ESE - 2025

MAINS EXAMINATION

QUESTIONS WITH DETAILED SOLUTIONS

ELECTRICAL ENGINEERING

(Paper-1)

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ELECTRICAL ENGINEERING

ESE MAINS 2025_PAPER – I

Questions with Detailed Solutions

SUBJECT WISE WEIGHTAGE

S.No	NAME OF THE SUBJECT	Marks
01	Engineering Mathematics	76
02	Electrical Materials	52
03	Electric Circuits and Fields	116
04	Electrical and Electronic Measurements	92
05	Computer Fundamentals	60
06	Basic Electronics Engineering	84
	Total Marks	**480**

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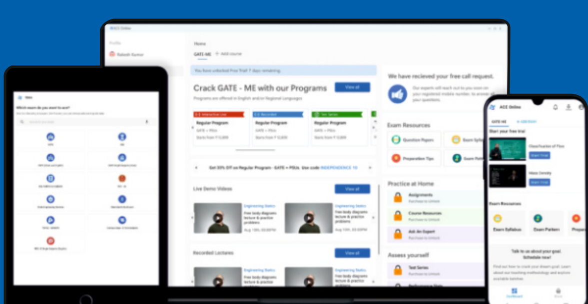

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SECTION – A

1[a] (i) If A is an n × n diagonalizable matrix and $A^2 = A$, then show that each eigen value of A is 0 or 1.

(ii) Show that all the eigen values of a Hermitian matrix are real. [6+6=12M]

Solution:

(i) Given A is an n × n

Diagonalizable matrix and $A^2 = A$

If λ is an eigen value of A then there exists a non zero vector x such that

$AX = \lambda X$

$A(AX) = A(\lambda X)$

$\Rightarrow A^2X = \lambda (AX)$

$\Rightarrow AX = \lambda (\lambda X) \quad (\because A^2 = A)$

$\Rightarrow AX = \lambda^2 X$

$\Rightarrow \lambda X = \lambda^2 X \quad (\because AX = \lambda X)$

$\Rightarrow \lambda X - \lambda^2 X = 0$

$\Rightarrow X(\lambda - \lambda^2) = 0$

$\Rightarrow \lambda - \lambda^2 = 0 \quad (\because X \text{ is non zero vector})$

$\Rightarrow \lambda (1 - \lambda) = 0$

$\Rightarrow \lambda = 0, 1$

∴ Eigen values of A are either 0 or 1

(ii) Given A is Hermitian matrix

$\Rightarrow A^\theta = A$ where $A^\theta = (\bar{A})^T$

Where A is complex conjugate of A

Let λ be an eigen value of A and X be the corresponding eigen vector

$\therefore AX = \lambda X$ ……….(1)

$(AX)^\theta = (\lambda X)^\theta$

$\Rightarrow X^\theta A^\theta = \bar{\lambda} X^\theta$

$\Rightarrow X^\theta A = \bar{\lambda} X^\theta \quad (\because A^\theta = A)$

Post multiplying both sides by X

$X^\theta AX = \bar{\lambda} X^\theta X$

$X^\theta \lambda X = \bar{\lambda} X^\theta X$ (By (1))

$\Rightarrow \lambda X^\theta X = \bar{\lambda} X^\theta X$

$\Rightarrow X^\theta X(\lambda - \bar{\lambda}) = 0$

$\Rightarrow \lambda - \bar{\lambda} \neq 0$ $(\because X \neq 0)$

$\Rightarrow \bar{\lambda} = \lambda$

λ is real

$\therefore$ Eigen values of Hermitian matrix are real.

1[b] The magnetic field strength in a material is 9×10^5 A/m and its magnetic susceptibility is 0.75×10^{-5}.

(i) Find the flux density and the magnetization in the material.

(ii) Also find its relative permeability. **[12M]**

Solution:

Given data,

$H = 9\times10^5$ A/m

$X = 0.75\times10^{-5}$

Magnetization $= M = X \times H$

$= 0.75 \times 10^{-5} \times 9 \times 10^5$

$= 0.67$ A/m^2

Magnetic flux $= B = \mu H$

$\mu = \mu_0 \mu_R = \mu_0 (1 + X)$

$B = \mu_0 (1 + X)H$

$= 4\pi \times 10^{-7} (1 + 0.75 \times 10^{-5}) \times 9 \times 10^5$

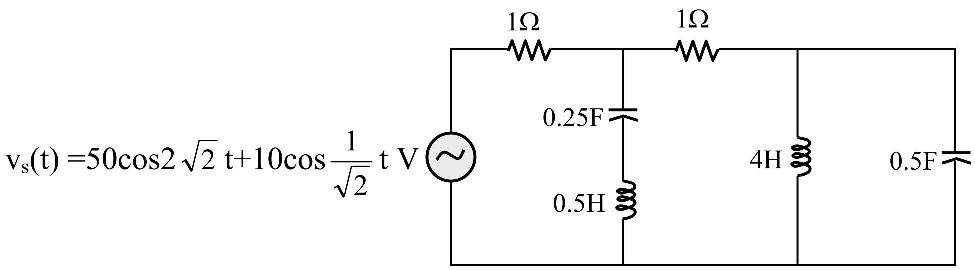
$= 1.1309$ Tesla

Relative permeability $= \mu_R = \dfrac{\mu}{\mu_0} = 1 + X$

$\mu_R = 1 + 0.75 \times 10^{-5} = 1.0000075$

1[c] For the circuit given in the figure below, find the current through 4Ω resistor and the total active power delivered by the source. The source voltage $V_s(t)$ = $50\cos 2\sqrt{2}t + 10\cos\frac{1}{\sqrt{2}}t$ volts :

[12M]

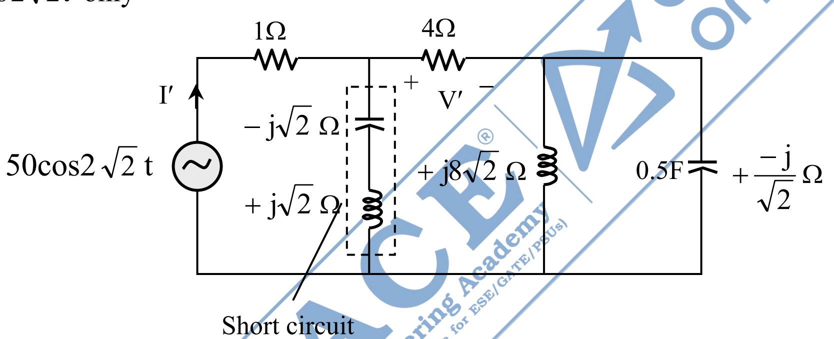


Solution:

Since two different frequency sources.

Apply super Position Theorem

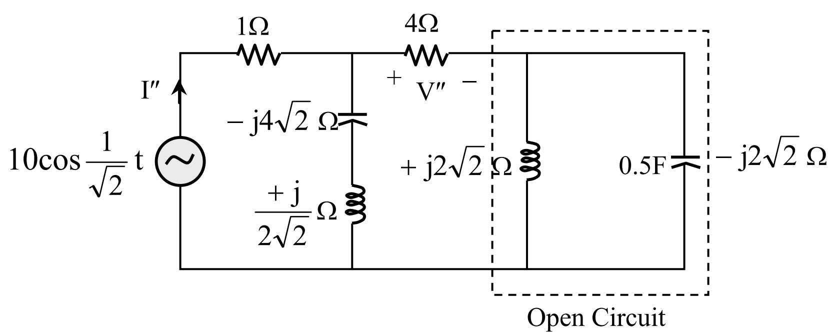
S-I: $50\cos 2\sqrt{2}t$ only



So, $V' = 0$ V

$$I' = \frac{50\cos 2\sqrt{2}t}{1} = 50\cos 2\sqrt{2}\,t \text{ A}$$

S-II: $10\cos\frac{1}{\sqrt{2}}.t$ V



So, $V'' = 0$ V

$$I'' = \frac{10\cos\frac{1}{\sqrt{2}}.t}{\left[1 - j4\sqrt{2} + \frac{j}{2\sqrt{2}}\right]} = \frac{10\cos\frac{1}{\sqrt{2}}.t}{[1 - j5.303]}$$

$$I'' = \frac{10\cos\frac{1}{\sqrt{2}}.t}{5.396\angle -79.321^\circ}$$

$$I'' = 1.853\cos\left(\frac{1}{\sqrt{2}}.t + 79.321^\circ\right) \text{ A}$$

So, $V_S(t) = 50\cos 2\sqrt{2}t + 10\cos\frac{1}{\sqrt{2}t}$ V

$$I = I' + I'' = 50\cos 2\sqrt{2}t + 1.853\cos\left(\frac{1}{\sqrt{2}}.t + 79.321\right) \text{ A}$$

⇒ Voltage across 4 Ω

$V = V' + V'' = 0 + 0 = 0$ V

⇒ Power delivered by source

$$P_{avg} = P = \frac{50}{\sqrt{2}}.\frac{50}{\sqrt{2}}\cos 0^\circ + \frac{10}{\sqrt{2}} \times \frac{(1.853)}{\sqrt{2}}\cos 79.321$$

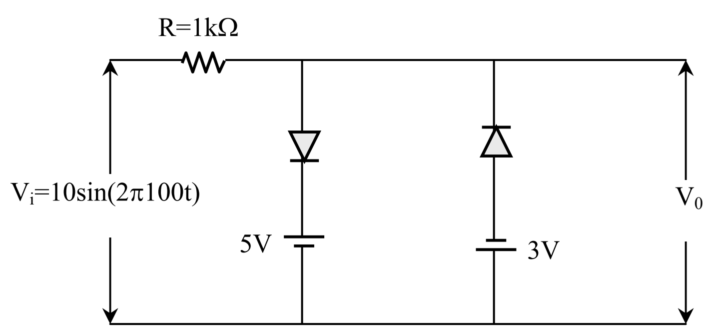
$= 1250 + 1.717$

$= 1251.717$ W

1[d] Consider the circuit shown in the figure below. Assuming that the diodes are ideal, sketch the following waveforms:

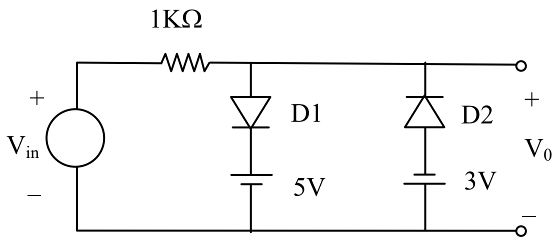
(i) Two cycles of V_i (input) and V_0 (output)

(ii) Transfer characteristics of the circuit, i.e., V_0 versus V_i **[12M]**

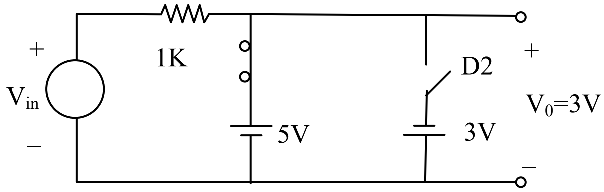


Solution:

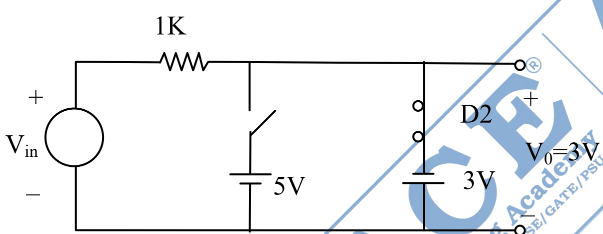
Given diodes are ideal, $V_{in} = 10\sin 2\pi 100t$



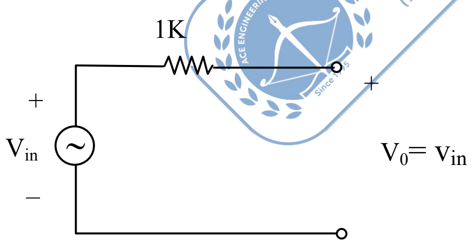
Case-1: If $V_{in} > 5V$ (D_1 ON) $\rightarrow V_0 = 5V$

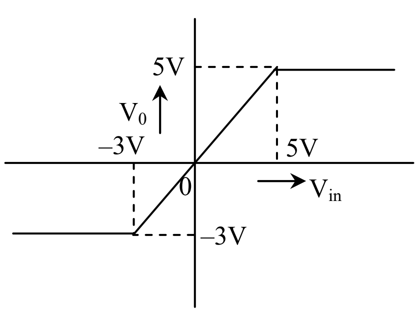


Case-2: If $V_{in} < -3V$ (D_2 ON) $\rightarrow V_0 = -3V$



Case-3: If $-3 \leq V_{in} \leq 5$ $\begin{pmatrix} D_1 OFF \\ D_2 OFF \end{pmatrix}$

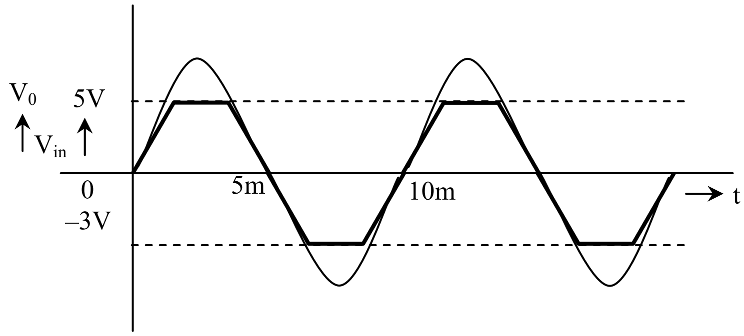




$V_{in} = V_m \sin\omega t = 10\sin 2\pi(100t)$

$\therefore\ \omega = 2\pi f = 2\pi(100) \rightarrow f = 100\text{Hz}$

$$T = \frac{1}{f} = \frac{1}{100} = 10\text{ms}$$



The output gets clipped above 5V and below –3V. This is a double biased clipper or a slicer circuit.

1[e] Draw the circuit diagram and explain the process of measurement of low resistance values using Kelvin's double bridge. Derive the expression and mention two conditions which ensure that the unknown resistance can be easily measured in terms of the standard resistance. [12M]

Solution:

The Kelvin bridge is a modification of the wheat-stone bridge and provides greatly increased accuracy in measurement of low value resistances.

The Kelvin bridge arrangement may be obtained by a study of the difficulties that arise in a wheat-stone bridge on account of the resistance of the leads and the contact resistances while measuring low valued resistors.

Procedure: The Kelvin double bridge incorporates the idea of a second set of ratio arms-hence the name double bridge and the use of four terminal resistors for the low resistance arms. The first set of ratio arms is P and Q. The second set of ratio arms, p and q is used to connect the galvanometer to a point 'd' at the appropriate potential between points 'm' and 'n' to eliminate the effect of connecting lead of resistance 'r' between the known resistance, R and the standard resistance, S. The ratio p/q is made equal to P/Q under balance conditions at which, there is no current through the galvanometer. Which means that the voltage drop between 'a' and 'b', E_{ab} is equal to the voltage drop E_{amd} between a and c.

$$\text{Now } E_{ab} = \frac{P}{P+Q} E_{ac}$$

$$E_{ac} = I\left[R + S + \frac{(p+q)r}{p+q+r}\right]$$

$$E_{amd} = I\left[R + \frac{p}{p+q}\left\{\frac{(p+q)r}{p+q+r}\right\}\right]$$

$$= I\left[R + \frac{pr}{p+q+r}\right]$$

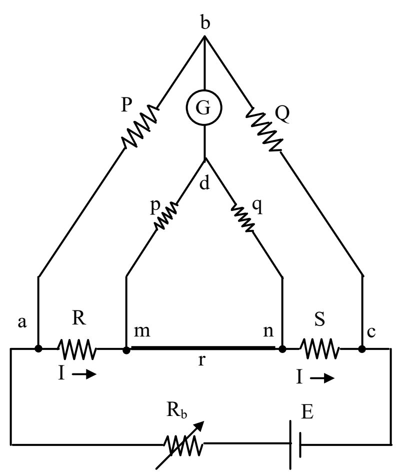


Fig: Kelvin Double bridge

Condition 1: Bridge Balance Condition

- The bridge must be **balanced**, meaning the potential difference between the galvanometer terminals is zero. For zero galvanometer deflection, $E_{ab} = E_{amd}$

$$\frac{P}{P+Q} I\left[R+S+\frac{(p+q)r}{p+q+r}\right] = I\left[R+\frac{pr}{p+q+r}\right]$$

$$R = \frac{P}{Q}S + \frac{qr}{p+q+r}\left[\frac{P}{Q}-\frac{p}{q}\right]$$

Condition 2: Equal Ratio Arms, the ratio of the arms in the main and auxiliary bridges must be **equal.**

Now if $\frac{P}{Q} = \frac{p}{q}$ then, $R = \frac{P}{Q}.S$

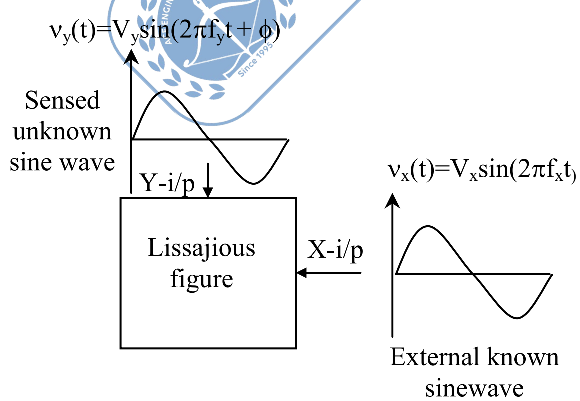
Above equation indicates resistance measurement, which is free from lead and contact resistance 'r'

$\therefore$ Accurate measurement will occur.

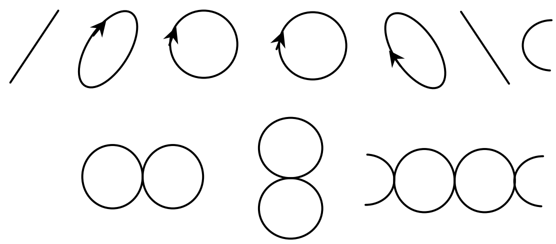
2[a] (i) What are Lissajous patterns? Explain. Also elaborate what patterns appear on the cathode ray oscilloscope screen, when voltages of different frequencies and phase differences are applied in the horizontal and vertical plates of the scope. Take two examples for each of the above two cases. Explain how the unknown signal frequency is measured accurately with the help of observing the patterns. [12M]

Solution:

* Lissajious patterns are the figures displayed on the screen of CRO when it is operated in X-Y display mode, as shown below



* Examples of Lissajious patterns

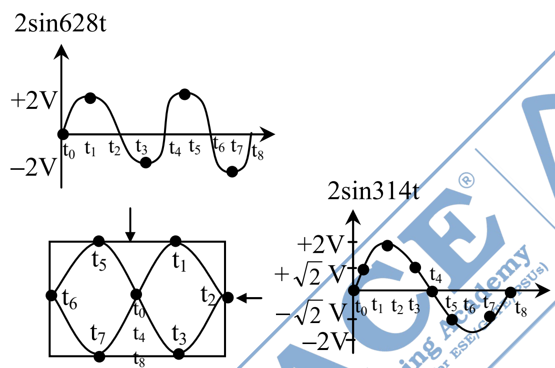


Consider 8 division × 8 division screen & $S = 2\dfrac{\text{div}}{\text{V}}$

* Case-1: Two signals of different frequencies

Example-1

Of case -1: $V_y(t) = 2\sin 628t$, $V_x(t) = 2\sin 314t$ i.e., $f_y = 2f_x$



$$2\text{V} \times 2\frac{\text{div}}{\text{V}} = 4\text{div}$$

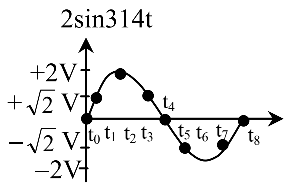
$$\sqrt{2}\text{V} \times 2\frac{\text{div}}{\text{V}} \cong 3\text{div}$$

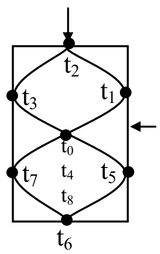
At	$\rightarrow (V_x, V_y) \rightarrow$	S(x, y)
t_0	$\rightarrow (0\text{V}, 0\text{V}) \rightarrow$	(0, 0)
t_1	$\rightarrow \left(\sqrt{2}\text{V}, 2\text{V}\right) \rightarrow$	(3div, 4div)
t_2	$\rightarrow (2\text{V}, 0\text{V}) \rightarrow$	(4div, 0)
t_3	$\rightarrow \left(\sqrt{2}\text{V} - 2\text{V}\right) \rightarrow$	(3div, –4div)
t_4	$\rightarrow (0\text{V}, 0\text{V}) \rightarrow$	(0,0)
t_5	$\rightarrow \left(-\sqrt{2}\text{V}, 2\text{V}\right) \rightarrow$	(–3div, 4div)

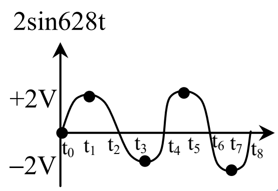
t_6	$\rightarrow$ (–2V, 0V) $\rightarrow$	(–4div, 0)
t_7	$\rightarrow \left(-\sqrt{2}V, -2V\right) \rightarrow$	(–3div, –4div)
t_8	$\rightarrow$ (0V, 0V) $\rightarrow$	(0,0)

Example-2:

Of Case-1: $V_y(t) = 2\sin 314t$, $V_x = 2\sin 628t$ i.e., $f_x = 2f_y$







$$2V \times 2\frac{\text{div}}{V} = 4\text{div}$$

$$\sqrt{2}V \times 2\frac{\text{div}}{V} \cong 3\text{div}$$

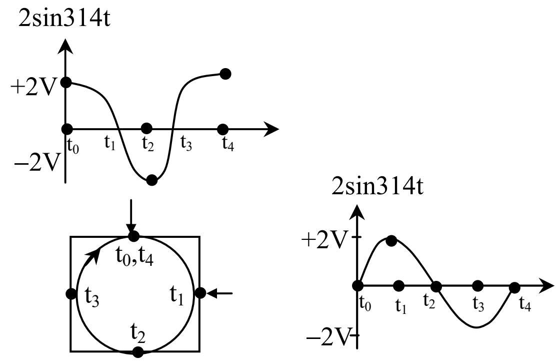
At	$\rightarrow (V_x, V_y) \rightarrow$	S(x, y)
t_0	$\rightarrow$ (0V, 0V) $\rightarrow$	(0, 0)
t_1	$\rightarrow \left(2V, \sqrt{2}V\right) \rightarrow$	(4div, 3div)
t_2	$\rightarrow$ (0V, 2V) $\rightarrow$	(0, 4div)
t_3	$\rightarrow \left(-2V, \sqrt{2}V\right) \rightarrow$	(–4div, 3div)
t_4	$\rightarrow$(0V, 0V) $\rightarrow$	(0,0)
t_5	$\rightarrow \left(2V, -\sqrt{2}V\right) \rightarrow$	(4div, –3div)
t_6	$\rightarrow$ (0V, –2V) $\rightarrow$	(0, –4div)
t_7	$\rightarrow \left(-2V, -\sqrt{2}V\right) \rightarrow$	(–4div, –3div)
t_8	$\rightarrow$ (0V, 0V) $\rightarrow$	(0,0)

II-Case-2: Two sinusoidal signals of phase difference

Example-1 of CASE 2:

$v_y(t) = 2\sin(314t + 90°)$; $v_x(t) = 2\sin 314t$

$= 2\cos 314t$



Circle
Anticlockwise rotating

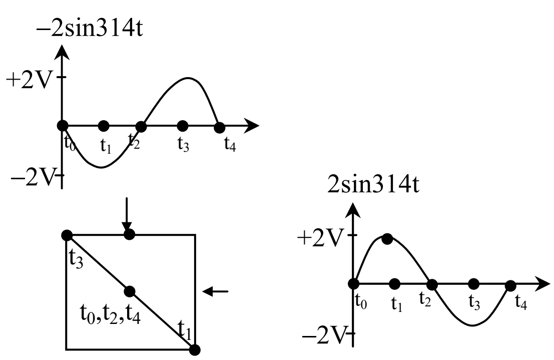
$$2V \times \frac{2\text{div}}{V} = 4 \text{ div}$$

At	→ (V$_x$, V$_y$) →	S(x, y)
t_0	→ (0V, +2V) →	(0, 4div)
t_1	→ (+2V, 0V→	(4div, 0)
t_2	→ (0V, –2V) →	(0, –4div)
t_3	→ (–2V, 0V)→	(–4div, 0)
t_4	→(0V, +2V) →	(0,+4div)

Example-2 of CASE 2:

$v_y(t) = 2\sin(314t + 180°)$; $v_y(t) = 2\sin 314t$

$= -2\sin 314t$



Diagonal line
Making 135° with
+ve X axix

$$2V \times \frac{2div}{V} = 4 \text{ div}$$

At	$\rightarrow (V_x, V_y) \rightarrow$	S(x, y)
t_0	$\rightarrow$ (0V, 0V) $\rightarrow$	(0, 0)
t_1	$\rightarrow$ (+2V, –2V)$\rightarrow$	(+4div, –4div)
t_2	$\rightarrow$ (0V, 0V) $\rightarrow$	(0, 0)
t_3	$\rightarrow$ (–2V, +2V)$\rightarrow$	(–4div, +4div)
t_4	$\rightarrow$(0V, 0V) $\rightarrow$	(0, 0)

Unknown signal frequency measurement with the help of observing Lissajious patterns:

There are two techniques namely Tangent technique and intersection technique

1. Tangent technique:

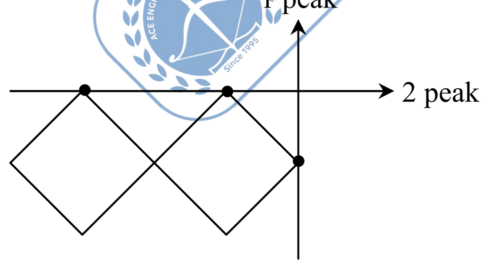
Draw both horizontal and vertical tangent lines for given Lissajious pattern

Count the number of maximas (peaks) as touch by both lines. Then unknown vertical frequency can be measured as:

$$f_y = f_x \times \frac{\text{Horizontal technique}}{\text{Vertical technique}}$$

Rule: Count closed loop points touched by line as full peaks and open loop points touched by line as $\frac{1}{2}$ peaks

Ex:



$$f_y = f_x \times \frac{2}{1}$$

$\Rightarrow f_y = 2f_x$ i.e., 2 : 1

If f_x = 1 kHz then f_y = 2 kHz

2. Intersection technique:

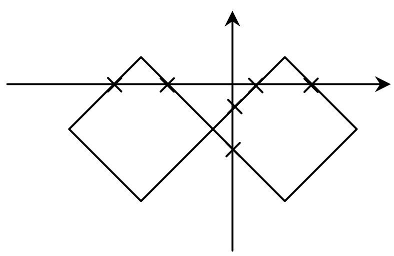
Draw both horizontal and vertical lines passing through given Lissajius pattern

Count the number of intersections made by both lines. Then unknown vertical frequency can be measured as

$$f_y = f_x \times \frac{\text{horizontal intersections}}{\text{Vertical intersections}}$$

Rule: Never draw any line via pre-existing intersection in Lissajious pattern

Ex:



$$f_y = f_x \times \frac{4}{2}$$

$$= f_x \times \frac{2}{1}$$

$$= 2f_x \quad \text{i.e., } 2:1$$

If $f_x = 1$ kHz, then $f_y = 2$ kHz

2[a] (ii) Explain the principle of operation of a piezoelectric transducer. Write its advantages, disadvantages and some applications. [8M]

Solution:

Principle of Operation:

Piezoelectric transducers operate based on the piezoelectric effect, which is the ability of certain materials (like quartz or specific ceramics) to generate an electric charge in response to applied mechanical stress (direct piezoelectric effect), and conversely, to undergo mechanical deformation when an electric field is applied (converse piezoelectric effect).

- Direct Piezoelectric Effect: When mechanical force or pressure is applied to a piezoelectric material, its internal atomic structure distorts, causing a separation of positive and negative charges and generating an electric voltage proportional to the applied stress.
- Converse Piezoelectric Effect: When an electric field is applied across a piezoelectric material, it deforms or changes shape, forming the basis for piezoelectric actuators used in applications requiring precise mechanical motion.

Advantages:

- Self-generating (Active Transducer)
- High Frequency Response
- Compact Size and Lightweight
- Rugged Construction

Disadvantages:

- Not Suitable for Static Measurements
- Temperature Sensitivity
- Low Output Voltage (Often requires amplification)
- Brittleness

Applications:

- Sensors
- Actuators
- Medical Devices
- Consumer Electronics
- Energy Harvesting

2[b] (i) Write a program in C language to print the following full pyramid of numbers: [10M]

```
                1
            2   3   2
        3   4   5   4   3
    4   5   6   7   6   5   4
5   6   7   8   9   8   7   6   5
```

Solution:

```
#include <stdio.h>
int main ( )    {
    int n = 5 ; // Number of rows
    int I, j, k, num;

    for  (i = 1; i < = n; i++)  {
        // print spaces for pyramid alignment
        for (j = i; j < n; j++)  {
```

```
            printf ("  ") ;
         }
        // print increasing numbers
        num = i;
        for (k = 1; k < = I; k++)   {
             printf (" %d ", num++);
        }
        // print decreasing numbers
        num —=2; // Adjust to avoid repeating the peak
        for (k = 1; k < i; k++)   {
             printf (" % d ", num– –);
        }
        Printf (" \n") ;
    }
    return 0;
}
```

Expected Output:

Output for n = 5:

```
                1
            2   3   2
        3   4   5   4   3
    4   5   6   7   6   5   4
5   6   7   8   9   8   7   6   5
```

Explanation:

1. The variable ‘n’ stores the total number of rows for the pyramid.
2. The outer loop (i) controls the number of rows.
3. The first inner loop prints spaces to align the pyramid shape.
4. The second inner loop prints the increasing sequence starting from the current row number.
5. The ‘num = 2’ step ensures the peak number is not repeated in the decreasing sequence.
6. The third inner loop prints the decreasing sequence.
7. Each row ends with a newline to move to the next line of the pyramid.

2[b] (ii) Minimize the four-variable logic function using K-map

$f(A, B, C, D) = \sum m(0,1,2,3,5,7,8,9,11,14)$ [10M]

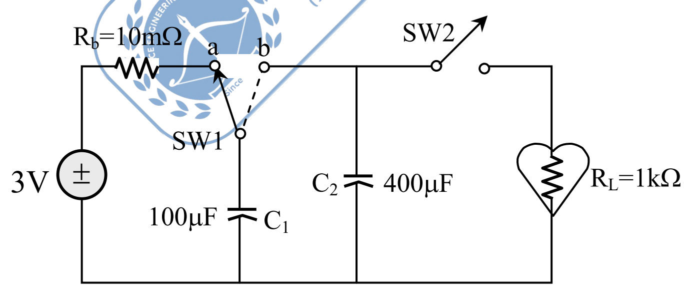
Solution:

$f(A, B, C, D) = \sum m(0,1,2,3,5,7,8,9,11,14)$

AB \ CD	00	01	11	10
g00	1	1	1	1
01		1	1	
11				1
10	1	1	1	

$$\overline{A}\,\overline{B} + \overline{A}D + \overline{B}\,\overline{C} + \overline{B}D + ABC\overline{D}$$

2[c] A cardiac pacemaker is represented by the circuit given in the figure below. The battery internal resistance R_b is 10mΩ, whereas the heart equivalent resistance is 1 kΩ. The switch 1 (SW1) is at position a initially for a long time when switch 2 (SW2) is OFF. Then SW1 is moved to position b at t = 0 and SW2 is ON simultaneously for next t = 10 ms. At t = 10 ms, SW1 moves to position a and SW2 is OFF for another 10ms. Find the voltages of the capacitors C_1 and C_2 at t=0, 10ms and 20ms, and sketch the capacitor voltages up to 20ms. Also calculate the energy dissipated in R_L during the interval 0 to 10ms when SW2 was ON: [20M]



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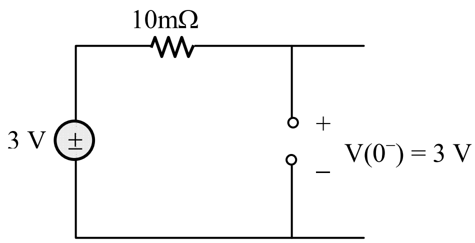
Solution:

At $t = 0^-$

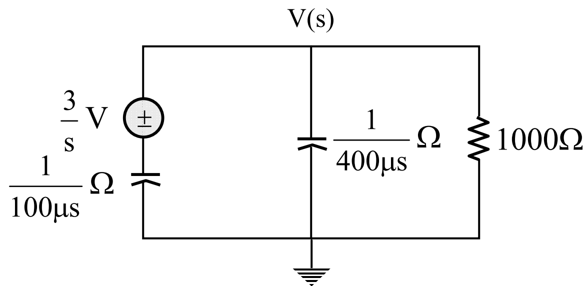


At t = 0

$V_{C1} = 3$ V

$V_{C2} = 0$ V

$0 < t \le 10$ msec



$$\frac{V(s)-\frac{3}{s}}{\frac{1}{100\mu s}}+\frac{V(s)}{\frac{1}{400\mu s}}+\frac{V(s)}{1000}=0$$

$$V(s)\left[100\mu s+400\mu s+\frac{1}{1000}\right]=300\ \mu s$$

$$V(s)\left[500\mu s+\frac{1}{1000}\right]=300\ \mu s$$

$$V(s)[500\mu s]\left[s+\frac{1}{1000\times 500\mu s}\right]=300\ \mu s$$

$$V(s)=\frac{\frac{3}{5}}{(s+2)}$$

$V(t) = L^{-1}[V(s)] = 0.6e^{-2t}$ V for $0 \le t \le 10$ msec

$$V_{C1}(t=10\text{msec}) = V_{C2}(t=10\text{msec}) = 0.6\,e^{-2\left(10\times10^{-3}\right)}$$

$$= 0.6e^{-0.02} = 0.6[0.98]$$

$$= 0.588 \text{ V}$$

$V_R(t) = 0.6e^{-2t}$ V

$$i_R(t) = \frac{V_R(t)}{R} = \frac{0.6}{1000}e^{-2t}\ \text{A}$$

$$P_R(t) = V_R(t)i_R(t) = \frac{.0.36}{1000}e^{-4t}\ \text{W}$$

$$E_R(t) = \int_0^{10m} \frac{0.36}{1000}e^{-4t}dt\ \text{J}$$

$$= \frac{0.36}{1000}\left[-\frac{1}{4}e^{-4(10m)} - \left(-\frac{1}{4}e^{-0}\right)\right]$$

$$= \frac{0.36}{1000}\left[-\frac{1}{4}(0.96) + \frac{1}{4}\right]$$

$$= \frac{0.09}{1000}[1-0.96]$$

$$= \frac{0.09\times 0.04}{1000}$$

$$= 3.6\ \mu\text{J}$$

At t = 10msec again switch SW_1 is moved to position (a) and SW_2 is off (open) again

So, V_{C2} remains at 0.588 volts (No losses)

But for V_{C1}

$$V(t) = V(\infty) + [V(0) - V(\infty)e^{-(t-10m)/\tau}$$

$$= 3 + [0.588 - 3]e^{-(t-10m)/100\mu.10m}$$

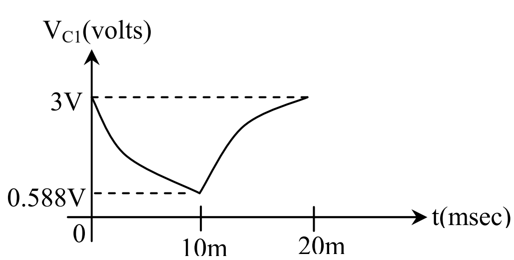
$$V(t) = 3 - 2.412e^{-(t-10m)\times 10^6}$$

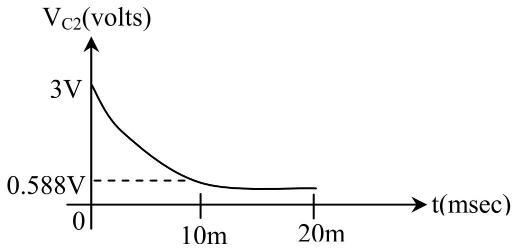
for (10m ≤ t ≤ 20 msec]

Now $V_{C1}(t = 20\text{ msec})$

$$= 3 - 2.412e^{-[20m-10m]\times 10^6 t}$$

$$\approx 3 - 2.412e^{-10\times 10^3} \approx 3\ \text{V}$$





3[a] (i) Find the singular solution of the partial differential equation $6yz - 6pxy - 3qy^2 + pq = 0$.

[10M]

Solution:

Given $6yz - 6pxy - 3qy^2 + pq = 0$ ………. (1)

Where $P = \dfrac{\partial z}{\partial x}$ and $q = \dfrac{\partial z}{\partial y}$

Let $F(x, y, z, p, q) = 6yz - 6pxy - 3qy^2 + pq$

$$\frac{\partial F}{\partial p} = -6xy + q$$

$$\frac{\partial F}{\partial q} = -3y^2 + p$$

$$\frac{\partial F}{\partial p} = 0 \Rightarrow -6xy + q = 0$$

$$\Rightarrow q = 6xy$$

$$\frac{\partial F}{\partial q} = 0 \Rightarrow -3y^2 + p = 0$$

$$\Rightarrow p = 3y^2$$

Substituting p and q values in equation (1)

$6yz - 6xy\,(3y^2) - 3y^2\,(6xy) + (3y^2)\,(6xy) = 0$

$\Rightarrow 6yz - 18xy^3 - 18xy^3 + 18xy^3 = 0$

$\Rightarrow 6yz - 18xy^3 = 0$

$\Rightarrow 6y\,(z - 3xy^2) = 0$

$\Rightarrow z - 3xy^2 = 0$

$\therefore z = 3xy^2$ is the singular solution

3[a] (ii) Derive the formula by Newton Raphson method to find next approximation of the root of the equation f(x) = 0, if x_0 is an initial approximation. Also perform three iterations to find a root of the equation $x^4 - x - 10 = 0$ which is near to x = 2, correct to three decimal places. [4+6=10M]

Solution:

Let x_0 be an approximate root of f(x) = 0 and let $x_1 = x_0 + h$ be the correct root so that $f(x_0 + h) = 0$

To find h, we expand $f(x_0 + h)$ by Taylor's Series

$$f(x_0 + h) = f(x_0) + hf'(x_0) + \frac{h^2}{2!} f''(x_0) + \ldots\ldots \quad [f(x_0 + h) = 0]$$

$$0 = f(x_0) + hf'(x_0) \quad \text{[Neglecting the second and higher order derivative]}$$

$$h = -\frac{f(x_0)}{f'(x_0)}$$

But $\quad x_1 = x_0 + h$

Putting the value of h, we get $\Rightarrow \; x_1 = x_0 - \dfrac{f(x_0)}{f'(x_0)}$

x_1 is better approximation than x_0. $\quad x_2 = x_1 - \dfrac{f(x_1)}{f'(x_1)}$

x_2 is better approximation than x_1.

Successive approximations are $x_3, x_4, \ldots\ldots\ldots x_{n+1}$

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$$

Let

$$f(x) = x^4 - x - 10$$

$$f(1) = -10, \text{ and } f(2) = 4$$

Since f(1) < 0 and f(2) > 0, the root lies between 1 and 2.

Let $x_0 = 2$

$$f(x) = 4x^3 - 1$$

By the Newton-Raphson method,

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$$

$$f(x_0) = f(2) = 4$$

$$f'(x_0) = f'(2) = 31$$

$$x_1 = x_0 - \frac{f(x_0)}{f'(x_0)}$$

$$= 2 - \frac{4}{31}$$

$f(x_1) = f(1.871) = 0.3835$

$f'(x_1) = f'(1.871) = 25.1988$

$$x_2 = x_1 - \frac{f(x_1)}{f'(x_1)}$$

$$= 1.871 - \frac{0.3835}{25.1988}$$

$$= 1.8558$$

$f(x_2) = f(1.8558) = 5.2922\times10^{-3}$

$f'(x_2) = f'(1.8558) = 24.5655$

$$x_3 = x_2 - \frac{f(x_2)}{f'(x_2)}$$

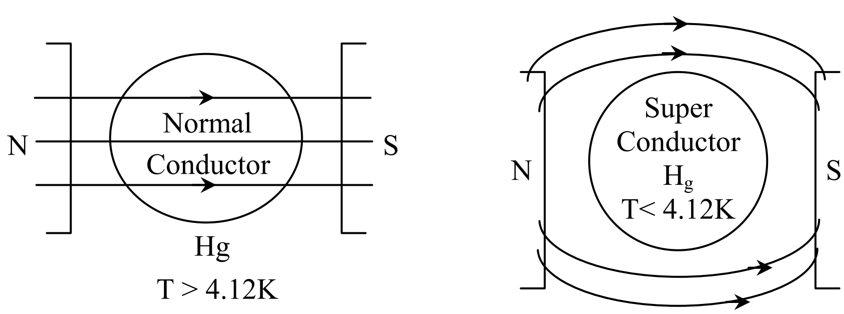
$$= 1.8558 - \frac{5.2922\times10^{-3}}{24.5655}$$

$$= 1.8556$$

3[b] (i) Prove that the susceptibility of a perfectly superconducting material is –1 and its relative permeability is zero. [8M]

Solution:

The super conductor obeys meisner effect, i.e., explusion of magnetic flux lines by the super conductor below critical temperature.



Magnetic flux density of super conductor = B = 0

Permeability = $\mu = \frac{B}{H} = 0$

Relative permeability = $\mu_R = \frac{\mu}{\mu_0} = 0$

Magnetic susceptibility $X = \mu_R - 1$

$$X = 0 - 1 = -1$$

Super conductor is a perfect diamagnetic material

3[b] (ii) Find the critical current and critical current density at temperature 4.2K for a superconducting wire made of lead with a diameter of 2mm. The critical temperature for lead is 7.2K and its critical field is $H_0 = 6.5\times10^4$ A/m. [12M]

Solution:

Given data

T = 4.2 K

d = 2 mm

$T_C = 7.2K$

$H_0 = 6.5\times10^4$ A/m

Critical magnetic field at 4.2K

$$H_{4.2} = H_0\left[1-\left(\frac{T}{\pi}\right)^2\right] = 6.5\times10^4\left[1-\left(\frac{4.2}{7.2}\right)^2\right]$$

$$= 4.28\times10^4$$

From silsebe rule

$$H_T = \frac{I}{2\pi r}$$

$$I = 2\pi r\, H_T$$

$$= 2\pi \times 1 \times 4.28 \times 10^4 \times 10^{-3}$$

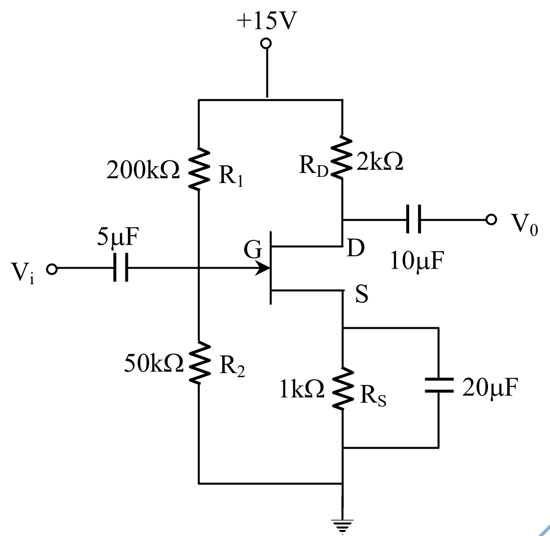
$$= 269.44 \text{ A}$$

Current density

$$J = \frac{I}{A} = \frac{269.44}{\pi\left(1\times10^{-3}\right)^2}$$

$$= 8.5764\times10^7 \text{ A/m}^2$$

3[c] Consider the circuit shown in the figure below:

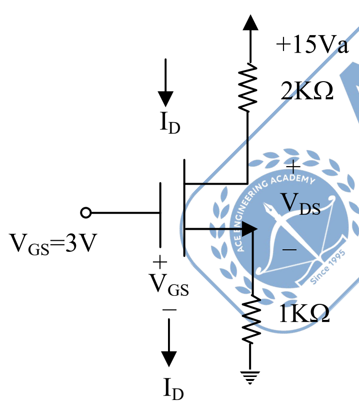


(i) Determine Q-point of the circuit by assuming maximum drain current I_{DSS} = 8mA and pinch-off voltage V_p = –4V.

(ii) Plot the transfer characteristics and DC load line, and indicate the Q-point. [20M]

Solution:

DC equivalent [Capacitor are replaced by open circuit]



$$V_G = \frac{15(50K)}{200K + 50K} = 3V$$

KVL,

$3 = V_{GS} + I_D(1K)$ …….(1) [Network equation]

$$I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]^2 \quad \text{[Device equation]}$$

The intersection of device equation over Network equation is the operating point

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$$I_D = 8m\left[1+\frac{V_{GS}}{4}\right]^2 \quad ………(2) \qquad \begin{bmatrix} Given \\ I_{DSS} = 8m \\ V_P = -4V \end{bmatrix}$$

Solve from (1) and (2)

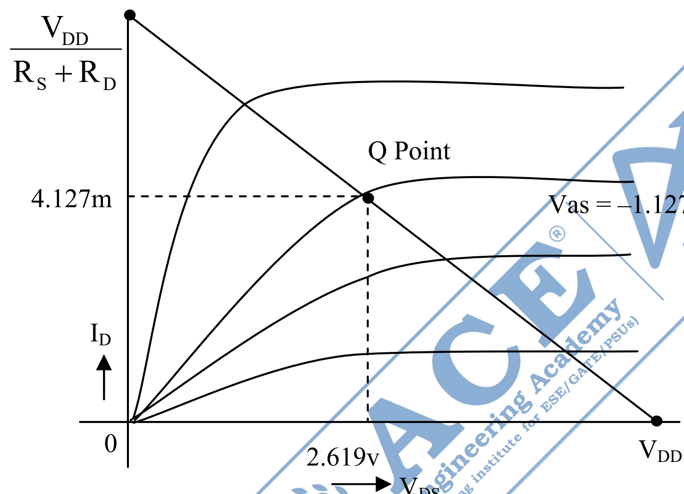
$$\frac{3-V_{GS}}{1K} = 8m\frac{[4+V_{GS}]^2}{16}$$

$$6 - 2V_{GS} = (4 + V_{GS})^2$$

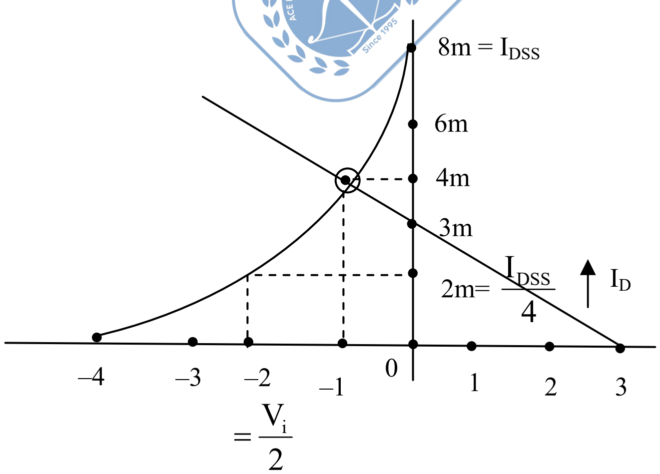
$$6 - 2V_{GS} = 16 + V_{GS}^2 + 8\,V_{GS}$$

$$V_{GS}^2 + 10V_{GS} + 10 = 0 \rightarrow V_{GS} = -1.127\,,\,-8.872$$

$$\therefore V_{GS} = -1.127V$$



Transfer characteristics



Equation-1

$$3 = V_{GS} + I_D(1K) \rightarrow I_D = 4.127m$$

Graphical

V_{GS}	I_D
0	3mA
3V	0

Apply KVL at output loop

$15 = I_D(2K) + V_{DS} + I_D(1K)$

$V_{DS} = 15 - I_D(3K)$

$= 15 - 4.127m\,(3K)$

$V_{DS} = 2.619V$

Q-Point

(V_{DS}, I_D)

$= (2.619, 4.127m)$

4[a] (i) In a factory, there are following two loads :

Lighting and heating load : 100 kW

Induction motor load : 1000 HP at 0.7 lagging power factor and 85% efficiency

The overall load power factor of the factory has to be raised to 0.95 lagging.

A 3-phase synchronous motor is installed for the above purpose. The motor is rated at 300 HP with 100% efficiency. Find the kVA rating of the synchronous motor. Also find the power factor of the synchronous motor. Given 1 HP (horsepower) = 746 watts. [12M]

Solution:

Load-1: $P_1 = 100$ kW

$\cos\phi_1 = 1$ [UPF $\rightarrow$ Heating load]

$$\text{So, } S_1 = \frac{P_1}{\cos\phi_1} = \frac{100\text{kW}}{1} = 100\text{kVA}$$

$Q_1 = S_1 \sin\phi_1 = 0$ kVAR

$S_1 = P_1 + jQ_1 = [100 + j0]$ kVA

Load-2:

Motor output = 1000 HP

$= 1000 \times 746 = 746000$ W

Motor P.F = 0.7 lag

% η = 0.85

So, motor input power $P_{in} = \dfrac{P_{out}}{\eta} = \dfrac{746000}{0.85}$

P_{in} = 877647 W = P_2

$\cos\phi_2$ = 0.7 (lag)

$$S_2 = \frac{P_2}{\text{Cos}\phi_2} = \frac{877647}{0.7} = 1253781 \quad \text{VAS}$$

$\theta_2 = S_2\sin\phi_2 = 1253781\left(\sqrt{1-(0.7)^2}\right)$

= 895378 VAR's

$S_2 = P_2 + jQ_2$ = [877.647 + j895.378] kVA

$$S = S_1 + S_2 = [100 + j0] + [877.647 + j895.378]\text{kVA}$$

= [977.647 + j895.378] kVA

= $1325.7\angle 42.485$

So, Total load power factor is

Cos 42.485 = 0.737 (lag)

Now Required P.F = 0.95 (lag)

$\theta_{SM} = P[\tan\phi_1 - \tan\phi_2]$

= 977647 [tan 42.485° – tan 18.195°]

($\because$ cos ϕ_2 = 0.95 $\Rightarrow \phi_2 = \cos^{-1}$[0.95] = 18.195°

= 977647 [0.916 – 0.329]

θ_{SM} = 574835.13 VAR's

Reactive power that should be supplied by Synchronous motor [Over-excited case] [Leading VAR's]

So, % η = 100% for synchronous motor

So, $P_{i(SM)} = P_{D(SM)}$

= 300 × 746 = 223800 W

$S_{T(SM)} = P_T + Q_{SM}$

= [223800 + j574835.13] VAR's

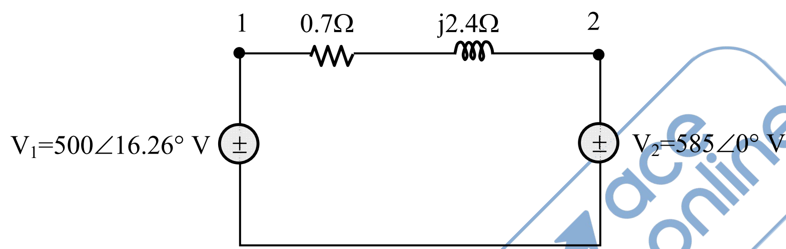
= 616864.55 $\angle$68.727°

So, kVA rating of synchronous motor is 615.973 kVA

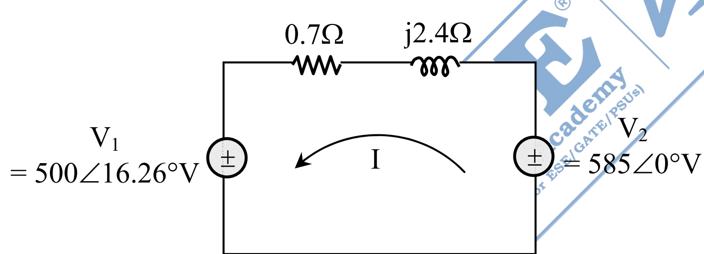
Power factor = $\dfrac{P_T}{S_T} = \dfrac{223800}{\sqrt{(223800)^2 + (574835.13)^2}}$

(or) cos 68.695° = 0.363 (Leading)

4[a] (ii) Two single-phase ideal voltage sources are connected by a line of impedance of (0.7+ j2.4) ohms as shown in the figure below. Given $V_1 = 500\angle 16.26°$ volts and $V_2 = 585\angle 0°$ volts. Find the complex power for each source and determine whether they are delivering or receiving real and reactive power. Also find the real and reactive power losses in the line : [8M]



Solution:



$$I = \frac{\bar{V}_2 - \bar{V}_1}{Z} = \frac{(585\angle 0°) - (585\angle 16.26°)}{0.7 + j2.4}$$

$$I = \frac{585 - [480 + j140]}{0.7 + j2.4}$$

$$I = \frac{105 - j140}{0.7 + j2.4} = [-42 - j56]$$

$$\bar{I} = 70\angle -126.86°\text{A}$$

For source V_2

Complex power = $V_2.I^*$ = [585∠0°] [70 ∠+126.86°]

= 40950∠+126.86°

= [–24564 + j32764] VAS

For source V_1

Complex power = V_1 I* [500∠16.26°] [70∠+126.86°]

= 35000∠143.12

= [–27996 + j21006]

Now for Transmission line

$P_{Loss} = |I|^2.R = |70|^2 (0.7) = 3430$ W

$Q_{Loss} = |I|^2 X_L = |70|^2 [2.4] = 11760$ VAR's

Conclusion:

Source V_2

Delivers P = 27966 W

Delivers Q = 32764 VAR's [Lagging]

Source V_1

Absorb P = 24564 W

Absorb Q = 21004 VAR's [Lagging]

4[b] A priority encoder truth table is given below:

Inputs				Outputs		
I_0	I_1	I_2	I_3	x	y	z
1	×	×	×	0	0	1
0	1	×	×	0	1	1
0	0	1	×	1	0	1
0	0	0	1	1	1	1
0	0	0	0	×	×	0

Obtain the minimized Boolean expression for x,y and z output. Design a combinational circuit for the minimized Boolean expressions of x, y and z. Consider that x is don't care. [20M]

Solution:

I_0	I_1	I_2	I_3	x	y	z
1	×	×	×	0	0	1
0	1	×	×	0	1	1
0	0	1	×	1	0	1
0	0	0	1	1	1	1
0	0	0	0	×	×	0

$x = \sum n(1, 2, 3) + d(0)$

$y = \sum m(1, 4, 5, 6, 7,) + d(0)$

$z = \sum m(1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 15)$

I_0I_1 \ I_2I_3	00	01	11	10
00	×	1	1	1
01				
11				
10				

$x = \bar{I}_0\bar{I}_1$

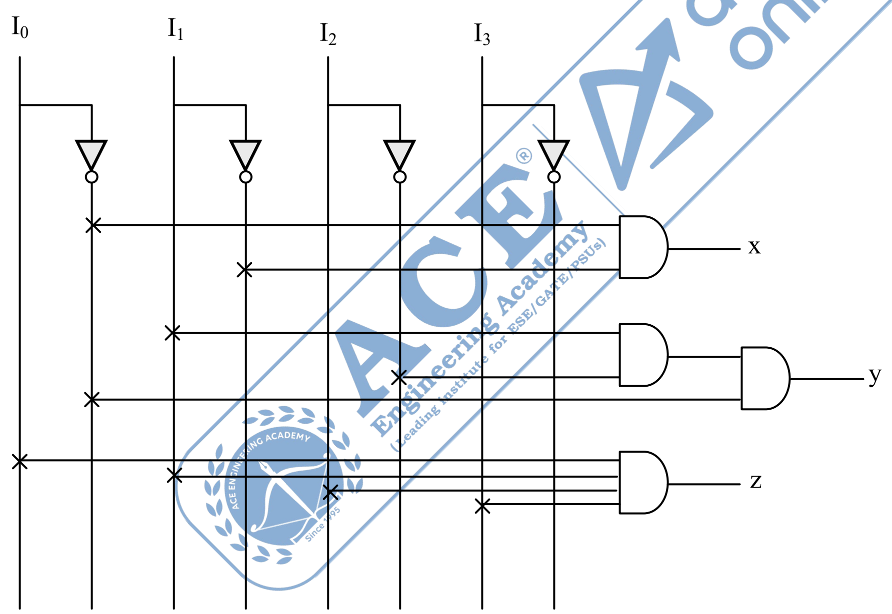
I_0I_1 \ I_2I_3	00	01	11	10
00	×	1		
01	1	1	1	1
11				
10				

$y = \bar{I}_0 I_1 + \bar{I}_0 \bar{I}_2$

$= \bar{I}_0 \left(I_1 + \bar{I}_2 \right)$

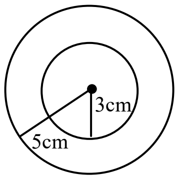
I_0I_1 \ I_2I_3	00	01	11	10
00		1	1	1
01	1	1	1	1
11	1	1	1	1
10	1	1	1	

$z = I_0 + I_1 + I_2 + I_3$



4[c] (i) A uniform volume charge density of 0.8 $\mu C/m^3$ is present throughout the spherical shell extending from r = 3 cm to r = 5 cm. If the volume charge density is zero elsewhere, find the total charge present throughout the shell. If the half of the total charge is located in the region where the radius varies as 3cm < r < r_1, find the value of r_1 in cm. [10M]

Solution:



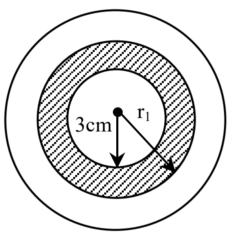
$\rho_v = 0.8\ \mu C/m^3$

$$Q = 0.8\times10^{-6}\left[\frac{4}{3}\pi\left(5\times10^{-3}\right)^3 - \frac{4}{3}\pi\left(3\times10^{-3}\right)^3\right]$$

$$Q = 0.8\times10^{-6}\times\frac{4}{3}\pi(12J-27)\times10^{-6}$$

$$Q = 328.4\times10^{-12}\ C$$

For Half REGION:



$$0.8\times10^{-6}\left[\frac{4}{3}\pi r_1^3 - \frac{4}{3}\pi\left(3\times10^{-2}\right)^3\right]$$

$$= \frac{1}{2}\times328.4\times10^{-12}$$

$$\frac{4\pi}{3}r_1^3 - \frac{4\pi}{3}\times9\times10^{-6} = 205\times10^{-6}$$

$$r_1^3 - 9\times10^{-6} = 205\times10^{-6}\times\frac{3}{4\pi}$$

$$r_1^3 = 205\times10^{-6}\times\frac{3}{4\pi} + 9\times10^{-6}$$

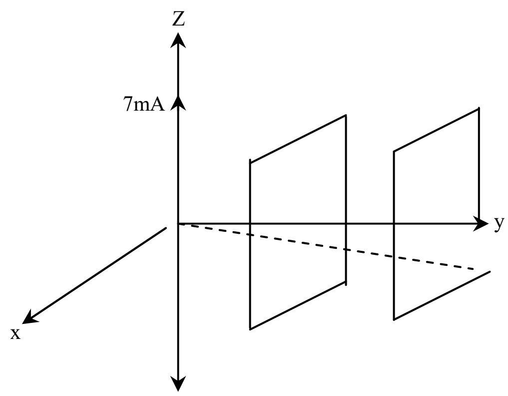
$$r_1^3 = 57.9\times10^{-6}$$

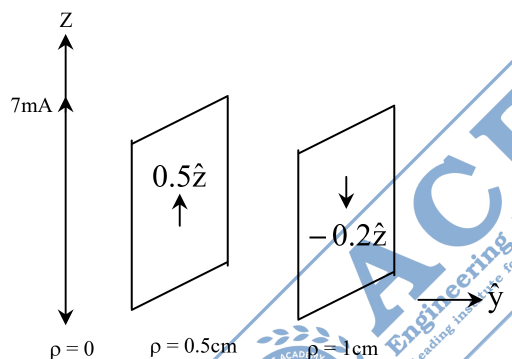
$$r_1 = 3.86\times10^{-2}\ m$$

$$r_1 = 3.86\ cm$$

4[c] (ii) A current filament on the z-axis carries a current of 7mA in the a_z direction and current sheets of $0.5a_z$ and $-0.2\ A_z$ A/m are located at $\rho = 1$ cm and $\rho = 0.5$ cm respectively. What is the value of H at $\rho = 4$cm? What value of current sheet should be located at $\rho = 4$ cm so that H = 0 for all $\rho > 4$ cm? Given, H: magnetic field intensity; ρ : radius variable of cylindrical coordinates. [10M]

Solution:





At $\rho = 4$cm:

$$\overline{H} = \frac{7\times10^{-3}}{2\pi\times4\times10^{-2}}(-\hat{x}) + \frac{0.5}{2}(-\hat{x}) + \frac{0.2}{2}(+\hat{x})$$

$$\overline{H} = \frac{7\times10^{-1}}{2\pi\times4}(-\hat{x}) - 0.15\hat{x}$$

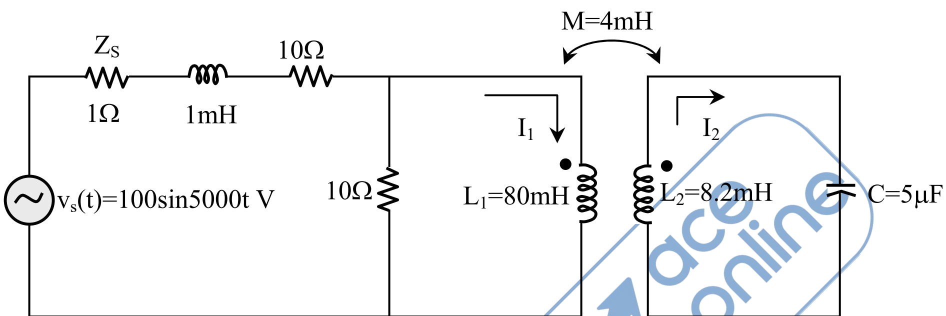
$$\overline{H} = -[0.27 + 0.15]\hat{x} = -(0.42)\hat{x}$$

And current sheet must be $-0.84\hat{z}$ so that $\overline{H}$ will be zero $\rho > 4$.

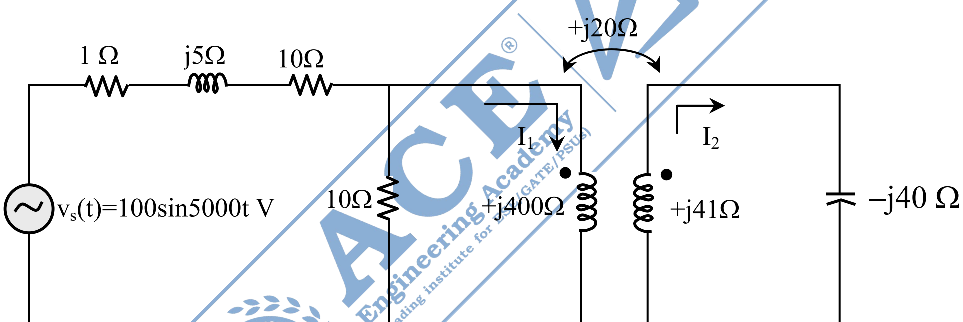
SECTION – B

5[a] For the circuit shown in the figure below, the two magnetically coupled coils have mutual inductance M = 4 mH. The self-inductances are L_1 = 80 mH and L_2 = 8.2 mH respectively. The source voltage is $V_s(t)$ = 100 sin5000t volts with a source resistance of 1Ω and inductance of 1mH. Find the power delivered by the source and the corresponding source power factor when the connected load with the second coil is a capacitor C of 5μF as shown in the figure:

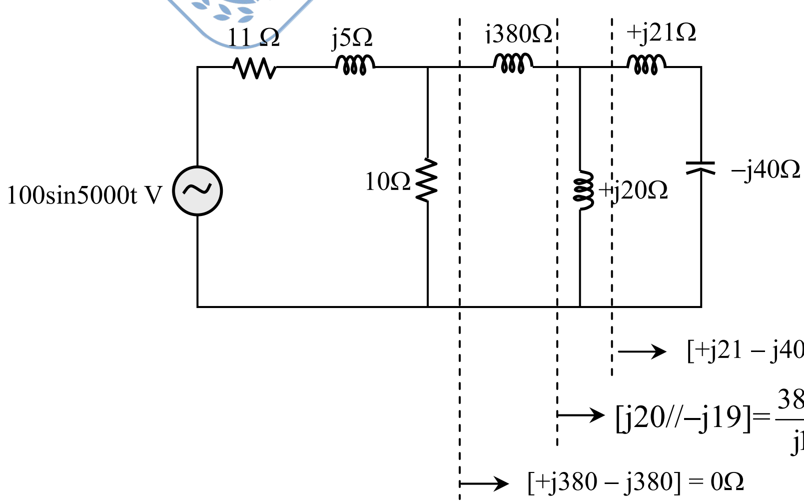
[12M]



Solution:



Using T-model

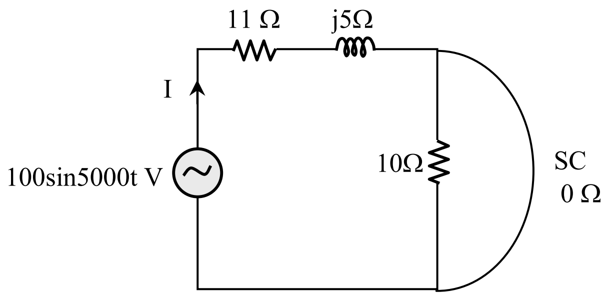


$\rightarrow$ [+j21 – j40] = –j19Ω

$\rightarrow$ $[j20//-j19] = \frac{380}{j1} = -j380\Omega$

$\rightarrow$ [+j380 – j380] = 0Ω

So, finally Network reduces to



$$I = \frac{V}{Z} = \frac{100\sin 5000t}{[11 + j5]} = \frac{100\angle 0°}{12.08\angle 24.444}$$

$I = 8.276\angle -24.444°$ A

$I = 8.276\sin(500t - 24.444°)$ A

$$P = \frac{100}{\sqrt{2}} \times \frac{8.276}{\sqrt{2}} \cos 24.444 = 376.71 \text{ W}$$

$= 413.8\cos 24.44$

Power factor ⇒ $\cos\phi = \cos 24.444°$

$= 0.91$ (lag)

5[b] Given, $\mu = 3 \times 10^{-5}$ H/m, $\varepsilon = 1.2 \times 10^{-10}$ F/m and $\sigma = 0$ everywhere. If $H = 2\cos(10^{10}t - \beta x)\bar{a}_z$ A/m, use Maxwell's equations to obtain the expressions for B, D, E and β.

Given, μ : Permeability

ε : Permittivity

B : Flux density

H : Magnetic field intensity

E : Electric field intensity

D : Electric flux density

β : Phase constant **[12M]**

Solution:

$$\bar{B} = \mu\bar{H} = 3 \times 10^{-5} \times 2\cos(10^4 t - \beta x)\hat{z}$$

$$\bar{B} = 6 \times 10^{-5}\cos(10^{10} t - \beta x)\hat{z}$$

$$\nabla \times \bar{H} = \bar{J} + \frac{\partial \sigma}{\partial t} = \frac{\partial \bar{E}}{\partial t}$$

$$\begin{vmatrix} \hat{x} & \hat{y} & \hat{z} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ 0 & 0 & 2\cos(10^{10}t-\beta x) \end{vmatrix} = \varepsilon\frac{\partial \bar{E}}{\partial t}$$

$$\Rightarrow \hat{y} + 2\beta\sin(10^{10}t-\beta x) = \varepsilon\frac{\partial E_y}{\partial t}$$

$$dE_y = \frac{2\beta}{\varepsilon}\sin(10^{10}t-\beta x)dt$$

$$E_y = \frac{2\beta}{\varepsilon}\left[-\frac{\cos(10^{10}t-\beta x)}{10^{10}}\right]$$

$$E_y = \frac{2\times\beta}{1.2\times10^{-10}}\left[-\cos(10^{10}t-\beta x)\hat{y}\right]$$

$$E_y = -\frac{2\times\beta}{1.2\times10^{-10}\times10^{10}}\cos(10^{10}t-\beta x)$$

$$E_y = -\frac{2\times\beta}{1.2}\cos(10^{10}t-\beta x)\hat{y}$$

$$\bar{D} = \varepsilon\bar{E}$$

$$\bar{D} = 1.2\times10^{-10}\times\left(-\frac{2\beta}{1.2}\cos(10^{10}t-\beta x)\hat{y}\right)$$

$$= -2\beta\times10^{-10}\cos(10^{10}t-\beta x)\hat{y}$$

$$\beta = \omega\sqrt{\mu\varepsilon} = 10^{10}\sqrt{3\times10^{-5}\times1.2\times10^{-10}}$$

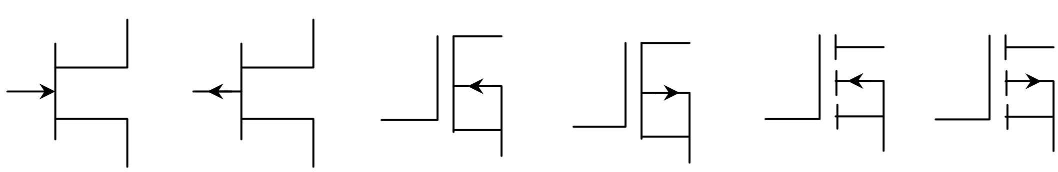
$$= 10^{10}\sqrt{3.6\times10^{-15}}$$

$$= 10^{10}\times1.89\times3.16\times10^{-8}$$

$$\beta = 5.9767\times100$$

$$\beta = 597.67 \text{ rad/m}$$

5[c] Identify the names of the following electronic devices, mark their terminals and plot their transfer characteristics: [12M]



(i) (ii) (iii) (iv) (v) (vi)

Solution:

(i) N-Channel JFET

Terminals:

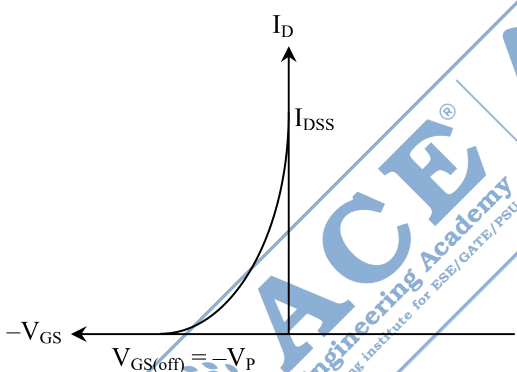
- Gate (G) – Arrow pointing toward channel
- Drain (D) – Upper terminal
- Source (S) – Lower terminal

Transfer characteristics:

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2$$

- I_D maximum at $V_{GS} = 0$, goes to zero at pinch-off V_P (negative).

Transfer characteristics: Plot of Drain Current (I_D) versus Gate-Source Voltage (V_{GS}) for a constant Drain-Source Voltage (V_{DS}). For an N-JFET, as V_{GS} becomes more negative (beyond pinch-off voltage V_P), I_D decreases, eventually reaching zero (cutoff).



(ii) **P-Channel JFET**

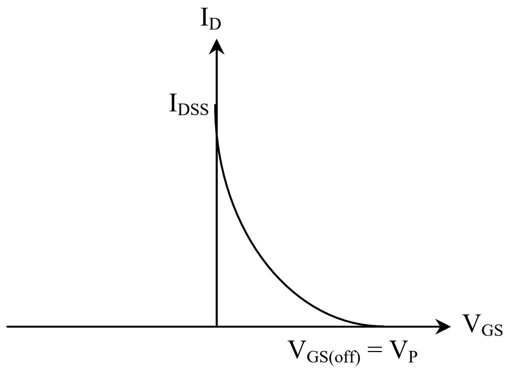
Terminals:

- Gate (G) – Arrow pointing away from channel
- Drain (D) – Upper terminal
- Source (S) – Lower terminal.

Transfer characteristic:

- Same equation as N-JFET but V_P is positive and V_{GS} polarity reversed.

Transfer Characteristics: Plot of Drain Current (I_D) versus Gate-Source Voltage (V_{GS}) for a constant Drain-Source Voltage (V_{DS}). For a P-JFET, as V_{GS} becomes more positive (beyond pinch-off voltage V_P), I_D decreases, eventually reaching zero (cutoff).



(iii) N-Channel Depletion-Type MOSFET

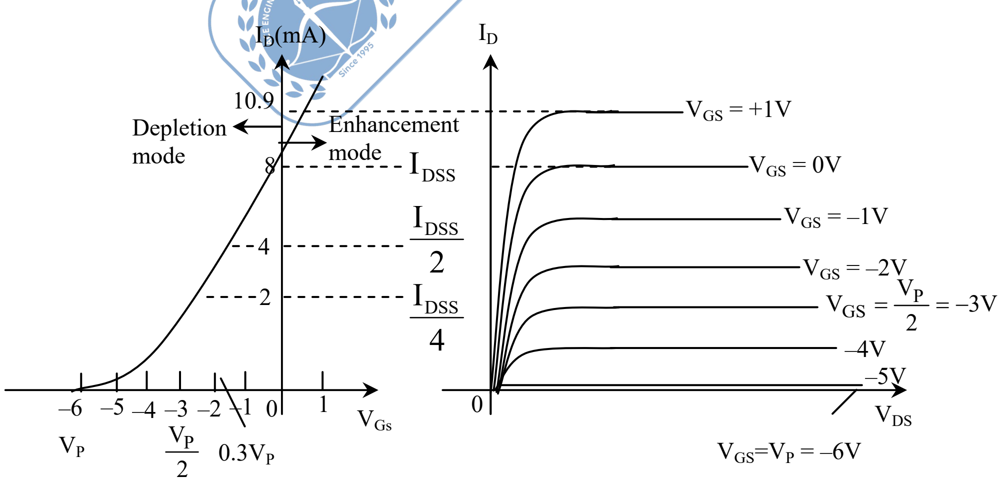
Terminals:

- Gate (G) – Arrow point toward channel
- Drain (D) – Upper terminal
- Source (S) – Lower terminal

Transfer Characteristics:

- Can conduct even at $V_{GS} = 0$
- I_D decreases for negative V_{GS}, increases for positive V_{GS}
- Graph is symmetric around $V_{GS} = 0$.

Transfer Characteristics: Plot of Drain Current (I_D) versus Gate-Source Voltage (V_{GS}) for a constant Drain-Source Voltage (V_{DS}). N-DMOSFETs conduct even with $V_{GS} = 0$, and I_D decreases as V_{GS} becomes more negative, eventually cutting off.



Drain and Transfer Characteristics for an n-channel depletion-type MOSFET

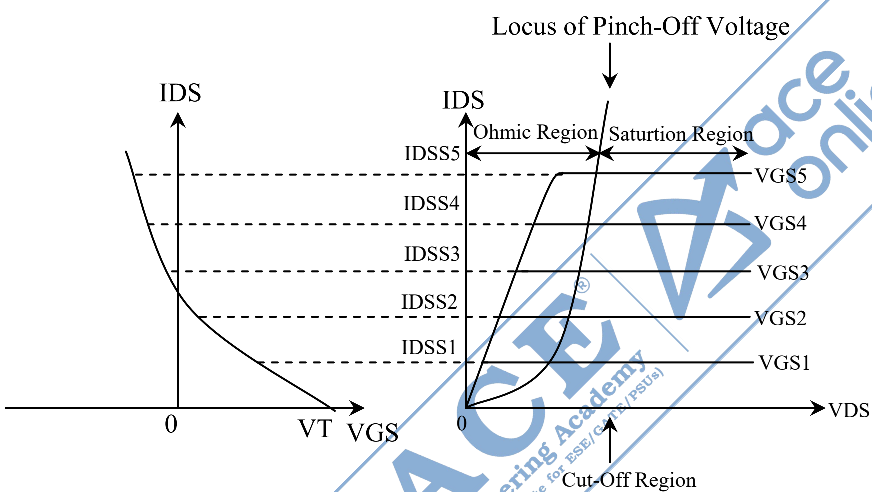
(iv) P-Channel Depletion-mode MOSFET (P-DMOSFET)

- Name: P-Channel Depletion-mode Metal-Oxide-Semiconductor Field-Effect Transistor (P-DMOSFET).

Terminals:

- Gate (G): The terminal parallel to the channel, insulated from it.
- Drain (D): The upper terminal connected to the channel (solid line).
- Source (S): The lower terminal connected to the channel (solid line), with an outward-pointing arrow (or body diode arrow pointing from drain to source).

Transfer Characteristics: Plot of Drain Current (I_D) versus Gate-Source Voltage (V_{GS}) for a constant Drain-Source Voltage (V_{DS}). P-DMOSFETs conduct even with V_{GS} = 0, and I_D decreases as V_{GS} becomes more positive, eventually cutting off.



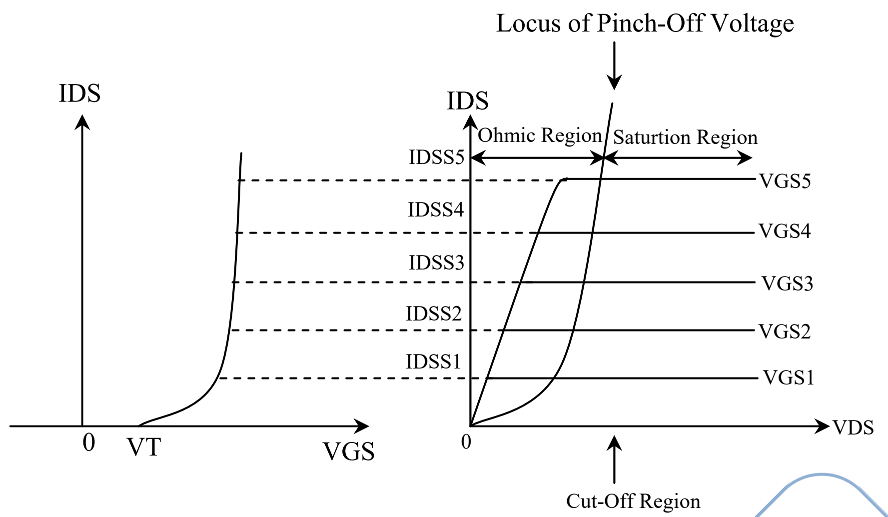
(v) N-Channel Enhancement-mode MOSFET (N-EMOSFET)

- Name: N-Channel Enhancement-mode Metal-Oxide-Semiconductor Field-Effect Transistor (N-EMOSFET).

  Terminals:

- Gate (G): The terminal parallel to the channel, insulated from it.
- Drain (D): The upper terminal, connected to the broken channel line.
- Source (S): The lower terminal connected to the broken channel line, with an inward-pointing arrow (or body diode arrow pointing from source to drain).

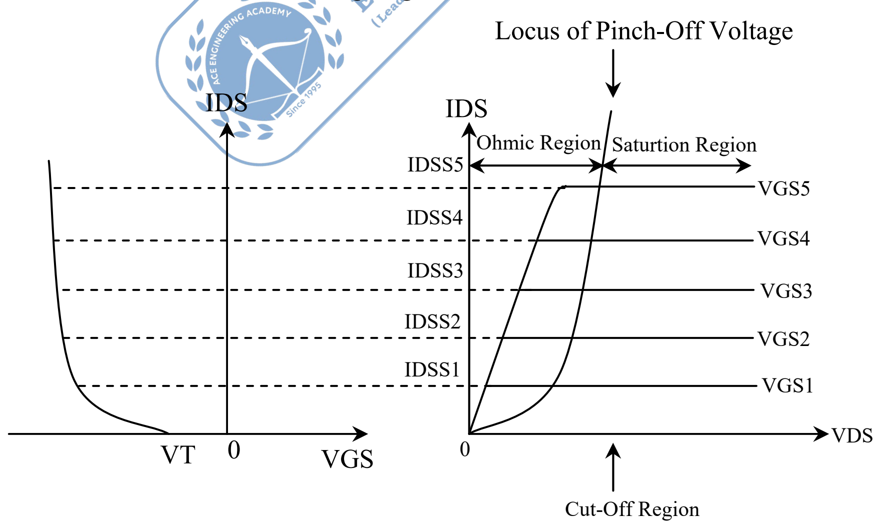
Transfer Characteristics: Plot of Drain Current (I_D) versus Gate-Source Voltage (V_{GS}) for a constant Drain-Source Voltage (V_{DS}). N-EMOSFETs start conducting only when V_{GS} exceeds a positive threshold voltage (V_{TH}), and I_D increases with increasing positive V_{GS}.



(vi) P-Channel Enhancement-mode MOSFET (P-EMOSFET)

- Name: P-Channel Enhancement-mode Metal-Oxide-Semiconductor Field-Effect Transistor (P-EMOSFET). Terminals:
- Gate (G): The terminal parallel to the channel, insulated from it.
- Drain (D): The upper terminal, connected to the broken channel line.
- Source (S): The lower terminal connected to the broken channel line, with an outward-pointing arrow (or body diode arrow pointing from drain to source).

Transfer Characteristics: Plot of Drain Current (I_D) versus Gate-Source Voltage (V_{GS}) for a constant Drain-Source Voltage (V_{DS}). P-EMOSFETs start conducting only when V_{GS} falls below a negative threshold voltage (V_{TH}), and I_D decreases with decreasing negative V_{GS}.



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500+ SELECTIONS

CE : 434 | EE : 61 | ME : 20

5[d] If the probability of a bad reaction from certain injection is 0.001, determine the chance that out of 2000 persons, more than two will get a bad reaction. [12M]

Solution:

Given n = 2000, P = 0.001

$\lambda = np = 2000 \times 0.001$

$\lambda = 2$

Let x = number of persons will get bad reaction

$P(x > 2) = 1 - P(x \leq 2)$

$= 1 - P(x = 0) - P(x = 1) - P(x = 2)$

$= 1 - e^{-\lambda} - \lambda\, e^{-\lambda} - \dfrac{\lambda^2 e^{-\lambda}}{2!}$

$= 1 - e^{-2} - 2e^{-2} - \dfrac{4e^{-2}}{2}$

$= 1 - e^{-2} - 2e^{-2} - 2e^{-2}$

$P(x > 2) = 1 - 5e^{-2}$

5[e] (i) Determine the possible base of the number in the operation mentioned below:

23 + 44 + 14 + 32 = 223

(ii) Find the number of divisors and sum of divisors of 4900. [6+6=12M]

Solution:

(i) 23 + 44 + 14 + 32 = 223

Assuming base is b

$2b + 3 + 4b + 4 + b + 4 + 3b + 2 = 2b^2 + 2b + 3$

$2b^2 - 8b - 10 = 0$

$b^2 - 4b - 5 = 0$

$b^2 - 5b + b - 5 = 0$

$b(b - 5) + 1(b - 5) = 0$

$(b + 1)(b - 5) = 0$

$b = -1$ (or) 5

So, base is 5

(ii) If $N = a^p \times b^q \times c^r$……. where a, b, c,……. are distinct prime bases and p,q,r,…….. are integers then no. of divisors of N = (p + 1) (q + 1) (r + 1)………..

Sum of divisors of N is $\frac{(a^{p+1}-1)(b^{q+1}-1)(c^{r+1}-1)\ldots\ldots}{(a-1)(b-1)(c-1)\ldots\ldots\ldots}$

$N = 4900 = 2^1 \times 5^2 \times 7^2$

No. of divisors = (2 + 1) (2 + 1) (2 + 1) = 27

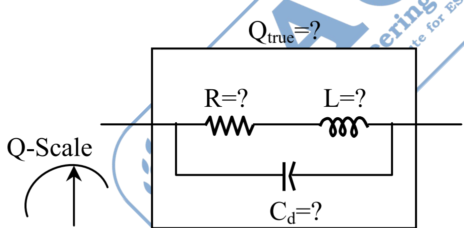
Sum of divisors = $\frac{(2^3-1)(5^3-1)(7^3-1)}{(2-1)(5-1)(7-1)} = \frac{7\times124\times342}{1\times4\times6} = 12369$

6[a] (i) Explain the principle on which a Q-meter works. Describe briefly the direct connection, series connection and parallel connection of using the Q-meter. Also mention for which types of loads, these connections are used. [12M]

Solution:

* Q-meter stands for Quality factor meter
* Q-meter is basically a Series RLC circuit
* Voltage magnification property exhibited by Series RLC circuit at resonance is used in the design of Q-meter
* There are 3-types of connections of Q-meter

(1) Direct connection (Direct measurement mode) used for measurement of various Electrical properties of an unknown coil (test coil)



Q_{true} = True Q of coil

L = Self Inductance of coil

C_d = Distributed capacitance of coil (Self capacitance of coil)

R = Resistance of coil

(2) Series connection used for measurement of unknown low impedance (Low R, Low L, High C)

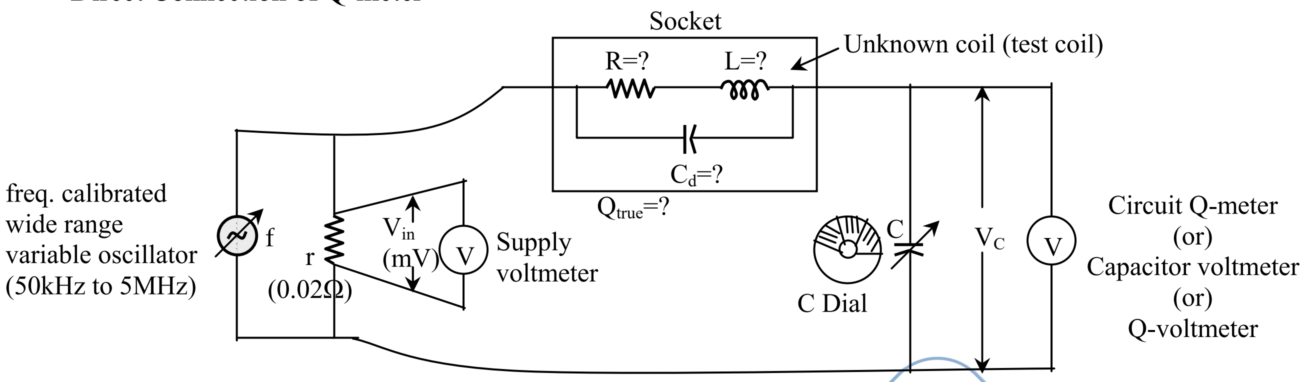
(3) Shunt connection (Parallel connection) used for measurement of unknown High impedance (High R, High L, Low C)

* A series RLC circuit behaves as a voltage magnifier at Resonance i.e., V_{in} gets magnified by Q-times

This is used as design idea behind Q-meter

$$Q = \frac{V_{C\max}}{V_{in}}$$

* Direct Connection of Q-meter



$$Q_{ind} = \frac{\omega L}{R + r} \text{(or)} \frac{1}{\omega(C + C_d)(R + r)}$$

* In above circuit

f = frequency of oscillator

r = insertion resistance (shunt resistance placed across oscillator to protect supply voltmeter)

V_{in} = Oscillatory input voltage injected into circuit

C = tuning capacitor or resonating capacitor

V_C = Voltage across capacitor

*** Steps for measuring Q_{true} of Coil**

(1) Insert unknown coil into socket of Q-meter

(2) Resonate it

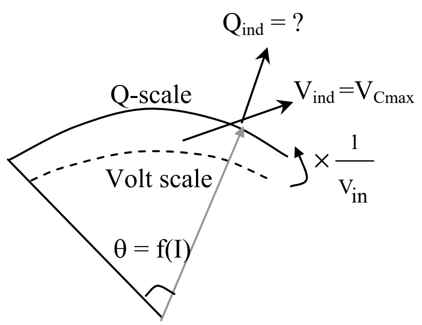
Fix input [V_{in}, f] & vary C till capacitor voltmeter indicates max voltage

[Ex: 500mV, 100kHz]

(3) Note down readings: f, V_{in}, C, $V_{C\max}$

(4) Manufacturer calibrates voltage scale of capacitor V_R into Q-scale using the formula

$$Q = \frac{V_{C\max}}{V_{in}}$$



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Selected in: MES
& many more..
Total 150+ Selections
CE-98
EE-29
ME-24

Q_{ind} = Total circuit Q, which is less than true Q of coil

* Indicate Q (measured Q or observed Q) is circuit Q

$$Q_{ind} < Q_{true}$$

$$\leftarrow \text{Error} \rightarrow$$

* Error = $Q_{ind} - Q_{true}$

* % Error = $\dfrac{Q_{ind} - Q_{true}}{Q_{true}} \times 100\%$

* For correction $\Rightarrow \dfrac{Q_{true}}{Q_{ind}} = K$

6[a] (ii) A power transformer was tested to determine losses and efficiency. The input power was measured as 3650 watts and the delivered output power was 3385 watts, with each reading in doubt by ±10 watts. Calculate (1) the percentage uncertainty in losses of the transformer and (2) the percentage uncertainty in the efficiency of the transformer, as determined by the difference in input and output power readings. [8M]

Solution:

I/P = 3650 watts, doubt = ± 10 watts

O/P = 3385 watts, doubt = ± 10 watts

Loss = I/P – O/P

Uncertainty in W = $\sqrt{(1\times 10)^2 + (1\times 10)^2} = \sqrt{200} = 10\sqrt{2} = 14.14 \text{ W}$

$\therefore$ Loss = $265 \pm 10\sqrt{2} = 265 \pm 5.33\%$

Uncertainty in loss = $10\sqrt{2}$ W = 5.33%

6[b] (i) An electric field in x-y plane is given by f(x, y) =$3x^2y - y^3$. Find the stream function g(x, y) such that the complex potential w = f +ig is an analytic function. [10M]

Solution:

Given w = f + ig

where $f(x, y) = 3x^2y - y^3$

$f_x = 6xy$, $f_y = 3x^2 - 3y^2$

By the definition of total derivative

$dg = g_x dx + g_y dy$

$dg = -f_y dx + f_x dy$

$dg = (3y^2 - 3x^2)dx + 6xydy$

$\int dg = \int(3y^2 - 3x^2)dx + \int 6xy\, dy$

y constant

(terms do not contain x)

$g = 3xy^2 - x^3 + c$

6[b] (ii) Find the mass of the surface of the cone $z = 2 + \sqrt{z^2 + y^2}$, $2 \le z \le 7$ in the first octant, if the density $\rho(x, y, z)$ at any point of the surface is proportional to its distance from x-y plane.

[10M]

Solution:

$z = 2 + \sqrt{x^2 + y^2}$, $2 \le z \le 7$

The density $\rho(x,y,z)$ at any point is proportional to its distance from xy plane i.e., $\rho(x,y,z) = kz$

$$\text{Mass } M = \iint_S \rho\sqrt{1 + \left(\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)^2}\, dxdy$$

$$\frac{\partial z}{\partial x} = \frac{x}{\sqrt{x^2 + y^2}}, \quad \frac{\partial z}{\partial y} = \frac{y}{\sqrt{x^2 + y^2}}$$

$$1 + \left(\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)^2 = 1 + \frac{x^2}{x^2 + y^2} + \frac{y^2}{x^2 + y^2} = 2$$

$z = 2 + \sqrt{x^2 + y^2}$

$z = 2 + r$ (in polar form)

If $z = 2$ then $r = 0$

If $z = 7$ then $r = 5$

$$\text{Mass } M = \iint Kz.\sqrt{2}dxdy$$

$$= K\sqrt{2}\iint(2 + r)dxdy$$

Converting to polar coordinates

r varies from 0 to 5

θ varies from 0 to $\pi/2$

$dxdy = r\, dr\, d\theta$

$$\text{Mass} = K\sqrt{2}\int_{r=0}^{5}\int_{\theta=0}^{\pi/2}(2+r).r\,dr d\theta$$

$$= K\sqrt{2}\int_{r=0}^{5}\int_{\theta=0}^{\pi/2}(2r+r^2)dr d\theta$$

$$= K\sqrt{2}\int_{0}^{\pi/2}\left(r^2+\frac{r^3}{3}\right)_0^5 d\theta$$

$$= K\sqrt{2}\int_{0}^{\pi/2}\left(25+\frac{125}{3}\right)d\theta$$

$$= K\sqrt{2}.\frac{200}{3}.(\theta)_0^{\pi/2}$$

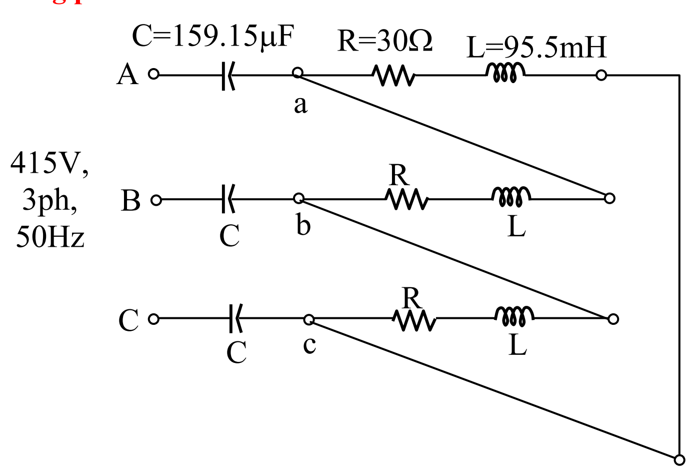
$$\text{Mass} = K\sqrt{2}.\frac{200}{3}.\frac{\pi}{2}$$

$$= \frac{200}{3\sqrt{2}}.\pi$$

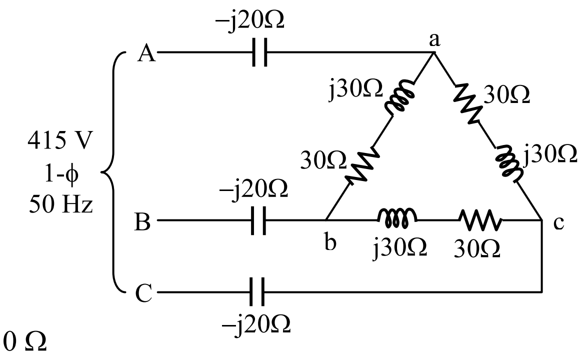
$$= \frac{100.\sqrt{2}.\sqrt{2}}{3\sqrt{2}}\pi$$

$$\text{Mass} = \frac{100\sqrt{2}}{3}\pi$$

6[c] A balanced load is shown in the figure below, where R= 30 Ω, C =159.15 μF and L = 95.5 mH. The r.m.s. value of the balanced input supply voltage is 415 V (L-L), 50 Hz. Now find (i) the magnitude of the voltage V_{ab}, (ii) the phase of V_{ab} with respect to V_{AB} and (iii) the total power supplied to the load and corresponding power factor calculated from source side: [20M]



Solution:

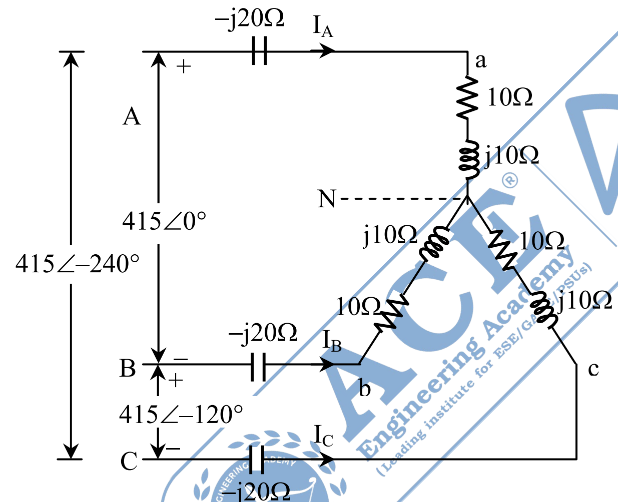


R = 30 Ω

$X_L = +j2\pi(50)(95.5 \times 10^{-3}) = j30\ \Omega$

$X_C = \dfrac{-j}{2\pi(50)(159.5\times10^{-6})} = -j20\ \Omega$

Convert into star



$$I_A = \frac{V_{AN}}{Z_A} = \frac{\frac{415}{\sqrt{3}}\angle -30}{[-j20+10+j10]} = \frac{240\angle -30°}{[10-j10]} = \frac{240\angle -30°}{10\sqrt{2}\angle -45°}$$

$I_A = 16.97\angle{+15°}$ A

$I_B = 16.97\angle{-105°}$ A

$I_C = 16.97\angle{-225°}$ A

Now, $V_{aN} = I_A[10 + j10] = [16.97\angle{+15°}][10\sqrt{2}\ \angle 45°]$

$V_{aN} = 240\angle{+60°}$ V

$V_{bN} = 240\angle{-60°}$ V

$V_{cN} = 240\angle{-180°}$ V

Then $V_{ab} = V_{aN} - V_{bN} = [240\angle{+60°}] - [240\angle{-60°}]$

$= 415\angle{+90°}$ V

(i) $|V_{ab}| = 415$ volts

(ii) Phase of V_{ab} with respect to V_{AB}

$\phi = 90°$ (leading)

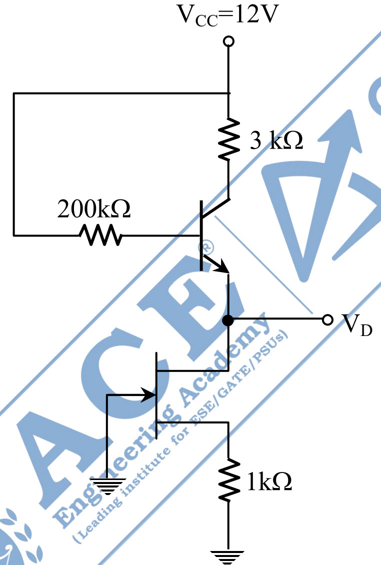
(iii) $P_T = \sqrt{3}V_L I_L \cos\phi = \sqrt{3}[415][16.97]\cos 45° = 8625.32$ W

Power factor, cos45° = 0.707 leading.

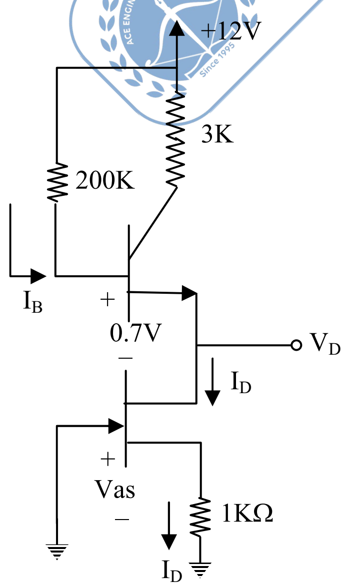
7[a] Consider the silicon transistor circuit shown in the figure below. The data pertaining to transistors are as follows:

(i) $\beta = 100$, (ii) Maximum drain current $I_{DSS} = 6$mA, (iii) Pinch-off voltage $V_p = -2$V.

Determine the voltage V_D. **[20M]**



Solution:



$I_{DSS} = 6$mA
VP = –2V
$\beta = 100$

Given

$$I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]^2$$

$$I_D = 6m\left[1 + \frac{V_{GS}}{2}\right]^2 \quad \ldots\ldots(1)$$

KVL $V_{GS} + I_D(1K) = 0$

$$\rightarrow I_D = -\frac{V_{GS}}{1K} \quad \ldots\ldots\ldots(2)$$

Sub (2) in (1)

$$-\frac{V_{GS}}{1K} = 6m\frac{[2+V_{GS}]^2}{4}$$

$$I_D = I_E = 1.131\text{mA}$$

$$I_B = \frac{I_E}{1+\beta} = \frac{1.131m}{101}$$

KVL

$12 = I_B\,(200K) + 0.7 + V_D$

$$\rightarrow V_D = 12 - \frac{1.131m}{101}(200K) - 0.7$$

$V_D = 9.06V$

$-2V_{GS} = 3[4 + V_{GS}^2 + 4V_{GS}]$

$-V_{GS} = 12 + 3V_{GS}^2 + 12V_{GS}$

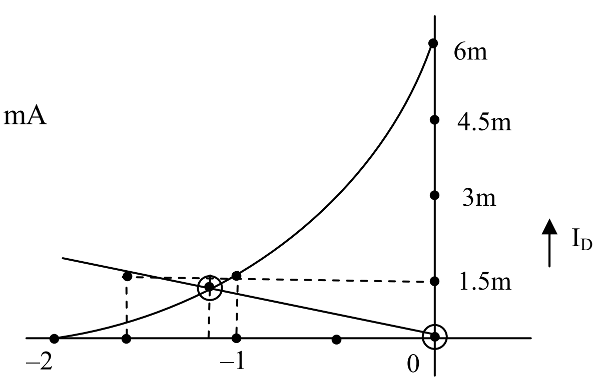
$3V_{GS}^2 + 14V_{GS} + 12 = 0$

$$V_{GS} = \frac{-14 \pm \sqrt{(14)^2 - 4(3)(12)}}{2(3)}$$

$= -14 \pm 7.2111$

$= -1.131V, -3.535V$

$\therefore V_{GS} = -1.131V \rightarrow I_D = +1.131\text{mA}$

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AIR 10 CE Adnan Quasain
& mamy more....

eq(2) If $V_{GS} = 0 \rightarrow I_D = 0$

If $I_D = 1.5m \rightarrow V_{GS} = -1.5V$.

7[b] A conducting wire has resistivity of $1.57\times10^{-8}\Omega$-m at room temperature. There are 5.85×10^{28} number of conducting electrons per m^3 for the material at room temperature. For an electric field of 1.1 V/cm along the wire, calculate the (i) drift velocity, (ii) relaxation time, (iii) mobility and (iv) mean free path for the conducting electrons in the material.

(Assume charge of electron = 1.609×10^{-19} C, mass of electron = 9.11×10^{-31} kg, velocity of electrons v = 3×10^8 m/s and isotropic scattering). [20M]

Solution:

Given data,

$\rho = 1.57 \times 10^{-8}\ \Omega$-m

$n = 5.85 \times 10^{28}\ e^-/m^3$

E = 1.1 V/cm

(1) Mobility of e^-

$$\rho = \frac{1}{ne\mu}$$

$$\mu = \frac{1}{\rho ne} = \frac{1}{1.57\times10^{-8}\times5.85\times10^{28}\times1.6\times10^{-19}} = 6.804\times10^{-3}\ m^2/V-S$$

(2) Drift velocity = $V_d = E \times \mu_e$

$$= \frac{1.1}{10^{-2}}\times6.804\times10^{-3} = 0.7484\ m/s$$

(3) Relaxation time = t

$$\mu_e = \frac{et}{m}$$

$$t = \frac{\mu_e.m}{e} = \frac{6.804\times10^{-3}\times9.1\times10^{-31}}{1.6\times10^{-19}} = 3.8\times10^{-14}\ sec$$

(4) Mean free path (λ)

$$\lambda = V \times t = 3 \times 10^8 \times 3.8 \times 10^{-14}$$

$$= 11.4 \times 10^{-6}\ m$$

7[c] (i) Differentiate between isolated I/O and memory-mapped I/O with their advantages and disadvantages [8M]

Solution:

Feature	Isolated I/O (Port-Mapped I/O)	Memory-Mapped I/O
Address Space	Has a separate I/O address space, distinct from main memory.	Uses the same address space for both memory and I/O devices.
Instruction Set	Requires special I/O instructions (IN, OUT in x86) to access devices.	Uses normal memory access instructions (LOAD, STORE, MOV) to communicate with devices.
Addressing	Devices have their own port addresses (I/O ports).	Devices are assigned specific memory addresses.
CPU Control Signals	Needs separate control signals for I/O read/write (IORead, IOWrite).	Uses the same memory read/write control signals as normal memory operations.
Speed	Slightly slower due to extra decoding logic for I/O space.	Potentially faster since it uses normal memory instructions.
Implementation	Easier to implement without interfering with memory.	More flexible but can reduce available memory address space.

Advantages and Disadvantages

Isolated I/O (Port-Mapped I/O)

Advantages

Separate address space → no reduction in main memory addresses.

Simpler to design for small systems where memory and I/O are clearly distinct.

Avoids accidental memory access conflicts.

Disadvantages

Requires special instructions (less programming flexibility).

CPU must support separate I/O instruction set.

Usually slower than memory-mapped I/O due to extra address decoding.

Memory-Mapped I/O

Advantages

No special I/O instructions → uses the same load/store instructions.

Can use normal CPU instructions for device registers (easier programming).

Enables direct access to device registers in high-level languages.

Potentially faster (no extra I/O decode stage).

Disadvantages

Shares address space with memory → reduces available memory addresses.

Risk of accidental overwriting of device registers if not protected.

Requires careful memory mapping to avoid conflicts.

7[c] (ii) Represent the following numbers and arithmetic operations given in the table: [12M]

Numbers/Operations	8 bit signed magnitude	1's complement (8 bit)	2's complement (8-bit)
+68			
–83			
(+68) + (–83)			
(–68)+(+83)			

Solution:

+ 68:

2 | 68
2 | 34 – 0
2 | 17 – 0
2 | 8 – 1
2 | 4 – 0
2 | 2 – 0
| 1 – 0

01000100 in signed magnetism represent

01000100 in 1's complement representation

01000100 in 2's complement representation

–83:

2 | 83
2 | 41 – 1
2 | 20 – 1
2 | 10 – 0
2 | 5 – 0
2 | 2 – 1
| 1 – 0

11010011 → in signed magnitude representation

01010011 → +83 in all

10101100 → –83 in 1's

10101101 → –83 in 2's

+68 + (–83) = –15

in signed magnitude representation 10001111

1's complement representation

  01000100
+ 10101100

+ 11110000

2's complement representation

  01000100
+ 10101101

+ 11110001

(–68) + (+83):

Signed magnitude representation

+ 15

00001111

1's complement representation

10111011
01010011

---

(1) 00001110
→ + 1

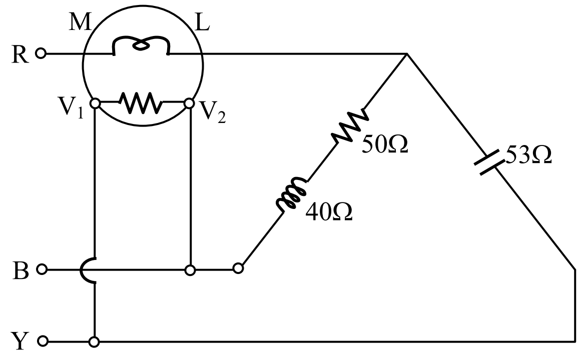
00001111

2's complement representation

10111100
01010011

00001111

8[a]



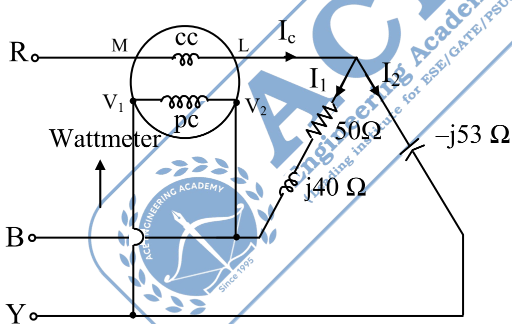
Find the reading of the wattmeter when the network shown is connected to a symmetrical 440 V, 3-phase supply. Neglect all losses in the instrument. The phase sequence is RYB. Also draw the phasor diagram of the network **[20M]**

Solution:

$V_{RY} = 440\angle 0°$

$V_{YB} = 440\angle -120°;$

$V_{BR} = 440\angle 120°$



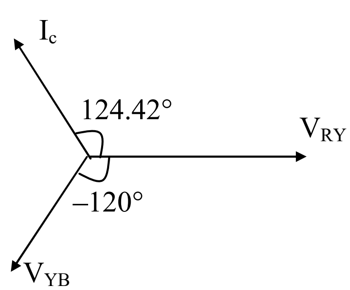
Current through current coil $I_c = I_1 + I_2$

$$= \frac{V_{RB}}{50 + j40} + \frac{V_{RY}}{-j53}$$

$$= \frac{-440\angle 120°}{64.03\angle 38.65} + \frac{440\angle 0°}{-j53}$$

$$= -6.871\angle 81.35 - 8.301\angle -90°$$

$$= 1.828\angle 124.42 A$$



Voltage across potential coil

$$= V_{YB} = 440\angle -120° A$$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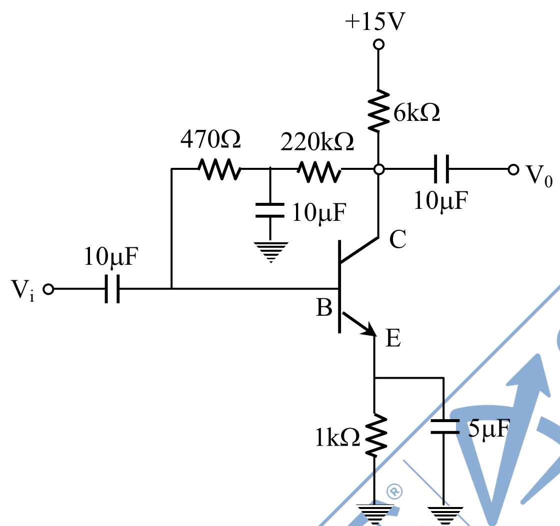
AIR 9 E&T T PIYUSH DAYANAND
AIR 9 EE ANMOL SINGH
AIR 9 ME KRISHNA KUMAR D
AIR 10 CE RAJESH BADUGU
AIR 10 E&T RAJVARDHAN SHARMA
AIR 10 ME AKSHAY VIDHATE
TOTAL 36 SELECTIONS IN TOP 10
CE: 09 | ME: 10 | EE: 08 | E&T: 09

Wattmeter reading $= V_{YB}.\ I_c \cos(V_{YB} \text{ and } I_c)$

$= 440 \times 1.828 \cos(244.42)$

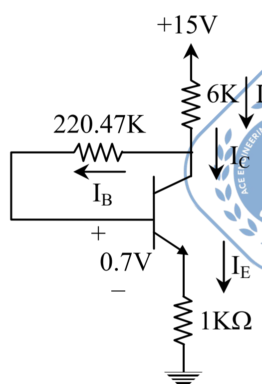
$= -347.28\text{W}$

8[b] Determine the collector voltage V_C of the silicon transistor circuit shown in the figure below, if (i) $\beta = 100$ and (ii) $\beta = 50$: [20M]



Solution:

DC equivalent [Capacitors are replaced by open circuit]



Apply KVL at I/P loop

$15 = I_E(6K) + I_B(220.47K) + 0.7 + I_E(1K)$

$\rightarrow 15 = I_E(7K) + 0.7 + \dfrac{I_E}{1+\beta}(220.47K)$

$$\left[\because I_B = \frac{I_E}{1+\beta}\right]$$

$$\therefore\ I_E = \frac{15-0.7}{7K + \frac{220.47K}{1+\beta}}$$

$V_C = 15 - I_E\,(6K)$

For $\beta = 100$

$$I_E = \frac{14.3}{7K + \frac{22.47K}{101}} = 1.5572\text{mA}$$

$\rightarrow V_C = 5.656$ V

For $\beta = 50$

$$I_E = \frac{14.3}{7K + \frac{220.47K}{51}} = 1.2629\text{mA}$$

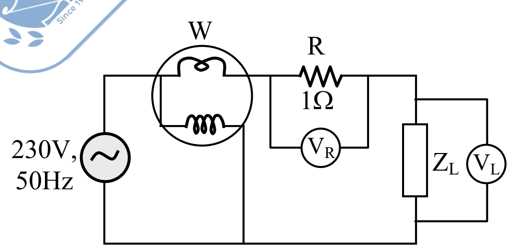
$\rightarrow V_C = 7.422$ V

8[c] Voltmeters are connected across the resistance R = 1 Ω and load impedance Z_L and wattmeter is connected at the input side of the circuit as shown in the figure below. The source voltage is 230 V, 50 Hz and the voltmeters read V_R = 10 V, V_L = 225 V

(i) Find the wattmeter reading, source current and input power factor with the same supply voltage and frequency.

(ii) Find the voltmeter and wattmeter readings when the supply frequency is changed to 60 Hz at same supply voltage of 230 V

(iii) Draw the phasor diagram of voltage and currents for (i) above [20M]



Solution:

(i) Given data, R = 1Ω, V_s = 230V, f_1 = 50 Hz

V_R = 10V, V_L = 225V

Source current, $I_s = \frac{V_R}{R} = \frac{10}{1} = 10\text{A}$

Load impedance magnitude, $|Z_L| = \frac{225}{10} = 22.5\Omega$

Let $Z_L = R_L + jX_L$

$$\therefore \sqrt{R_L^2 + X_L^2} = 22.5$$

$$\Rightarrow R_L^2 + X_L^2 = (22.5)^2 \ ......(1)$$

Total impedance across the load $|Z| = \frac{230}{10} = 23\Omega$

$$\Rightarrow |R + R_L + jX_L| = 23\Omega$$

$$(1 + R_L)^2 + (X_L)^2 = 23^2$$

$$1 + R_L^2 + 2R_L + (X_L)^2 = (23)^2$$

$$1 + 2R_L = (23)^2 - (22.5)^2 \qquad [\because \text{From (1)}]$$

$$\Rightarrow R_L = 10.875\Omega$$

Now, input power factor, $\cos\phi = \frac{R + R_L}{|Z|} = \frac{1 + 10.875}{23}$

$= 0.5163$ lag

Wattmeter reading $= V_s\, I_s \cos\phi$

$= 230 \times 10 \times 0.5163$

$= 1187.5$W

(ii) $f_2 = 60$ Hz, $X_L = \sqrt{(22.5)^2 - (10.875)^2} = 19.69\Omega$

We know that, $X_L \propto f$

$$X_{L2} = \frac{f_2}{f_1} \times X_L = \frac{60}{50} \times 19.69$$

$= 23.63\Omega$

Now, source current $I_s = \frac{230\angle 0°}{R + R_L + jX_{L_2}}$

$= 8.69\angle -63.31$

Now, input power factor $= \cos(63.31) = 0.4491$ lag

Wattmeter reading $= V_s\, I_s \cos\phi$

$= 230 \times 8.69 \times 0.4491$

$= 897.6$ W

Voltmeter readings:

$|V_R| = 8.69 \times 1 = 8.69V$

$|V_L| = (8.69\angle{-63.31}) \times (10.875 + j23.63)$

$= 226.05V$

(iii) Taking V_s (Source voltage as reference)

$Z_L = 10.87 + j19.69$

$Z_L = 22.49\angle 61.09°$

$V_L = I\angle{-\phi} \times Z\angle\theta$

$= I\angle{-68.91} \times Z\angle 61.09 = V_L\angle 2.174$