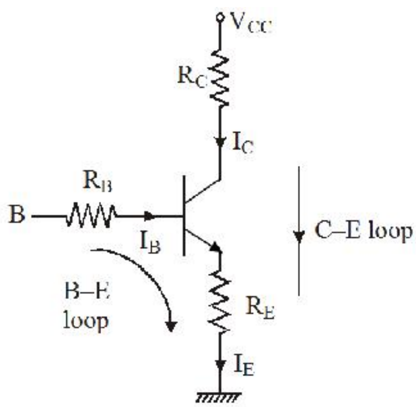
(*c*) Transistor under **saturation region**:

To find whether transistor is in active mode or saturation mode

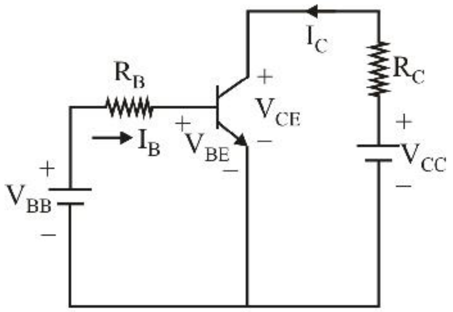
$$V_{BE} = 0.7V$$
$$I_C \neq \quad I_B \neq \sim I_E$$
$$V_{CEsat} = 0.2V$$

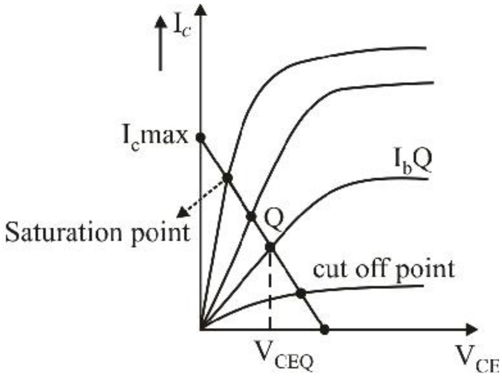
I. If I_C active > I_C (saturation) then transistor is in saturation and Q point is (I_C (saturation),0.2).

II. If I_C (saturation) > I_C (active) then transistor is in active region and Q point is (I_C (active), V_{CE}).



Transistor DC Load Line and Q Point





- DC load line is a straight line which joins $I_{c\max}$ and V_{CC} or which joins saturation and cutoff point.
- DC load line is the locus of all possible operating point at which it remains in active region.
- Q point is called quiescent point or operating point and it is a function of I_B, I_C, and V_{CC}.
- For best performance of amplifier in the BJT the Q point must be located at the center of D.C. load line.

Stability Factor:

I_C is a function of I_{CO}, V_{BE}, (Temperature dependent parameter)

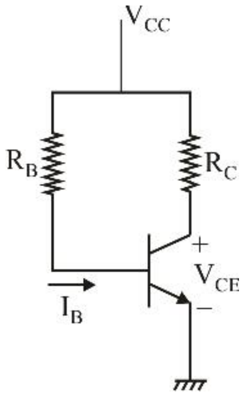
$$\textbf{Stability S} = \left.\frac{\partial I_C}{\partial I_{CO}}\right|_{V_{BE},}$$

Smaller the values of S better will be thermal stability.

The general equation for **stability factor S:** $\boxed{S = \dfrac{1+}{1-\dfrac{\partial I_B}{\partial I_C}}}$

Transistor Biasing Circuits and Their Stability:

A. Fixed Bias Circuit (Base – Bias)



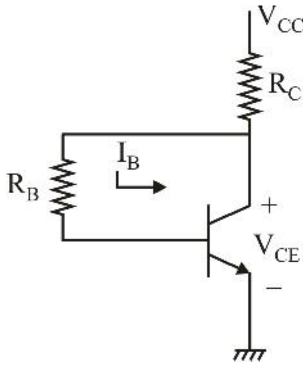
$$I_C = \frac{V_{CC} - V_{CE}}{R_C}$$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B}$$

Stability $\boxed{S = 1+}$

Fixed bias circuit is unstable.

B. Collector to base bias circuits



$$I_B = \frac{V_{CC} - V_{BE}}{(\ \ +1)R_C + R_B}$$

$$I_C \simeq \ \ I_B$$

Stability $$\boxed{S = \frac{1+}{1+ \quad \frac{R_C}{R_C + R_B}}}$$

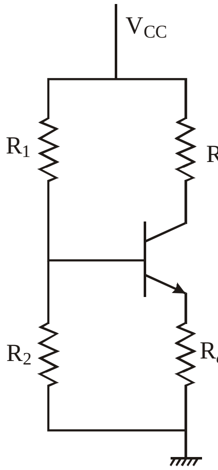
The circuit is having good thermal stability.

C. Self bias circuit $\rightarrow$ (Potential divider bias circuit)

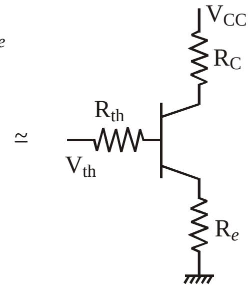
Emitter bias circuit

It is popularly used in biasing circuit.

It gives 180° phase shift.



$R_1 >> R_2$ or $R_1 >> 10\ R_2$



when,

$$V_{th} = \frac{V_{CC}R_2}{R_1 + R_2} \qquad R_{th} = \frac{R_1 R_2}{R_1 + R_2}$$

$$I_C = \frac{V_{CC} - V_{CE}}{R_C + R_E} \qquad I_E = \frac{V_{th} - B_{BE}}{R_E + \left(\frac{R_{th}}{B+1}\right)}$$

Stability factor $$S = \frac{1+}{1+ \quad \frac{R_E}{R_{th} + R_E}} = \frac{}{\frac{R_E}{R_E + R_{th}}}$$

$$\boxed{S = 1 + \frac{R_{th}}{R_E}}$$

Thermal Runway:

- The self destruction of the transistor due to the excess heat produced within the device is called thermal runaway.
- It is due to I_{CO}
- BJT suffers from thermal runway.
- In FET, there is no thermal runway.

Conditions to eliminate thermal runway: $V_{CE} \le \frac{V_{CC}}{2}$ & $\frac{\partial P_C}{\partial T_j} < \frac{1}{\ }$

7

SIGNALS AND SYSTEMS

CONTENTS

1. BASIC PROPERTIES OF SIGNALS

Operations on Signals:

Time Shifting: $y(t) = x(t + \alpha)$

- Shift the signal towards right side by $|\alpha|$ when $\alpha < 0$. This is also called as **time delay.**
- Shift the signal left towards side by $|\alpha|$ when $\alpha > 0$. This is also called as **time advance**.

Time Reversal $y(t) = x(-t)$

Rotate the signal w.r.t. *y*-axis. It is mirror image of signal.

$$y(t) = -x(t)$$

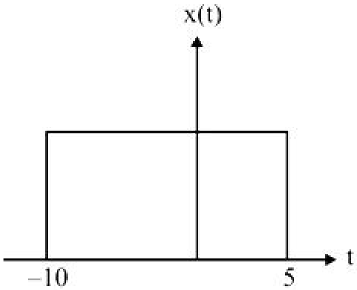
Rotate the signal w.r.t. *x*-axis.

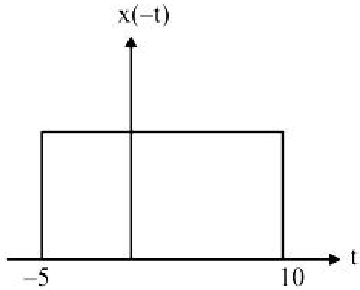
Time Scaling $y(t) = x(\alpha t)$

- When $\alpha > 1$, compress the signal.
- When $\alpha < 1$, expand the signal.

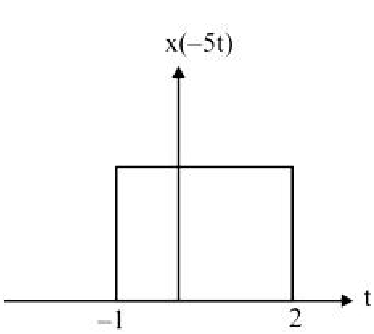
Eg. $\rightarrow$ $y(t) = x(-5t + 3)$ $\qquad y(t) = x\left[-5\left(t - \frac{3}{5}\right)\right]$

Steps: 1. First rotate the signal w.r.t. *y*-axis.
2. Compress the signal by 5 times.
3. Shift the signal by $\frac{3}{5}$ unit towards right side.

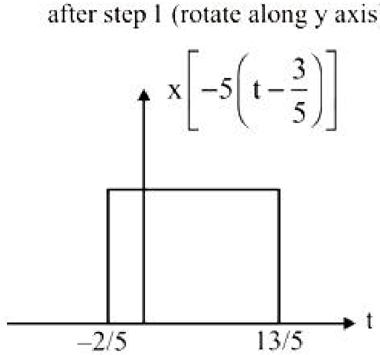




after step 1 (rotate along y axis)



after step 2 (compress)

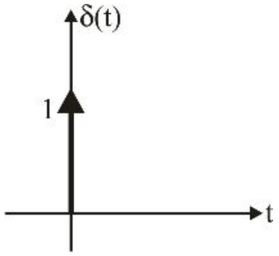


after step 3 (compress)

Standard Signals: Continuous time signals

Impulse signal (Direct Delta Function)

$$\delta(t)=\begin{cases}\infty\ , & t=0\\ 0\ , & t\neq 0\end{cases} \quad \& \quad \int_{-\infty}^{\infty}\delta(t)dt=1$$



Properties of Impulse Signal

(*i*) $x(t)\,\delta(t)=x(0)\,\delta(t)$

(*ii*) $x(t)\,\delta(t-t_o)=x(t_o)\,\delta(t-t_o)$

(*iii*) $\delta[\alpha(t-\beta)]=\dfrac{1}{|\alpha|}\delta(t-\beta)$

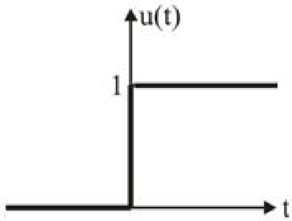
(*iv*) $\int_{-\infty}^{\infty}\delta(t)\,dt=1$

(*v*) $\int_{-\infty}^{\infty}x(t)\,\delta(t-t_o)=x(t_o)$

(*vi*) $x(t)*\delta(t-t_o)=x(t-t_o)$

Unit Step signal:

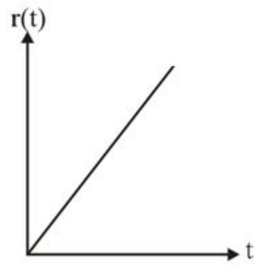
$$u(t)=\begin{cases}1, & t\geq 0\\ 0, & t<0\end{cases}$$



Unit Ramp signal:

$$r(t)=t\,u(t)$$

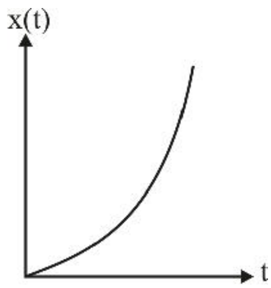
$$r(t)=\begin{cases}t\ , & t\geq 0\\ 0\ , & t<0\end{cases}$$



Parabolic signal:

$$x(t)=\frac{At^2}{2}u(t)$$

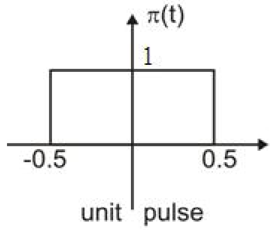
$$x(t)=\begin{cases}\dfrac{At^2}{2}, & t\geq 0\\ 0\ , & t<0\end{cases}$$



unit parabolic signal $x(t)=\begin{cases}\dfrac{t^2}{2} & , \quad t\geq 0\\ 0 & , \quad t<0\end{cases}$

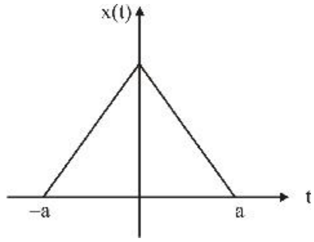
Unit Pulse signal:

$$\boxed{\text{®}(t) = u\left(t+\frac{1}{2}\right) - u\left(t-\frac{1}{2}\right)}$$



Triangular signal:

$$x(t) = \begin{cases} 1-\dfrac{|t|}{a}, & |t| \le a \\ 0, & |t| > a \end{cases}$$

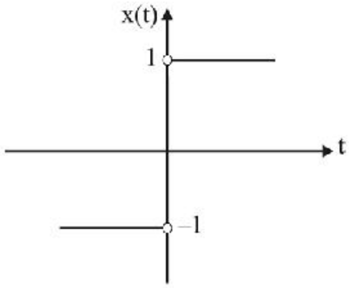


Signum Signal:

$$x(t) = \text{sgm}(t) = \begin{cases} 1, & t > 0 \\ -1, & t < 0 \end{cases}$$

$$\text{sgn}(t) = 2u(t) - 1$$

$$\text{sgn} = u(t) - u(-t)$$



Relationship between u(*t*), ¢(*t*) and *r*(*t*): $u(t) = \int_{-\infty}^{t} \text{¢}(t)dt$

$r(t) = tu(t)$ $\qquad$ $r(t) \xrightarrow{\frac{d}{dt}} u(t) \xrightarrow{\frac{d}{dt}} \text{¢}(t)$

Even and Odd Signal: Even signal $x(t) = x(-t)$

Odd signal $x(-t) = -x(t)$

Impulse is an even signal. An arbitrary signal can be divided into even and odd part:

Even part $x_e(t) = \dfrac{x(t) + x(-t)}{2}$

Odd part $x_o(t) = \dfrac{x(t) - x(-t)}{2}$

Periodic Signal:

(*i*) $x(t) = x(t + T)$, T is the time period of signal.

Signal must exist from $-\infty$ to ∞.

- A constant signal is always periodic with **fundamental period** undefined.
- Complex exponential signals are always periodic.
- Real exponential signals are always aperiodic.

Power and Energy Signals:

Energy $$E_x = \int_{-\infty}^{\infty} |x(t)|^2 \, dt$$

Power $$P_x = \frac{1}{2T} \int_{-T}^{T} |x(t)|^2 dt \qquad (T \to \infty)$$

$$P_x = \frac{E_x}{2T} \qquad (T \to \infty)$$

(*i*) When energy is finite; then power is zero (Energy Signal).

(*ii*) When power is finite, then energy is infinite (Power Signal).

- All periodic signals are power signals but the converse is not true.
- Absolute stable signal is energy signal.
- Unstable signal is neither energy nor power signal.
- Marginally stable signal is power signal.

2. LTI SYSTEMS

Static and Dynamic systems
If output depends only on present value of input then it is known as static (memory less).

e.g. $y(t) = x(t)$

Otherwise the system is dynamic or having memory.

e.g. $y(t) = x(t + 2)$

Causal or non-causal systems
Causal: Output at any time depends only on present or past values of input.
Non-causal: Output depends on future.
$y(t) = x(t - 2) \rightarrow$ causal system $y(t) = x(t + 2) \rightarrow$ non-causal system

Important
Above mentioned are system definitions. (Causal or non causal system is different to causal or non causal signals).

Causal, non-causal and anti-causal signals:

- A signal is said to be causal if it is defined for t ≥ 0. Therefore, if x(t) is causal, then x(t) = 0 for t < 0.
- A signal is said to be non-causal, if it is defined for either t ≤ 0 or both t ≤ 0 and t > 0.
- When x(t) = 0 for t > 0 then it is called as anti-causal.

Linear and non-linear systems
A system is said to be linear if it satisfies the principal of superposition. Principal of superposition consists of two properties:

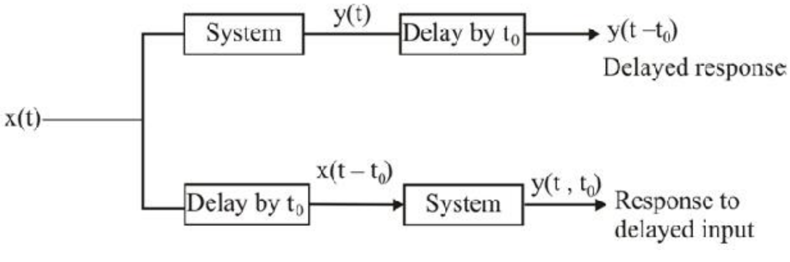
(*i*) Additive property (*ii*) Homogeneity property
Otherwise system is non-linear.
Additive property: The response to $x_1(t) + x_2(t)$ is $y_1(t) + y_2(t)$

- Homogeneity Property: The response to $\sim x_1(t)\ is \sim y_i(t)$

Time Variant and **Time Invariant Systems:** A system is said to be time invariant if the time shifts in the input signal results in an identical shift in the output signal.

For Time Invariant System: $y(t - t_o) = f[x(t - t_o)]$

i.e. Delayed response = Response to delayed input



8

COMMUNICATION SYSTEMS

CONTENTS

1. ANALOG MODULATION

Modulation is the process of placing the message signal over some carrier signal to make it suitable for transmission.

Need for Modulation:

1. Size of antenna required for receiving the wave is reduced if signal is transmitted at high frequency.
2. Many number of signals can be transmitted simultaneously by selecting the carriers of different frequencies.
3. The interference of noise and other signals can be reduced by changing the frequency of transmission.
4. Integration of different communication system is possible.

Amplitude Modulation

Amplitude Modulated Signal:

AM may be defined as a system in which the maximum amplitude of the carrier wave is made proportional to the instantaneous value (amplitude) of the modulating or base band signal.

$x_m(t) = A_m \cos \mu_m t$

$x_c(t) = A_c \cos \mu_c t$

$x(t) = A_c[1 + K_a x_m(t)] \cos \mu_c t$ where $\mu = K_a A_m$

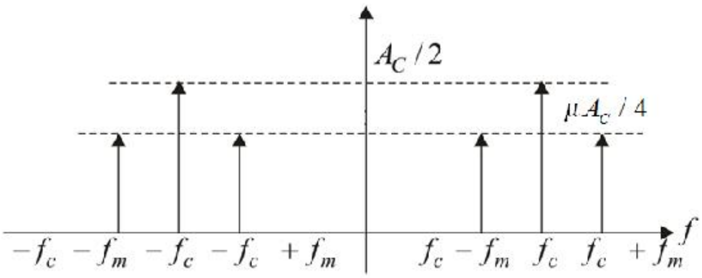
$x(t) = A_c \cos \mu_c t + A_c K_a x_m(t) \cos \mu_c t$

where μ = modulation index

$x_m(t) \rightarrow$ message signal

$x(t) = A_c \cos \omega_c t + \mu A_c \cos \omega_m t \cos \omega_c t$

Frequency spectrum of AM wave:



Bandwidth = $2 f_m$

- Frequency band from f_c to $f_c + f_m$ is called as **upper sideband**
- Frequency band from $f_c - f_m$ to f_c is called as **lower sideband**

$\text{«} = \dfrac{A_{\max} - A_{\min}}{A_{\max} + A_{\min}}$ $A_{\max} = A_C[1 + \text{«}]$ $A_{\min} = A_C[1 - \text{«}]$

A_{max} – maximum amplitude

A_{min} – minimum amplitude

Power Relations in AM wave:

$$P_{total} = P_{carrier} + P_{LSB} + P_{USB} \qquad P_{carrier} = \frac{A_c^2}{2} \; P_{LSB} = P_{USB} = \frac{\mu^2 A_c^2}{8}$$

$$P_{total} = \frac{A_c^2}{2} + \frac{\mu^2 A_c^2}{8} + \frac{\mu^2 A_c^2}{8} \qquad P_{total} = \left(1 + \frac{\mu^2}{2}\right) P_c$$

Maximum power dissipated in AM wave is $\mathbf{P_{AM} = 1.5\, P_c}$ for $\boldsymbol{\mu = 1}$ and this is maximum power that amplifier can handle without distortion.

Efficiency of Amplitude Modulated System:

$$\eta_{AM} = \frac{P_{SB}}{P_t} \times 100\% \qquad \boxed{\eta_{AM} = \left(\frac{\mu^2}{\mu^2 + 2}\right) \times 100\%}$$

For satisfactory modulation $0 \le \mu \le 1$

Current relations in AM wave:

$$P_t = \left(1 + \frac{\mu^2}{2}\right) P_c \qquad I_C \sqrt{1 + \frac{\mu^2}{2}}$$

Multi-tone Modulation: When carrier is modulated simultaneously by more than one sinusoidal signal.

Resultant Modulation Index $\mu = \sqrt{\mu_1^2 + \mu_2^2 + \mu_3^2 \ldots\ldots\ldots\ldots}$

Double side Band Suppressed Carrier modulation DSB-SC:

$$s(t) = \mu A_c \cos \omega_c t \cos \omega_m t$$

$\mu \rightarrow$ modulation index $\qquad A_c \rightarrow$ carrier amplitude

In DSB-SC the carrier signal is suppressed at the time of modulation. Only side-bands are transmitted in modulated wave.

Bandwidth = $2 f_m$ $\qquad$ **Transmitted Power** $P_t = \frac{\mu^2}{2} P_c$

Power saving = 66.67% (for $\mu = 1$)

Single Sideband Modulation (SSB): In this technique, along with modulation carrier one side band gets suppressed from AM modulated wave.

$$s(t) = A_c\, m(t) \cos 2\pi f_c t \mp A_c \hat{m}(t) \sin 2\pi f_c t$$

$\widehat{m}(t)$ is Hilbert transform of message signal.

Bandwidth = f_m $\qquad$ **Transmitter Power** $P_t = \frac{\mu^2}{4} P_C$

Power saving $\rightarrow$ 83.3%

Vestigial Sideband (VSB) modulation: In this modulation one side band and vestige of another sideband is transmitted.

- It is used for transmission of video signal in television broadcasting.
- It is also used for high speed data signal and facsimile.
- Vocal signal transmission of T.V. via F.M.

AM Modulators:

- For Generation of AM or DSB/Full carrier wave

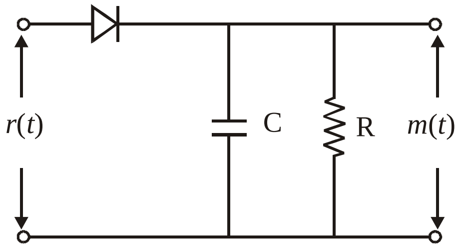
  A. Product Modulator B. Square Law Modulator C. Switching Modulator
- For Generation DSB-SC wave

  A. Filter method/frequency discrimination method
  B. Phase shift method/Phase discrimination method
  C. Third method/Weaver's method

Demodulation of Amplitude Modulate wave:

A. Synchronous or coherent detection B. Envelop detector

Envelop Detector:



$r(t)$ is received signal and $m(t)$ is message signal and for better reception RC must be selected such as $$\frac{1}{f_c} << RC << \frac{1}{W}$$

f_c = carrier frequency w is bandwidth of message signal

To avoid diagonal clipping $\frac{1}{RC} > \frac{\mu\,\omega_m}{\sqrt{1-\mu^2}}$

Key points:

- Demodulation of AM signal is simpler than DSB-SC and SSB systems, Demodulation of DSB-SC and SSB is rather difficult and expensive.
- It is quite easier to generate conventional AM signals at high power level as compared to DSB-SC and SSB signals. For this reason, conventional AM systems are used for broad casting purpose.
- The advantage of DSB-SC and SSB systems over conventional AM system is that the former requires lesser power to transmit the same information.
- SSB scheme needs only one half of the bandwidth required in DSB-SC system and less than that required in VSB also.
- SSB modulation scheme is used for long distance transmission of voice signals because it allows longer spacing between repeaters.

Angle Modulation:

- Angle modulation may be defined as the process in which the total phase angle of a carrier wave is varied in accordance with the instantaneous value of modulating or message signal while keeping the amplitude of carrier constant.
- Two types of angle modulation schemes:

PM (Phase modulation)
FM (Frequency Modulation)

Phase Modulation: The phase of the carrier signal is varied according to message signal.

Single Tone Modulation: Let $m(t) = A_m \cos \omega_m t$

PM signal in general form $x(t) = A_c \cos \theta(t)$

where $\bar{}(t) = w_c t + K_P m(t)$

$$x(t) = A_c \cos(\mu_c t + k_p m = A_C \cos(w_C t + \quad \cos w_m t)(t))$$

$$x(t) = A_c \cos(\mu_c t + k_p A_m \cos \mu_m t)$$

Where, $= K_P A_m$

Instantaneous Frequency: $\omega = \dfrac{d\theta}{dt}$

$$\mu = \frac{d}{dt}(\mu_c t + \quad \cos \mu_m t) \qquad f = f_c - \quad f_m \sin \mu_m, t$$

Frequency deviation of signal $\Delta f = \quad f_m \qquad \Delta f = K_p A_m f_m$

For Phase Modulation:

Phase deviation = $K_p \,|m(t)|_{\max}$

Frequency deviation $= K_P A_m f_m$

Frequency Modulation: Frequency of FM wave is varied in direct proportion of the modulating signal.

$$x(t) = A_c \cos(\mu_c t + 2® k_f \int_0^t m(t)\, dt)$$

If $m(t) = A_m \cos \mu_m t$

$$x(t) = A_c \cos(\mu_c t + \quad \sin \mu_m t$$

where β_f = Frequency Modulation Index

$$= \frac{k_f A_m}{f_m} = \frac{\Delta f}{f_m}$$

Frequency deviation $= K_f \,|m(t)|_{\max} = K_f A_m$

Phase deviation $2® K_f \int m(t) df \,|_{\max}$

Carrier Swing:

The total variation in frequency from the lowest to the highest point is called carrier swing.

Carrier swing = 2 × Δf

The amount of frequency deviation depends upon the amplitude of the modulating signal. This means that louder the sound, greater the frequency deviation and vice – versa.

Relationship between phase modulation and frequency modulation:

In PM, the phase angle varies linearly with base band signal $m(t)$ whereas in FM, the phase angle varies with the integral of base band signal $m(t)$.

- To get FM by using PM, we first integrate the base band signal and then apply to Phase Modulator.

- PM wave may be generated by using frequency modulator by first differentiating base band signal $m(t)$ and then applying to the Frequency Modulator.

Power Carried by FM and PM signals: Since the Amplitude of Frequency and Phase modulated signal is constant, the power transmitted in FM and PM waves is independent of modulation index

i.e. $$P_t = \frac{A_c^2}{2}$$

- Because of constant Amplitude, Noise level in FM and PM can be kept within limits. That's why it is used in Audio Communication.

Classification of FM signals:
(1) Narrow Band FM signals (NBFM)
(2) Wide Band FM signals (WBFM)

Narrow Band FM signal (NBFM): For these signals modulation index is less than unity.

$$\text{¤}(t) = \quad \sin 2\text{®} f_m t$$

$$x(t) = \mathrm{A}_c \cos[\omega_c t + \phi(t)] = A_c[\cos \mu_c t \cos \text{¤}(t) - \sin \mu_c t \sin \text{¤}(t)]$$

$\{\phi(t)$ is small, so $\cos \text{¤}(t) \simeq 1, \sin \text{¤}(t) \simeq \text{¤}(t)\}$

$$x(t) = A_c \cos \mu_c t - A_c \quad \sin \mu_c \sin \mu_m t$$

$$= A_c \cos \mu_c t + \frac{A_c}{2}\left[\cos(\mu_c + \mu_m)t - \cos(\mu_c - \mu_m)t\right]$$

Above signal is called **NBFM** signal. It has two bands similar to AM wave and both have same bandwidth requirements.
The lower side band of NBFM is inverted version of upper side band of AM signal.
It can be detected using Envelop Detector.

WBFM signal: $x(t) = \sum_{n=\infty}^{\infty} A_c J_n \quad) \cos(\mu_c + n\mu_m)t$

A wideband FM signal has infinite number of side bands.
Ideally the Bandwidth requirement of F_m signal is infinite because it has infinite number of side bands.

Carson's Law:
Transmission Bandwidth of FM signal:

BW = $2 f_m$ If $\beta < 1$ (NBFM)

BW = $2(\Delta f + f_m)$ If $\beta > 1$ (WBFM) or $BW = 2(\quad +1) f_m$

$$BW = 2(\Delta\text{¤} + f_m) \qquad or \qquad BW = 2(\quad +1) f_m$$

FM over **AM**

It is possible to reduce noise still further by increasing the frequency deviation but in AM this is not possible.

- Standard frequency allocations provide a guard band between commercial FM stations. Due to this, there is less adjacent channel interference in F_M.

9

ELECTROMAGNETIC THEORY

CONTENTS

1. COORDINATE SYSTEMS AND VECTOR CALCULUS

Vector Calculus:

- **Gradient**: The gradient of scalar V is written as ∇V and result is vector quantity.

For Cartesian: $\nabla V = \frac{\partial V}{\partial x}\hat{a}_x + \frac{\partial V}{\partial y}\hat{a}_y + \frac{\partial V}{\partial z}\hat{a}_z$

For Cylindrical: $\nabla V = \frac{\partial V}{\partial \rho}\hat{a}_\rho + \frac{1}{\rho}\frac{\partial V}{\partial \phi}\hat{a}_\phi + \frac{\partial V}{\partial z}\hat{a}_z$

For Spherical: $\nabla V = \frac{\partial V}{\partial r}\hat{a}_r + \frac{1}{r}\frac{\partial V}{\partial \theta}\hat{a}_\theta + \frac{1}{r\sin\theta}\frac{\partial V}{\partial \phi}\hat{a}_\phi$

- **Divergence**: The divergence of vector $\vec{A}$ is written as $\nabla.\vec{A}$ and result is scalar quantity.

For Cartesian: $\nabla.\vec{A} = \frac{\partial A_x}{\partial x} + \frac{\partial A_y}{\partial y} + \frac{\partial A_z}{\partial z}$

For Cylindrical: $\nabla.\vec{A} = \frac{1}{\rho}\frac{\partial}{\partial \rho}(\rho A_\rho) + \frac{1}{\rho}\frac{\partial A_\phi}{\partial \phi} + \frac{\partial A_z}{\partial z}$

For Spherical: $\nabla.\vec{A} = \frac{1}{r^2}\frac{\partial}{\partial r}(r^2 A_r) + \frac{1}{r\sin\theta}\frac{\partial}{\partial \theta}(\sin\theta A_\theta) + \frac{1}{r\sin\theta}\frac{\partial A_\phi}{\partial \phi}$

- **Curl of vector**: The curl of vector $\vec{A}$ is defined as $\nabla\times\vec{A}$ and result is vector quantity.

For Cartesian:
$$\nabla\times\vec{A} = \begin{vmatrix} \hat{a}_x & \hat{a}_y & \hat{a}_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ A_x & A_y & A_z \end{vmatrix}$$

For Cylinderical:
$$\nabla\times\vec{A} = \begin{vmatrix} \frac{\hat{a}_r}{\rho} & \hat{a}_\phi & \frac{\hat{a}_z}{\rho} \\ \frac{\partial}{\partial \rho} & \frac{\partial}{\partial \phi} & \frac{\partial}{\partial z} \\ A_\rho & \rho A_\phi & A_z \end{vmatrix}$$

For Spherical:
$$\nabla\times\vec{A} = \begin{vmatrix} \frac{\hat{a}_r}{r^2\sin\theta} & \frac{\hat{a}_\theta}{r\sin\theta} & \frac{\hat{a}_\phi}{r} \\ \frac{\partial}{\partial r} & \frac{\partial}{\partial \theta} & \frac{\partial}{\partial \phi} \\ A_r & rA_\theta & r\sin\theta A_\phi \end{vmatrix}$$

- **Laplacian of Scalar:** Laplacian of scalar field V is written as $\nabla^2 V$. It is the divergence of gradient of V. The result is a scalar quantity.

For Cartesian: $$\nabla^2 V = \frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2}$$

For Cylinderical: $$\nabla^2 V = \frac{1}{\rho}\frac{\partial}{\partial \rho}\left(\rho \frac{\partial V}{\partial \rho}\right) + \frac{1}{\rho^2}\frac{\partial^2 V}{\partial \phi^2} + \frac{\partial^2 V}{\partial z^2}$$

For Spherical: $$\nabla^2 V = \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \frac{\partial V}{\partial r}\right) + \frac{1}{r^2 \sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta \frac{\partial V}{\partial \theta}\right) + \frac{1}{r^2 \sin^2\theta}\frac{\partial^2 V}{\partial \phi^2}$$

- **Laplacian of Vector:** It is a vector quantity.

$$\nabla^2 \vec{A} = \nabla(\nabla.\vec{A}) - \nabla \times \nabla \times \vec{A}$$

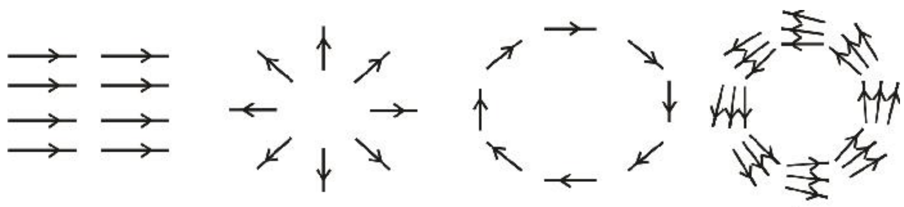
- **Divergence** of a curl of vector is always zero $\nabla.(\nabla \times \vec{A}) = 0$
- **Curl** of gradient of a scalar field is always zero $\nabla \times (\nabla V) = 0$
- The vector field is said to be **solenoidal** or **divergence less** if $\nabla.\vec{A} = 0$
- A vector field is said to be **irrotational** (or potential) if $\nabla \times \vec{A} = 0$
- A vector field is said to be harmonic if $\nabla^2 V = 0$
- $\nabla \times \nabla \times A = \nabla(\nabla.\vec{A}) - \nabla^2 \vec{A}$
- $\nabla.(\vec{A} \times \vec{B}) = \vec{B}.(\nabla \times A) - \vec{A}.(\nabla \times \vec{B})$

Divergence Theorem: It states that total outward flux of vector field $\vec{A}$ through closed surface S is the same as volume integral of the **divergence** of $\vec{A}$.

$$\oint_s \vec{A}.\vec{ds} = \int_v \nabla.\vec{A}\, dv$$

Stokes' Theorem: It states that line integral of a vector field $\vec{A}$ over a closed path is equal to surface integral of **curl** of $\vec{A}$.

$$\oint_l \vec{A}.\vec{dl} = \int_s (\nabla \times \vec{A}).\vec{ds}$$



$\nabla.\vec{A} = 0$	$\nabla.\vec{A} \neq 0$	$\nabla.\vec{A} = 0$	$\nabla.\vec{A} \neq 0$
$\nabla \times \vec{A} = 0$	$\nabla \times \vec{A} = 0$	$\nabla \times \vec{A} \neq 0$	$\nabla \times \vec{A} \neq 0$

2. ELECTROSTATIC FIELDS

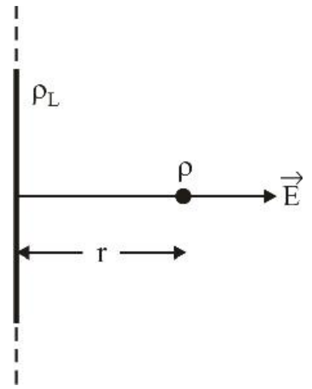
Coulomb's Law: Force between two point charges

$$\boxed{\vec{F}_{12} = \frac{k\,Q_1Q_2}{R^2}\,\hat{a}_{r_{12}}} \qquad \text{Where,}\quad k = \frac{1}{4\pi\varepsilon_o} = 9\times10^9\ \text{m/ F}$$

Electric Field Intensity: Force per unit charge when placed in electric field.

$$\boxed{\vec{E} = \frac{\vec{E}}{Q}}$$

Electric Field Intensity due to Infinite long line charge:



$$\boxed{\vec{E} = \frac{\rho_L}{2\pi\varepsilon_o\rho}\,\hat{a}_\rho}$$

$\hat{a}_\rho \rightarrow$ Unit normal vector to line

$\rho \rightarrow$ Perpendicular distance of the point from line (minimum distance)

Electric Field Intensity due to Infinite charge sheet:

$$\boxed{\vec{E} = \frac{\rho_s}{2\varepsilon_0}\,\hat{a}_n}$$

ρ_s = surface charge density, $\hat{a}_n \rightarrow$ unit vector Normal to sheet

In parallel plate capacitor, the electric field existing between the two plates having equal and opposite charges; $\boxed{\vec{E} = \frac{\rho}{\varepsilon_0}\,\hat{a}_n}$

Electric Field Intensity due to uniformly charged sphere

$$\vec{E} = \begin{cases} \dfrac{r}{3\varepsilon_0}\rho_o\,\hat{a}_r & ;0 \le r \le a \\ \dfrac{a^3}{3\varepsilon_o r^2}\rho_0\,\hat{a}_r & ;r \ge a \end{cases}$$

ρ_o = volume charge density, a = radius of sphere

Electric Flux Density ($\vec{D}$): $\vec{D} = \varepsilon_0 \vec{E}$

Electric Flux $\psi = \int_s \vec{D}\cdot\vec{ds}$

Gauss's Law: The total electric flux ψ through any closed surface is equal to the total charge enclosed by surface.

$$Q = \int_s \vec{D}\cdot\vec{ds} = \int_v \rho_V\, dV = \psi \qquad \boxed{\nabla\cdot\vec{D} = \rho_V}$$

Electric Potential: $V_{AB} = \dfrac{W}{Q} = -\int_A^B \vec{E}\cdot\vec{dl} = \dfrac{Q}{4\pi\varepsilon_o}\left[\dfrac{1}{r_B} - \dfrac{1}{r_A}\right] = V_B - V_A$

- Negative sign indicates that the work is being done by external agent.

  V_{AB} = potential difference between A and B

Potential at any point r due to point charge Q located at origin is

$$\boxed{V = \frac{Q}{4\pi\varepsilon_0 r}}$$

Potential between two points in the field of point charge $\boxed{V_{AB} = \dfrac{Q}{4\pi\varepsilon_0}\left(\dfrac{1}{r_b} - \dfrac{1}{r_a}\right)}$

Work done while moving a charge in electric field is independent of path followed. It depends only on initial and final paths.

$$W = -Q\int \vec{E}\cdot\vec{dl} = 0 \qquad \boxed{\nabla\times\vec{E} = 0}$$

Electro static field is conservative or irrotational.

Energy density of Electro static field

$$W_E = \frac{1}{2}\vec{D}\cdot\vec{E} \qquad \boxed{W_E = \frac{1}{2}\in E^2 = \frac{1}{2}\frac{D^2}{\in}}$$

The gradient of potential field gives the electric field intensity. The electric field intensity in terms of potential is given by

$$\boxed{\vec{E} = -\nabla V}$$

- **Electric flux line** is an imaginary path or line drawn in such a way that its direction at any point is the direction of the electric field at that point connection current density $\vec{J} = \rho_v \vec{u}$

$\rho_v \rightarrow$ Charge density $\vec{u} \rightarrow$ charge velocity

Conduction current density $\vec{J} = \sigma \vec{E}$ where $\sigma = \dfrac{ne^2\tau}{m}$

A **perfect conductor** cannot contain an electrostatic field within it.

Inside a conductor $\vec{E} = 0,\ \rho_v = 0,\ V_{ab} = 0$

Dielectric constant and polarization:

$$\vec{D} = \varepsilon_0 (1 + \chi_e) \vec{E} = \varepsilon_0\ \varepsilon_r\ \vec{E}$$

$$\vec{D} = \varepsilon_0 \vec{E} + \vec{P} \qquad \text{where} \quad \vec{P} = \chi_e\ e_0\ \vec{E}$$

$$\varepsilon_r = 1 + \chi_e = \frac{\varepsilon}{\varepsilon_0} \qquad \chi_e \rightarrow \text{Electric susceptibility}$$

- **Dielectric strength** is maximum electric field that a dielectric can tolerate to withstand breakdown.

Continuity Equation $\boxed{\nabla . \vec{J} = -\dfrac{\partial \rho_v}{\partial t}}$

Relaxation Time $\boxed{T_r = \dfrac{\varepsilon}{\sigma}}$ $\boxed{\rho_v = \rho_{vo}\ e^{-t/T_r}}$

Boundary Conditions:

Dielectric – Dielectric Boundary Conditions:

Tangential Component Relation

$$\boxed{E_{1t} = E_{2t}} \quad \text{or} \quad \boxed{\frac{D_{1t}}{\varepsilon_1} = \frac{D_{2t}}{\varepsilon_2}}$$

Normal Component Relation: $\boxed{D_{1n} - D_{2n} = \rho_s}$

$\rho_s \rightarrow$ Free charge density placed at boundary.

- The tangential component E_t is continuous across the boundary and tangential component D_t is discontinuous at boundary.
- The normal component of $\vec{D}$ is continuous while that of $\vec{E}$ is discontinuous at boundary.

$$\boxed{\frac{\tan \theta_1}{\tan \theta_2} = \frac{\varepsilon_{r1}}{\varepsilon_{r2}}}$$

This is the law of refraction of the electric field at a boundary free of charge.

Conductor – Dielectric Boundary:

$$\boxed{D_t = \varepsilon_o \varepsilon_r\ E_t = 0,\ D_n = \varepsilon_o \varepsilon_r\ E_n = \rho_s}$$

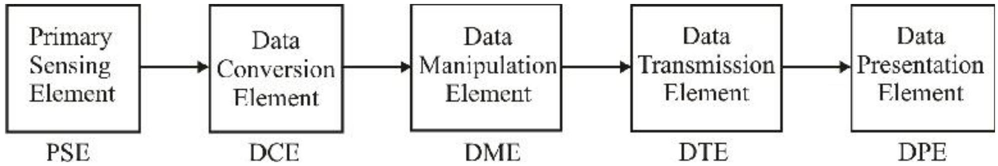
10

MEASUREMENTS & INSTRUMENTATION

CONTENTS

1. MEASURING INSTRUMENT CHARACTERISTICS

Generalized Measuring Instrument: The block diagram of generalized measuring system may be represented as:



IMPORTANT DEFINITIONS:

Accuracy: Closeness with which an instrument reading approaches the true value of the variable being measured. It can be improved by recalibration.

Precision: It is a measure of the degree to which successive measurement differ from one another.

- It is design time characteristic.

High precision does not mean high accuracy. A highly precise instrument may be inaccurate.

Ex: If reading are 101, 102, 103, 104, 105. Most precise value is 103

Resolution: The smallest change in measured value to which the instrument will respond. It is improved by re-calibrating the instrument.

Sensitivity: It is ratio of change in output per unit change in input quantity of the instrument. It is design time characteristic.

Drift: It means deviation in output of the instrument from a derived value for a particular input.

Reproducibility: It is degree of closeness with which a given value may be measured repeatedly for a given period of time.

Repeatability: It is degree of closeness with which a given input is repeatably indicated for a given set of recordings.

Errors:

1. **Absolute Error/Static Error/Limiting Error:**

$$\delta A = A_m - A_T$$

$A_m \rightarrow$ Measured value of quantity of actual value

$A_T \rightarrow$ True value of quantity or nominal value

2. **Relative Error:** $\varepsilon_r = \pm \dfrac{\delta A}{A_T} = \dfrac{A_m - A_T}{A_T}$

3. **Percent Error:** $\% \, \varepsilon_r = \dfrac{\delta A}{A_T} \times 100$

Instrument Error is generally given in percent error.

4. **Percentage Error at reading** '*x*':

$$\% \, \varepsilon_{r,x} = \left[\frac{\text{Full Scale Reading}}{x}\right] \times [\% \, \varepsilon_r, \text{Full scale}]$$

Error due to combination of quantities:

1. Error due to Sum/Difference of quantities

$$X = x_1 \pm x_2$$

$$\%\varepsilon_r = \frac{\delta X}{X} = \pm\left[\frac{x_1}{X}\left(\frac{\delta x_1}{x_1}\right) + \frac{x_2}{X}\left(\frac{\delta x_2}{x_2}\right)\right]$$

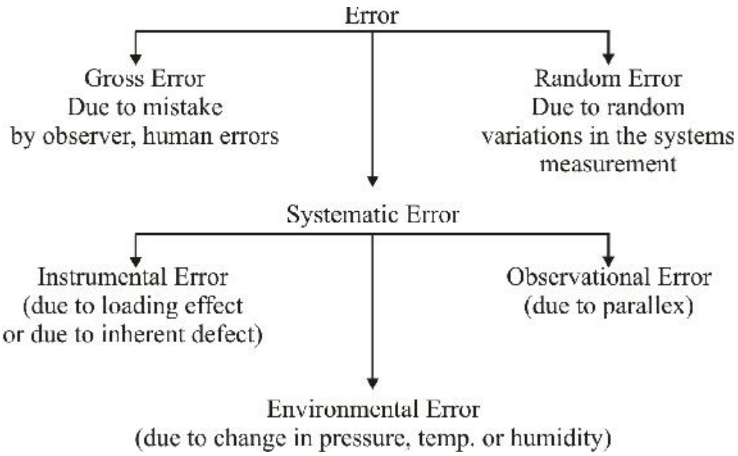
2. Error due to product or quotient of quantities

$$X = x_1 x_2 x_3 \quad \text{Or} \quad \frac{x_1}{x_2 x_3} \quad \text{or} \quad \frac{1}{x_1 x_2 x_3}$$

$$\frac{\delta X}{X} = \pm\left(\frac{\delta x_1}{x_1} + \frac{\delta x_2}{x_2} + \frac{\delta x_3}{x_3}\right)$$

3. Composite factors $X = x_1^n \,.\, x_2^m$ $\dfrac{\delta X}{X} = \pm\left(n\dfrac{\delta x_1}{x_1} + m\dfrac{\delta x_2}{x_2}\right)$

CLASSIFICATION OF ERRORS:



Standards of EMF:

(*a*) **Saturated Weston cell** is used for Primary standard of emf.
Its emf is 1.01864 volt, maximum current drawn is $100\,\mu A$. It contains $CdSO_4$ crystal and its internal resistance is $600\,\Omega$ to $800\,\Omega$.

(*b*) **Unsaturated Weston cell** is used for secondary standards. Its emf is 1.0180 to 1.0194 volt and does not have $CdSO_4$ crystal.

Standard of Resistance:

Maganin (Ni + Cu + Mn)

Nickel 4%

Magnese 12% [High Resistivity and low temperature coefficient]

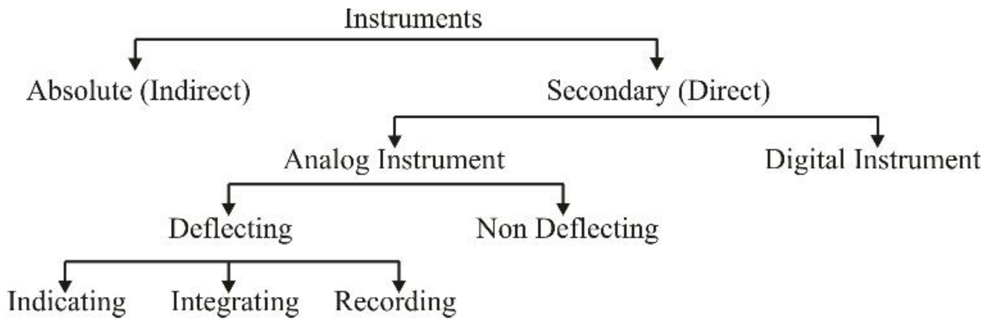
Copper 84%

Inductive effect of resistance can be eliminated, using **Bifilar winding.**

Standard of Time and Frequency:

Atomic clock is used as primary standard of time and frequency. Quartz, Rubidium crystal is used as secondary standard of time and frequency. Example: Cesium 133, hydrogen maser etc.

2. CLASSIFICATION OF ELECTRICAL INSTRUMENTS



Absolute Instrument: It gives the value of parameters under measurement in terms of the physical constant of the instrument.
e.g.→ Transient Galvanometer, Rayleigh current balance etc.

Secondary Instrument:
It gives the value of parameter for directly under measurement.
e.g.→ voltmeter, thermometer, pressure gauge etc.

Note: Absolute instruments are highly accurate than secondary instrument as they contain less number of moving mechanical parts resulting in a lower operational of power consumption.

Classification of analog instruments

1. **Indicating type**: Voltmeter, Ammeter, Wattmeter .
2. **Recording type**: Recorders.
3. **Integrating type**: Energy meter.
4. **Comparison type**: Potentiometer and bridges or null deflection.
5. **Deflecting type**: PMMC

Note: Null deflecting instruments are highly accurate as compression to deflecting instrument as their operational power consumption at zero deflection is zero.

Principle of Operation of Analog Instruments:

Magnetic effect: Moving Iron, PMMC, Dynamometer

Induction effect: Energy meter

Heating effect: Thermocouple and Hotwire type, Bolometer

Electro static effect: Electro static type voltmeter

Hall Effect: Poynting vector type voltmeter, Flux-meter

Damping system used in indicating instruments:

It is provided in the instrument which helps the moving system of the instrument to reach to final position at earliest.

Electromagnetic damping: Galvanometer and moving coil type

Eddy current damping: PMMC voltmeter and energy meter

Air frictional damping: Moving iron and dynamometer

Fluid friction damping: Electrostatic type voltmeter

- PMMC Instruments are used only for DC measurements.
- Induction type instruments are used only for AC measurements.
- Hotwire and Thermal type instruments measure RMS value of input.
- Electrostatic type instruments are used to measure high voltages in kV.
- Rectifier type instruments responds to average value.

Permanent Magnet Moving Coil instruments:

- These are also called self shielding instruments.
- Aluminium former is used to provide eddy current damping.
- Magnetic field in these is in range of 0.1 to $1\,wb/m^2$ which is strong field.
- Control spring which is made of phosphor-bronze material in these instruments provides a control force and also provides a path for current entering to moving coil.
- If control spring is broken, current through the coil is zero and instrument reads zero.
- It is used for measurement of DC only.
- Material used for magnet in PMMC is Alnico and Alcomax (Al + Co +Ni).
- Torque to weight ratio of the moving system should be high and equal to 0.1, $\frac{T}{weight} \geq 0.1$; It decides sensitivity which is high in PMMC
- It can sense a current upto 50 μA.
- Deflecting torque (T_d) = NBAI
- Controlling torque (T_c) = $k\theta$

At balance $T_d = T_c$

$$\boxed{\theta = \frac{G}{K} I = \frac{NBA}{K} I}$$

$N \rightarrow$ Number of turns $\quad$ $A \rightarrow$ Area of cross section of vowing coil

$B \rightarrow$ Magnetic flux $\quad$ $I \rightarrow$ Current through coil

Key points:

The control spring in PMMC have dual utility, they not only produce controlling torque but also used to lead the current into the system.

Source of Errors:

- Ageing effect of the permanent magnet (can be reduced by using a pre-edged magnet)
- Temperature effect of coil and the control spring.

11

MATERIALS SCIENCE

CONTENTS

1. STRUCTURE OF MATERIALS

1. Simple Cubic (SC):

- Distance between adjacent atoms $d_{SC} = a = 2r$
- Coordination number = 6
- No of atoms per unit cell $= 8 \text{ corners} \times \frac{1}{8} \text{ part} = 1$
- Packing efficiency = 52%

  Example →Polonium, Fluorspar

2. Body Centered Cubic (BCC):

- Distance between adjacent atom $d_{BCC} = 2r = \frac{\sqrt{3}}{2} a$
- Coordination number = 8
- No of atoms per unit cell $= 8 \times \frac{1}{8} + 1 = 2$
- Packing efficiency = 68%

Example → Fe, Cr, Na

3. Face Centered Cubic (FCC):

- Distance between adjacent atoms $d_{FCC} = 2r = \frac{a}{\sqrt{2}}$
- Coordination number = 12
- No of atoms per unit cell $= 8 \times \frac{1}{8} + 3 = 4$
- Packing efficiency = 74%

Example → Cu, Silver, Gold

Hexagonal Closed Pack (HCP):

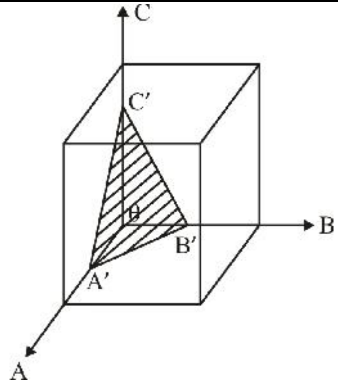
- Coordination number = 12
- No of atoms per unit cell $= 12 \times \frac{1}{12} + 3 = 4$
- Packing efficiency = 74%

Example → Cd, Mg

Different types of unit cell

Type of unit cell	Volume of unit cell
Cubic	a^3
Tetragonal	a^2c
Orthorhombic	a b c
Hexagonal	$\frac{3\sqrt{3}a^2c}{2}$

Crystallographic Plane and Miller Indices:



Miller indices are used to specify directions and planes and it could be in lattices or in crystals.

Miller Indices for plane A′B′C′

$$h=\frac{OA}{OA'},\ k=\frac{OB}{OB'},\ \ell=\frac{OC}{OC'}$$

Example:

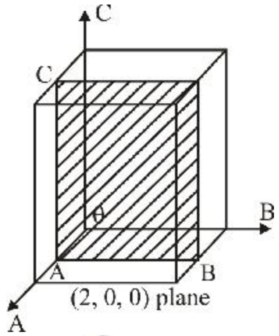
1.

$$h=\frac{OA}{\frac{OA}{2}}=2$$

$$k=\frac{OB}{\infty}=0$$

$$\ell=\frac{OC}{\infty}=0$$

$$(h,k,\ell)=(2,0,0)$$



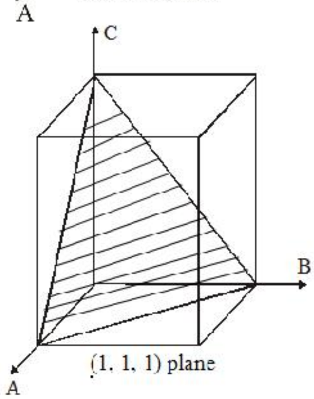
2.

$$h=\frac{OA}{OA}=1$$

$$k=\frac{OB}{OB}=1$$

$$\ell=\frac{OC}{OC}=1$$

$$(h,k,\ell)=(1,1,1)$$



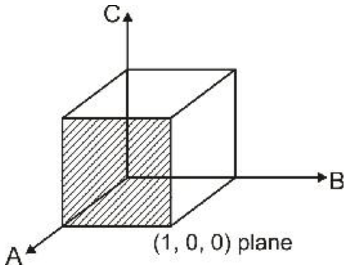
3.

$$h=\frac{OA}{OA}=1$$

$$k=\frac{OB}{\infty}=0$$

$$l=\frac{OC}{\infty}=0$$

$$(h,k,l)=(1,0,0)$$



2. ELECTRIC MATERIALS & PROPERTIES

Dielectric Constant:

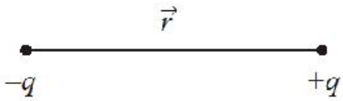
$$\boxed{\in = \frac{D}{E}}$$ D: Electric flux density, E: Electric field Intensity

$\in = \in_o \in_r$ $\in$: permittivity of the medium (farad per meter)

$$\boxed{\in_o = \frac{10^{-9}}{36\pi} \text{F/ m}}$$ $\in_r$:Relative permittivity

Dipole Moment: Product of either of two charges and separation between charges.

$$\boxed{\vec{p} = q\vec{r}}$$ Coulomb-meter



Polarization:

It is defined as electric dipole moment per unit volume. It is denoted by $\vec{P}$.

$$\boxed{\vec{P} = N\vec{p}}$$ coulomb/m^2 N $\rightarrow$ Number of dipoles per unit volume

Polarizability: $\boxed{\vec{P} = \alpha\vec{E}}$ $\alpha \rightarrow$ Polarizability, $F-m^2$

$\vec{E} \rightarrow$ Electrical Field Intensity, V/m,

$\vec{p} \rightarrow$ Dipole moment, coulomb-m

Electric flux density: When an electric field is applied

$$\boxed{\vec{D} = \varepsilon_o \vec{E} + \vec{P} = \varepsilon_o \vec{E} + \varepsilon_o \chi_e \vec{E}}$$

Polarization $\vec{P} = \varepsilon_o \chi_e \vec{E} = \varepsilon_o(\varepsilon_r - 1)\vec{E}$

$\therefore$ $\chi_e = \varepsilon_r - 1$

Polarization:

(*a*) **Electronic/Induced Polarization:** It is found in materials like inert gases in which there is no reaction among individual molecules.

$$\boxed{\vec{P}_e = N\alpha_e \vec{E}}$$ $\alpha_e \rightarrow$ Electronic polarizability

(*b*) **Ionic Polarization:** It is found in materials possessing ionic bonds between two dissimilar atoms like NaCl, HCl.
These materials have permanent dipole moment in absence of external field and exhibits both electronic and ionic polarization.

$$\vec{P} = \vec{P}_i + \vec{P}_e = N(\alpha_i + \alpha_e)\vec{E}$$ $\alpha_i \rightarrow$ Ionic polarizability

(*c*) **Orientational Polarization:** Occurs in materials having partly ionic bonds like H_2O, CO_2.

$$\boxed{\vec{P} = \frac{N p_p^2 \vec{E}}{3kT} = N\alpha_o \vec{E}}$$ where orientation polarization $\alpha_o = \frac{p_p^2}{3kT}$

$$\boxed{P \propto \frac{1}{T}}$$ $k \rightarrow$ Boltzman
$T \rightarrow$ Temperature

(*d*) Interfacial polarization: It is the result of lattice vacancies in the dielectrics.
Total polarization $P_T = P_i + P_e + P_o + P_s$ $P_s \rightarrow$ Interfacial polarization

- When alternating fields is applied, relative dielectric constant become function of frequency and at frequency about visible/optical ranges 5×10^{14}Hz material possesses only electronic polarization.
- ***Langevin-Debyes*** generalization of the ***Clausius-mossotti*** equation

$$\boxed{\frac{N\alpha_e}{3\varepsilon_o} = \frac{\alpha_r - 1}{\varepsilon_r + 2}}$$

$N \rightarrow$ Number of molecules per unit volume $\alpha_e \rightarrow$ Electronic Polarizability
It is applicable for gaseous states only.

- **Lorentz Equation:** $$\boxed{\frac{N\alpha}{3\varepsilon_o} = \frac{n^2 - 1}{n^2 + 2}\frac{M}{P}}$$

It is applicable only for electronic polarization $\alpha_i = \alpha_e$ at optical frequencies.
Piezoelectric Materials: If mechanical stress is applied to a dielectric material, material gets polarized because of applied stress and vice versa. These types of materials are called **piezoelectric materials.**

Example: Quartz crystal, Rochelle salt, Barium Titanate $(Ba\,TiO_3)$, Lead Zirconate $(PbZr\,O_3)$.

Applications: Gramophone, Accelerometer.

- Some dielectric materials get strained when they are subjected to an electric field but reverse effect is not found. Then this property is **Electrostriction.**

Expression of voltage sensitivity:

$$\boxed{V = gtP = \frac{e}{\varepsilon_o\varepsilon_r} \times t \times \frac{F}{A} = \frac{Q}{C}}$$

g = voltage sensitivity = $\frac{d}{\varepsilon_o\varepsilon_r}$ volt-meter/Newton; $t =$ Thickness

$P = \frac{F}{A}$ stress applied; $A =$ Area of cross section of crystal

12

COMPUTER ORGANIZATION

CONTENTS

1. PROGRAMMING BASICS

Computer cannot execute a program written in assembly or high level language. The program first must need to be translated to machine language (machine language program is nothing more than sequence of 0s and 1s) which the computer can understand.

Compiler: Compiler is a translator, which converts high level language program into assembly language program.
Assembler: Assembler is a program that translates assembly language program into machine language (sequence of 0s and 1s) program.
Linker: Linker is a computer program that takes one or more object files generated by a compiler and combine them into a single executable program.
Loader: Loader is the part of an operating system that is responsible for loading programs. It places programs into memory and prepares them for execution.

Data types in C:

Data type	Size (in bytes)
char	1
int	2
float	4
double	8

int i = 10;
This declaration tells the C compiler to:

(a) Reserve space (2B) in memory to hold the integer value.
(b) Associate the name i with this memory location.
(c) Store that value of i at this location

i $\rightarrow$ *Location name*

$\boxed{10}$ $\rightarrow$ *Value at location*

1000 $\rightarrow$ *Address*

```
main ( )
{
    int i = 10;
    printf ("%u", &i);
    printf ("%d", i);
    printf ("%d", * (&i));
}
```

Output:

/*printf (“%u”, &i); */	1000
/*printf(“%d”, i); */	10
/*printf(“%d”, * (&i));	*(1000) = 10

* is called “value at address” operator.

Pointer: Pointers are variables which holds the address of another variable.

Example:

```
main( )
{
    int x = 5;
    int * y = &x;
    int**z = &y;
    printf("%u",&x);
    printf("%u",y);
    printf("%u",z);
    printf("%d",x);
    printf("%d",*y);
    printf("%d",**z);
}
```

Solution:

$\boxed{5}$

x

1000 1001

↑

$\boxed{1000}$

y

2000 2001

↑

$\boxed{2000}$

z

3000 3001

printf("%u",&x);	1000
printf("%u",y);	1000
printf("%u",z);	2000
printf("%d",x);	5
printf("%d",*y);	*1000=5
printf("%d",**z);	**2000=*1000=5

Note: Every pointer variable takes 2 byte

Parameter Passing Techniques:

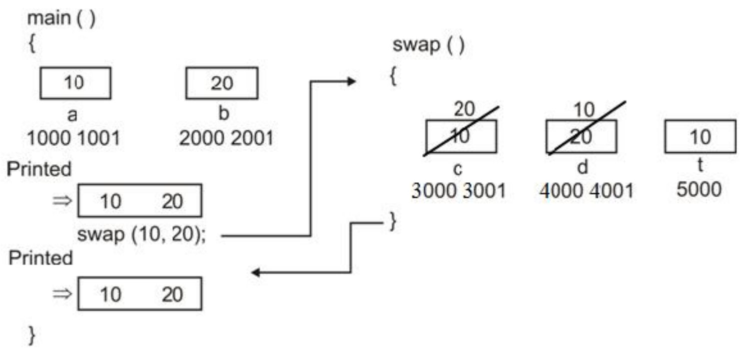
1. Call by value
2. Call by reference

Call by value:
Actual values of the parameter are passed to the called function.

Example: What is the output of the following program using Call by value as parameter passing technique?

```
main( )                          swap(int c, int d)
{                                {
  int a=10;                          int t;
  int b=20;                          t=c;
  printf ("%d%d",a,b);               c=d;
  swap(a,b);                         d=t;
  printf ("%d%d",a,b);            }
}
```

Solution:
Execution of program always starts from main ( )



Here, the changes will not reflect because we are passing the value of parameter to the function.

Call by reference:
In Call by reference, addresses of variables are passed as parameter to the called function.

Example: What is the output of above program, if compiler uses call by reference as parameter passing technique?
Solution: If compiler uses call by reference parameter passing technique, following changes are made to the program by the compiler.

13

MICROWAVES

CONTENTS

1. MICROWAVE BASICS AND TRANSMISSION LINES

- Microwaves are electromagnetic waves of which frequency ranges from 1 GHz to 1000 GHz.
- Microwaves behave more like rays of light than ordinary radio waves.
- Microwave frequency cannot be used for ground wave communication.

Advantages of Microwaves:

1. Increased bandwidth availability
2. Improved directive properties
3. Low fading effect and low power requirements

IEEE bands	**For microwave**
L	1.1 – 1.7 GHz
Ls	1.7 – 2.6 GHz
S	2.6 – 3.9 GHz
C	3.9 – 8 GHz
X	8 – 12.5 GHz
Ku	12.5 – 18 GHz
K	18 – 26 GHz
Ka	26 – 40 GHz

Propagation characteristics and applications of various bands:

Band	Frequency	Wavelength	Propagation characteristics	Applications
ELF	30 – 300 Hz	10 – 1 Mm	Penetration into earth and sea.	Communication with submarines.
VLF	3 – 30 kHz	100 –10 km	Surface wave up to 1000 km. Sky wave in the night extends range. Low attenuation during day and night.	Long distance point to point communication, Sonar navigation.
LF	30 – 300 kHz	10 – 1 km	Surface wave and sky wave at night. Surface wave attenuation greater than VHF.	Point-to-point marine communication, Time standard frequency broadcast.
MF	300–3000 kHz	1000–100m	Ground wave in day and sky wave in night. Attenuation is high in day and low in night.	AM broadcasting, direction finding, coastguard and marine communication.
HF	3 – 30 MHz	100 – 10 m	Reflection from ionosphere.	Moderate and long distance communication of all types: telephone, telegraph, radio.
VHF	30 – 300 MHz	10 – 1 m	Space wave, line of sight.	Television FM service, aviation and police.
UHF	300–3000 MHz	100 –10 cm	Same as VHF, affected by tall objects like hills.	Short distance communication, including radar, T.V, satellite communication.

Microwave Transmission Lines

Multi-conductor lines:

Coaxial cable: It is used upto 3GHz and it behaves like a LPF.

- Coaxial cables support TEM wave and has no cut off frequency.
- There is high radiation loss in coaxial cable at high frequencies.

Coaxial cable resistance: $R = \frac{1}{2\pi\delta\sigma_c}\left(\frac{1}{a}+\frac{1}{b}\right)\Omega / m$

$\delta \rightarrow$ Skin depth

$\sigma_c \rightarrow$ Conductivity

$a \rightarrow$ Inner conductor radius

$b \rightarrow$ Outer conductor radius

Inductance: $L = \frac{\mu}{2\pi}\ln\frac{b}{a}$ H/m

Capacitance: $C = \frac{2\pi\varepsilon}{\ln\frac{b}{a}}$ F/m

Characteristic Impedance: $Z_o = \sqrt{\frac{L}{C}} = \frac{1}{2\pi}\sqrt{\frac{\mu}{\varepsilon}}\,\ell n\left(\frac{b}{a}\right)\Omega$

$$\boxed{Z_o = \frac{60}{\sqrt{\varepsilon_r}}\ln\frac{b}{a}}$$

Breakdown power in coaxial cable: $P_{bd} = 3600\ a^2 ln\left(\frac{b}{a}\right)KW$

Strip Lines:

- These are modifications of coaxial lines and used at frequency from 100 MHz to 100 GHz.
- The dominant mode is TEM mode and has no radiation losses.
- These have higher isolation between adjacent circuits and no fringing fields after a certain distance from the edges of a conductor.
- It is difficult to mount active components on strip lines (i.e. line diode, circulators).

Characteristic Impedance:

$$Z_o = \frac{60}{\sqrt{\varepsilon_r}} ln\left(\frac{4b}{\pi d}\right)$$

$d \rightarrow$ Diameter of circular conductor

$b \rightarrow$ Thickness between ground plates

Micro strip lines:

- Cost is lower than strip line, coaxial cable or waveguide.
- Open structure of microstrip line leads to greater coupling and it is large to mount passive or active components.
- Open structure also leads to higher radiation losses and interference due to nearby conductors.
- Due to this interference a discontinuity in electric and magnetic field presents and this leads to impure TEM or quasi TEM modes.

Characteristic Impedance:

$$Z_o = \frac{60}{\sqrt{\varepsilon_r}} \ell n\left(\frac{4h}{d}\right) \qquad \text{If } h >> d$$

$$Z_o = \frac{377}{\sqrt{\varepsilon_r}} \frac{h}{w} \qquad \text{If } w >> h$$

$w \rightarrow$ strip line width $t \rightarrow$ thickness

$h \rightarrow$ distance between the line and ground plane.

2. WAVEGUIDES

Waveguides (single conductor lines)

- At frequencies higher than 3 GHz, there are more losses in Transmission lines.
- A hollow metallic tube used to transmit EM waves by successive reflections from inner walls of tube is called waveguide.

Difference with transmission line:

- In waveguides, only waves having frequencies greater than cut off frequency f_c will be propagated that is why waveguide act as a HPF.
- Waveguide is one conductor transmission line.

Rectangular waveguide:

- TM_{11} is dominant mode for TM waves.
- TE_{10} is dominant mode for TE wave and it is also overall dominant mode (when $a > b$).

  In this TM_{10} or TM_{01} does not exist.

Cut off frequency: $$\boxed{f_c = \frac{1}{2\sqrt{\mu\varepsilon}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}}$$

Phase constant : $$\boxed{\beta = \omega\sqrt{\mu\varepsilon}\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$$

Phase velocity: $$\boxed{v_p = \frac{\omega}{\beta} = \frac{1}{\sqrt{\omega\varepsilon}\sqrt{1-\left(\frac{f_c}{f}\right)^2}}}$$

Group velocity: $$\boxed{v_g = \frac{\partial\omega}{\partial\beta} = \frac{1}{\sqrt{\mu\varepsilon}}\sqrt{1-\left(\frac{f_c}{f}\right)^2}}$$

In waveguide: $\boxed{v_p > c > v_g}$

i.e. $\boxed{v_p v_g = c^2}$

In vacuum: $\boxed{v_p = c = v_g}$

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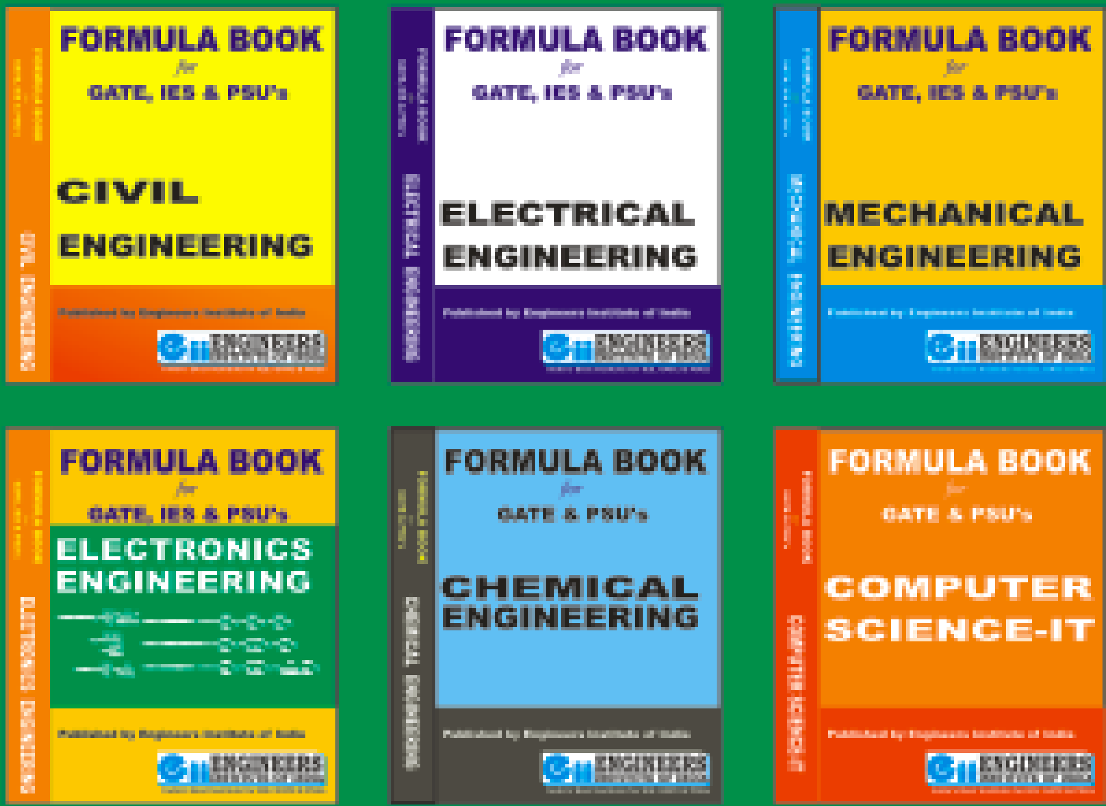

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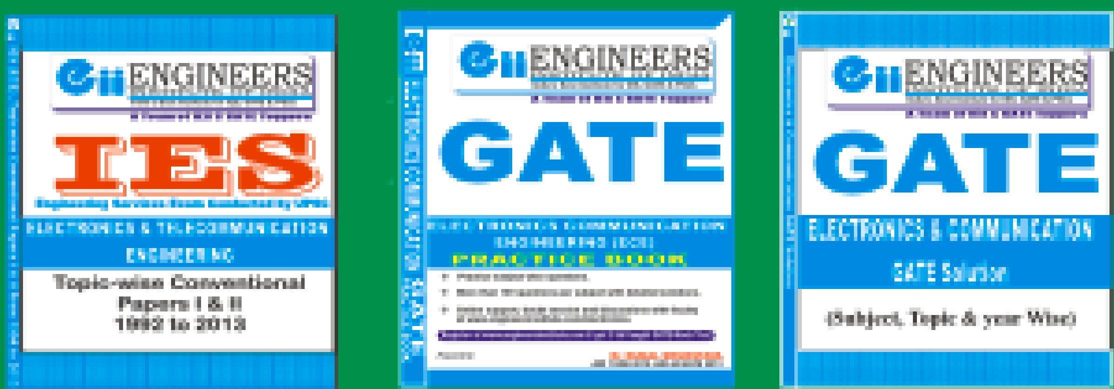

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