DEPARTMENT OF ELECTRONIC AND COMPUTER ENGINEERING
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

ELEC2400 ELECTRONIC CIRCUITS – FINAL EXAM

4:30pm – 7:30pm 18 May 2019 Tsang Shiu Tim Art Hall

Name: ____

Student No.: ______________________ **Seat No.:**____________

Questions	Maximum Scores	Scores
1	6	
2	8	
3	9	
4	6	
5	6	
6	9	
7	10	
8	11	
9	8	
10	8	
11	10	
12	9	
Total	**100**	

Equations for transient circuit analysis :

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

$$i(t) = I(\infty) + [I(0^+) - I(\infty)]e^{-t/\tau}$$

1. Answer **all** questions in the space provided.
2. This is a **closed book** examination. No additional sheet is allowed.
3. Only calculators approved by Hong Kong Examinations and Assessment Authority are allowed.
4. Show all your calculations clearly. No marks will be given for unjustified answers.

The HKUST Academic Honor Code

Honesty and integrity are central to the academic work of HKUST. Students of the University must observe and uphold the highest standards of academic integrity and honesty in all the work they do throughout their program of study.

As members of the University community, students have the responsibility to help maintain the academic reputation of HKUST in its academic endeavors.

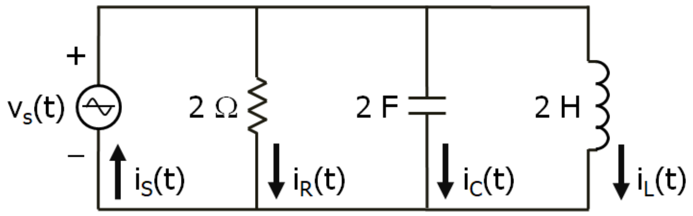
Sanctions will be imposed on students, if they are found to have violated the regulations governing academic integrity and honesty.

Declaration of Academic Integrity

I confirm that I have answered the questions using only materials specifically approved for use in this examination, that all the answers are my own work, and that I have not received any assistance during the examination.

Student's Signature: ______________________________

1. Given the source voltage $v_s(t) = -\sin\left(\frac{t}{2}\right)$ V.



(a) Find Z_R, Z_C and Z_L (the impedance of the resistor, capacitor and inductor).

From the given $v_s(t)$, we can see that $\omega = 0.5\ \text{rad/s}$. Therefore

$$Z_R = 2\ \Omega$$

$$Z_C = \frac{1}{j0.5 \times 2} = -j\ \Omega = 1\angle(-90°)\ \Omega$$

$$Z_L = j0.5 \times 2 = j\ \Omega = 1\angle 90°\ \Omega$$

(b) Find the currents I_R, I_C and I_L in phasor form.

Since

$$v_s(t) = -\sin\left(\frac{t}{2}\right) = \cos\left(\frac{t}{2} + 90°\right)\ \text{V}$$

In phasor form

$$V_s = 1\angle 90°\ \text{V}$$

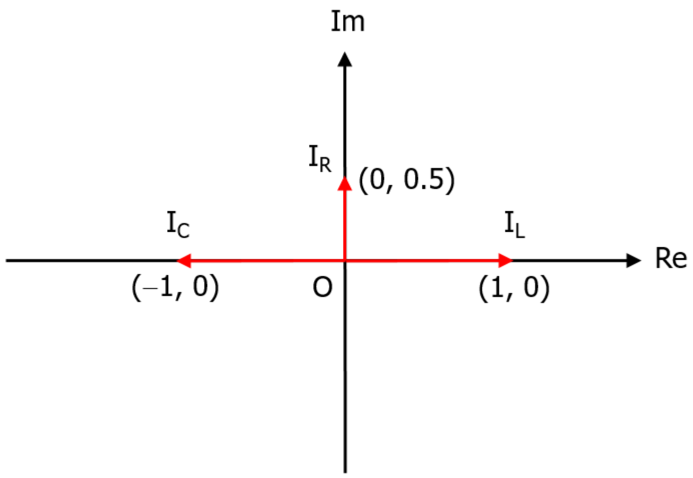
Therefore

$$I_R = \frac{V_s}{Z_R} = 0.5\angle 90°\ \text{A}$$

$$I_C = \frac{V_s}{Z_C} = 1\angle 180°\ \text{A}$$

$$I_L = \frac{V_s}{Z_L} = 1\angle 0°\ \text{A}$$

(c) Plot the currents I_R, I_C and I_L in the same phasor diagram.



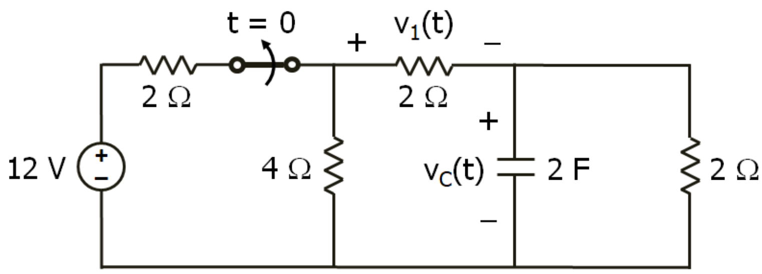
(d) Find the source current I_S in phasor form and find the source current $i_S(t)$ in the time domain.

$$I_S = I_R + I_C + I_L = 0.5\angle 90° + 1\angle 180° + 1\angle 0° = j0.5 - 1 + 1 = j0.5\ \text{A}$$

In the time domain

$$i_s(t) = 0.5\cos\left(\frac{t}{2} + 90°\right)\text{A} = -\,0.5\sin\left(\frac{t}{2}\right)\text{A}$$

2. Assume the switch has been closed for a long time. Then the switch is opened at t = 0.



(a) What is the value of the time constant for the transients that occur after t = 0?

Time constant is $\tau = RC$ where $C = 2$ F and $R = 2 \parallel (2 + 4) = 1.5\ \Omega$.

Therefore

$$\tau = 3\text{ s}$$

(b) Find the equation for $v_C(t)$ that is valid for $t > 0$.

At $t < 0$, the capacitor behaves as an open circuit. It is easy to see that

$$v_1(t < 0) = v_C(t < 0) = 3\text{ V}$$

The capacitor voltage $v_C(0^+)$ initially stays at 3 V right after the switch is opened. It then decays to the final value of zero after the stored energy in the capacitor is all dissipated.

The equation for $v_C(t)$ is therefore

$$v_C(t) = v_C(0^+)e^{-t/\tau} = 3e^{-t/3}\text{ V}$$

(c) Find the equation for $v_1(t)$ that is valid for $t > 0$.

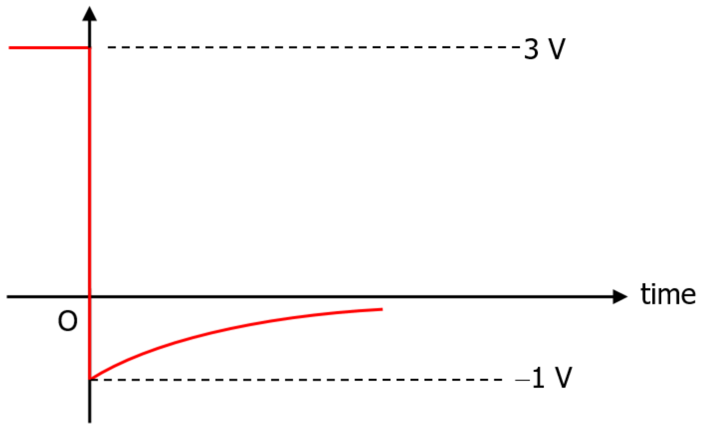
At time 0^+, $v_C(0^+) = 3\ \mathrm{V}$. This voltage is divided between the 2 Ω (having a voltage drop of $-v_1(0^+)$) and the 4 Ω resistors connected in series. Therefore

$$v_1(0^+) = -v_C(0^+)\frac{2}{2+4} = -1\ \mathrm{V}$$

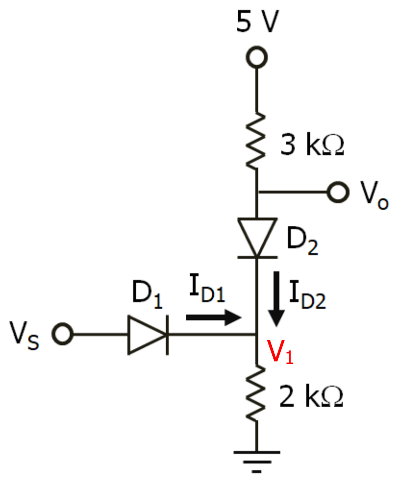
The final value of v_1 is also zero. Therefore

$$v_1(t) = v_1(0^+)e^{-t/\tau} = -e^{-t/3}\ \mathrm{V}$$

(d) Plot $v_1(t)$ as a function of time starting from $t < 0$.



3. Consider the diode circuit in below. Assume the diodes are ideal.



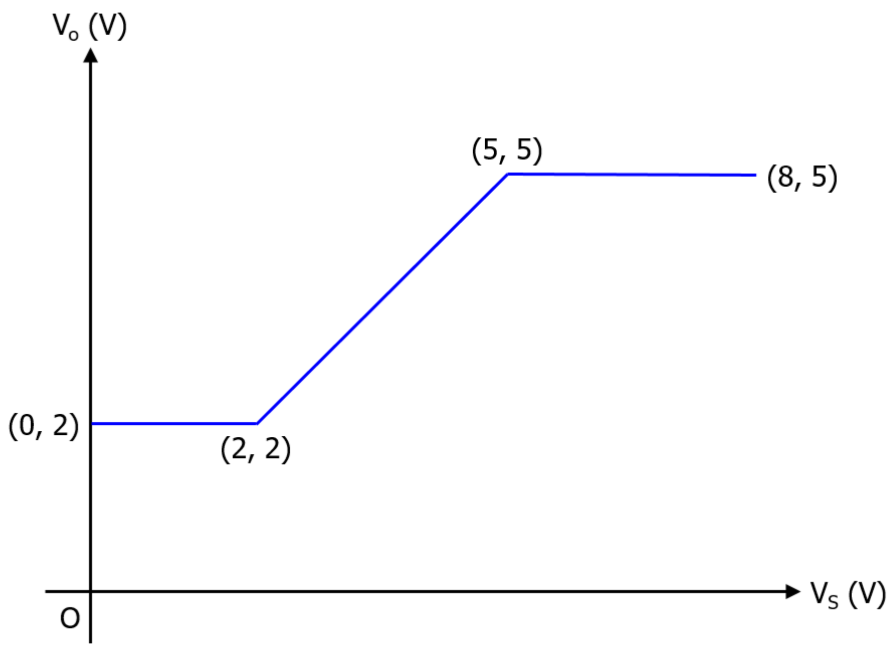
(a) Plot V_O versus V_S for V_S from 0 to 8 V, showing the exact coordinates of the starting point, the end point, and all the turning points.

As V_S starts increasing from 0 V, D_1 is OFF and D_2 is On. $V_o = V_1 = 2$ V.

When V_S reaches 2 V, D_1 is turned ON. $V_o = V_1 = V_S$.

When V_S reaches 5 V, D_2 is turned OFF. $V_o = 5$ V.

Here is the plot:



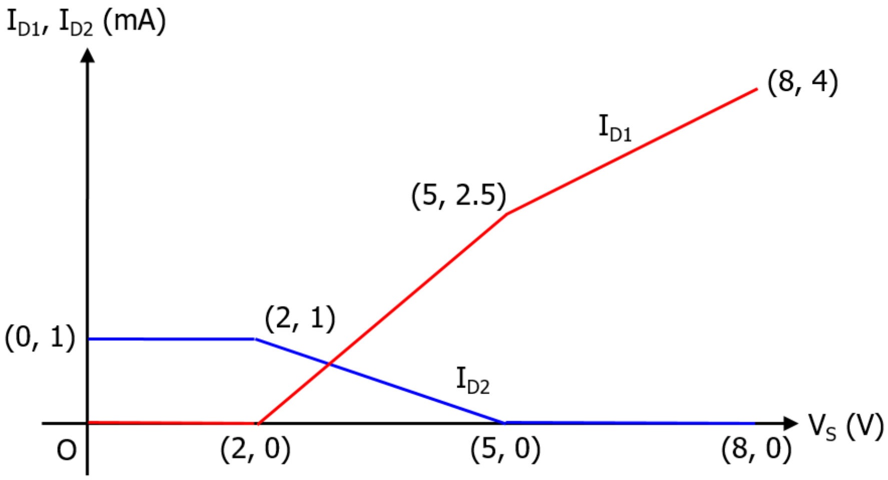
(b) Plot I_{D1} alongside with I_{D2} versus V_S for V_S from 0 to 8 V, showing the exact coordinates of the starting point, the end point, and all the turning points.

When $V_S < 2$ V, $I_{D1} = 0$ mA and $I_{D2} = 1$ mA.

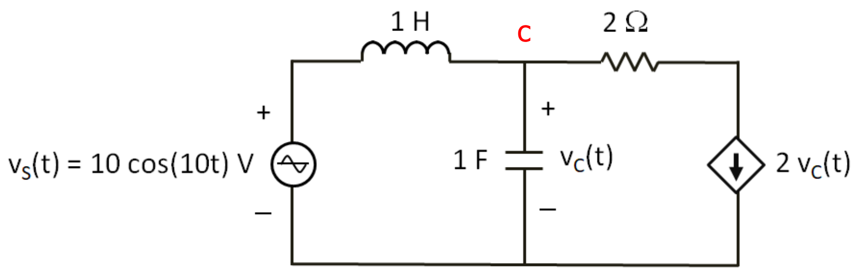
When $2 \text{ V} \leq V_S \leq 5$ V, $I_{D2} = (5 - V_S)/3$ mA and $I_{D1} = V_S/2 - I_{D2}$ mA.

When $V_S > 5$ V, $I_{D1} = V_S/2$ mA and $I_{D2} = 0$ mA.

Here is the plot:



4. Find $v_C(t)$ in the time domain for the circuit below that contains a voltage-dependent current source.



From the given $v_s(t)$, we can see that $\omega = 10\ \mathrm{rad/s}$. The impedance of the inductor is therefore j10 Ω, and that for the capacitor is 1/(j10) Ω.

Apply KCL at node c

$$\frac{V_c - V_s}{j10} + \frac{V_c}{\frac{1}{j10}} + 2V_c = 0$$

$$\frac{V_c - 10\angle 0°}{j10} + j10V_c + 2V_c = 0$$

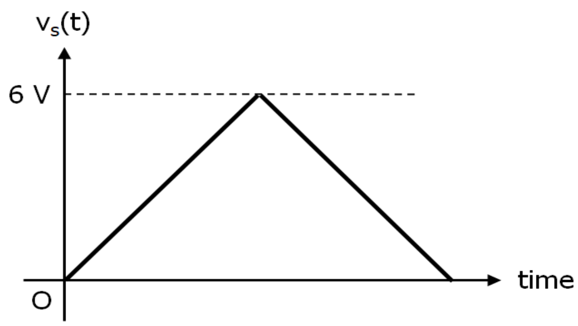
$$-j0.1V_c + j10V_c + 2V_c = -j$$

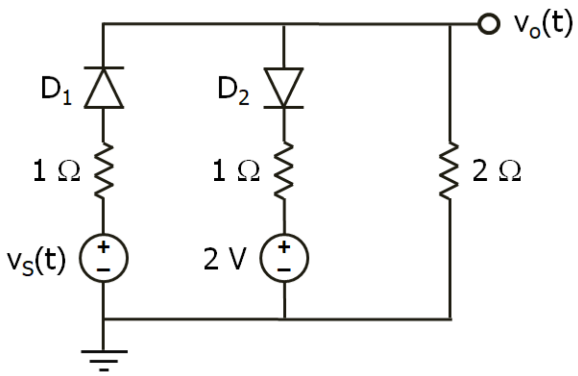
$$V_c = \frac{-j}{2 + j9.9} = \frac{1\angle(-90°)}{10.1\angle 78.58°} = 0.099\angle(-169°)\ \mathrm{V}\ \text{ or }\ 0.099\angle 191°\ \mathrm{V}$$

Therefore

$$v_c(t) = 0.099\cos(10t - 169°)\ \mathrm{V}\ \text{or}\ 0.099\cos(10t + 191°)\ \mathrm{V}$$

5. Consider the following diode circuit. Assume the diodes are ideal. A triangular pulse of 6 V peak voltage is applied at the input $v_s(t)$. Sketch $v_o(t)$ on the below graph and clearly label the exact voltages at the turning points.





D_1 is always ON. D_2 is ON when v_o exceeds 2 V.

When D_2 is OFF

$$v_o = \frac{2}{1+2} v_s = \frac{2}{3} v_s \quad \text{(Valid for } v_o < 2\text{ V)}$$

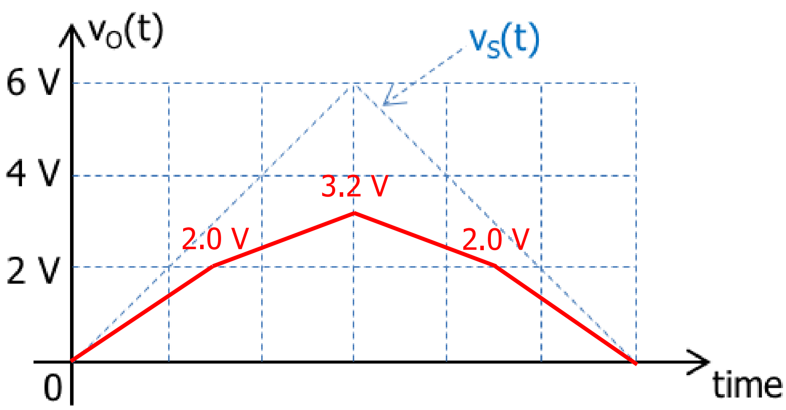
When D_2 is ON

$$\frac{v_s - v_o}{1} = \frac{v_o - 2}{1} + \frac{v_o}{2}$$

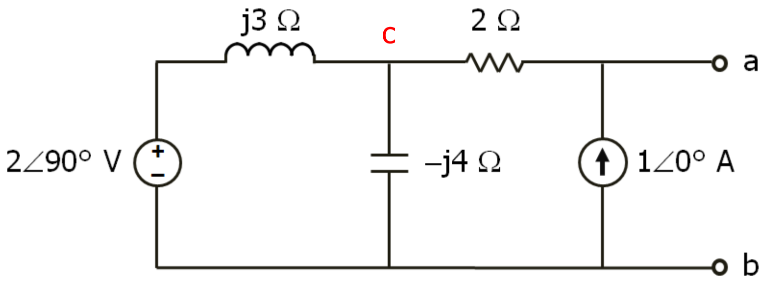
So

$$v_o = 0.4 v_s + 0.8\text{ V} \quad \text{(Valid for } v_o \geq 2\text{ V)}$$

Here is the plot:



6. Find and draw the Thevenin's and Norton's equivalent circuits of the following network with respect to the terminals a and b.



The equivalent impedance Z_{eq} is

$$Z_{eq} = 2 + j3 \parallel (-j4) = 2 + \frac{12}{-j} = 2 + j12 = 12.166\angle 80.538°\ \Omega$$

Apply KCL at node c

$$\frac{V_{cb} - 2\angle 90°}{j3} + \frac{V_{cb}}{-j4} = 1\angle 0°$$

$$\frac{V_{cb} - j2}{j3} + \frac{V_{cb}}{-j4} = 1$$

$$\frac{V_{cb}}{j}\left(\frac{1}{3} - \frac{1}{4}\right) = 1 + \frac{2}{3}$$

$$V_{cb} = j20$$

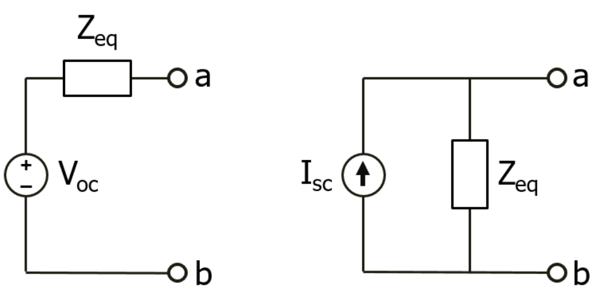
The open-circuit voltage V_{oc} is therefore

$$V_{oc} = V_{ab} = V_{cb} + 2 \times 1\angle 0° = 2 + j20 = 20.100\angle 84.289°\ V$$

The short-circuit current I_{sc} is given by

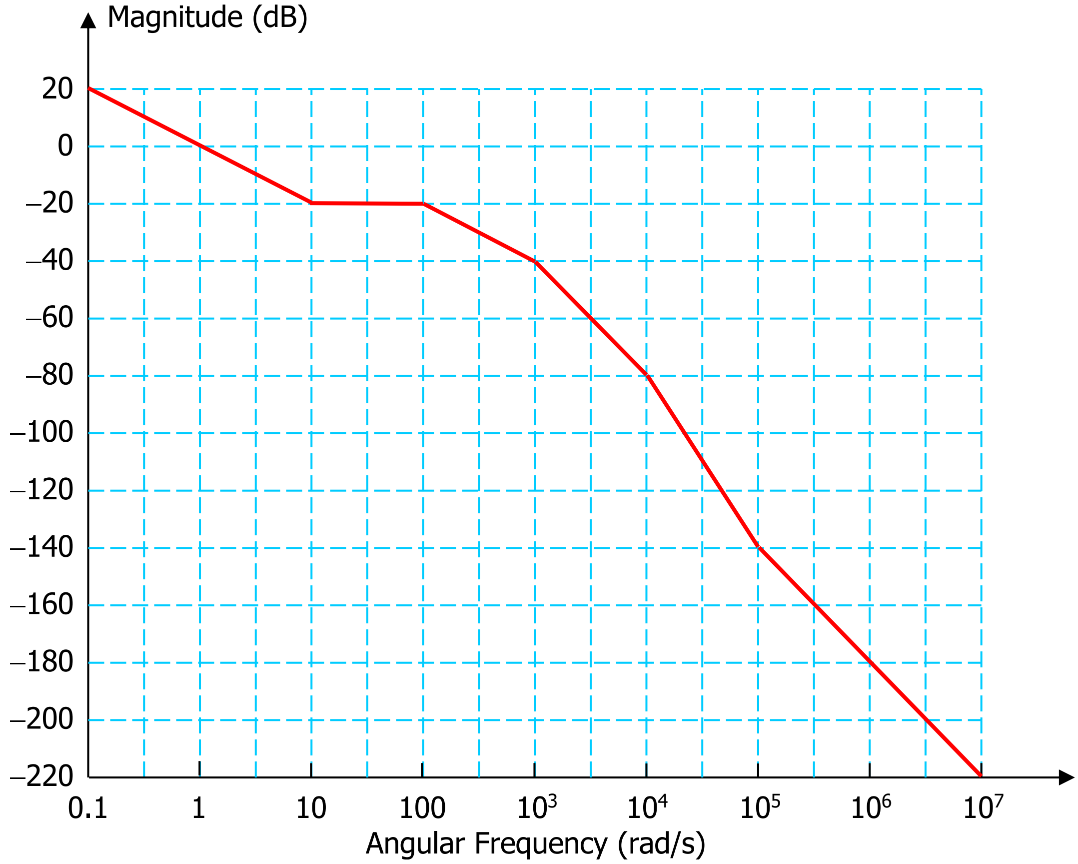
$$I_{sc} = \frac{V_{oc}}{Z_{eq}} = \frac{20.100\angle 84.289°}{12.166\angle 80.538°} = 1.65\angle 3.75°\ A$$

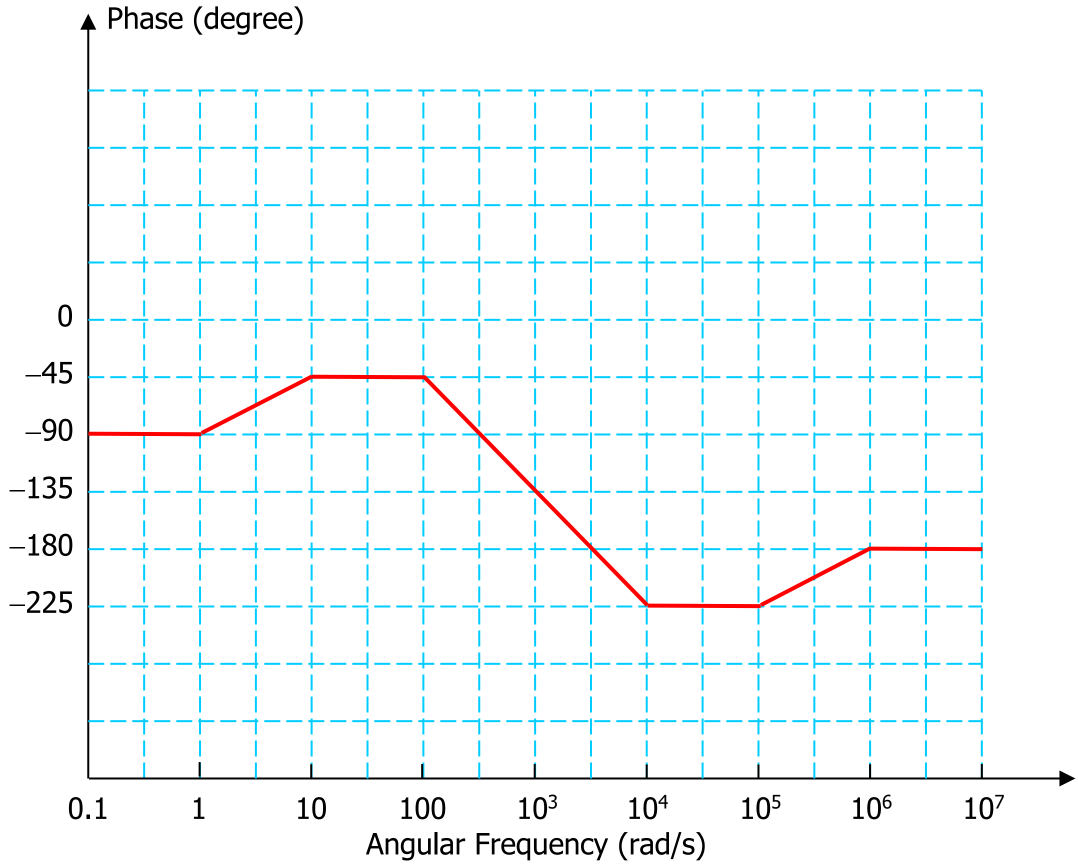
The equivalent circuits are as shown in below:



Thevenin Norton

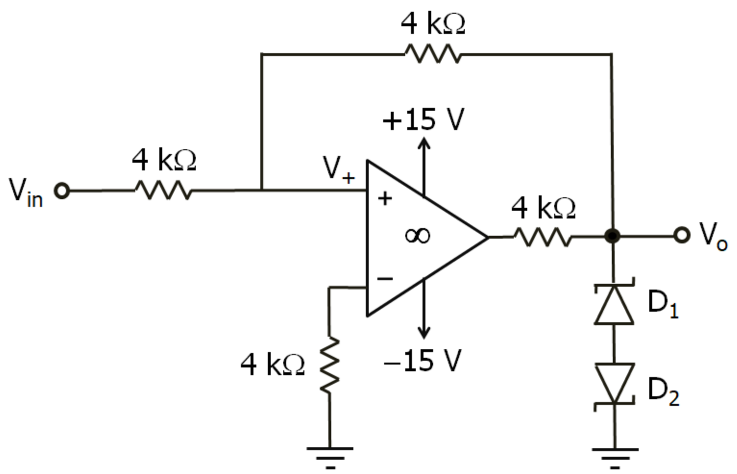
7. Sketch the Bode plots of $\dfrac{\left(10^{-1}s + 1\right)\left(10^{-5}s+1\right)}{s\left(10^{-2}s+1\right)\left(10^{-3}s+1\right)\left(10^{-4}s+1\right)}$ on the graph papers provided on the next page. Label the y-axis and y-scale clearly. You can try out the plots on the graph papers provided in the < Rough Work Paper > section.


Magnitude (dB)
20
0
–20
–40
–60
–80
–100
–120
–140
–160
–180
–200
–220
0.1
1
10
100
10^3
10^4
10^5
10^6
10^7
Angular Frequency (rad/s)


Phase (degree)
0
–45
–90
–135
–180
–225
0.1
1
10
100
10^3
10^4
10^5
10^6
10^7
Angular Frequency (rad/s)

(continue)

8. Two Zener diodes D_1 and D_2 are connected back-to-back in the circuit below. The forward turn-on and reverse breakdown voltages of the Zener diodes are V_F = 0.7 V and V_{Z0} = 4.3 V, respectively.



(a) Find V_o and V_+ when V_{in} = 10 V.

When the back-to-back Zener diodes conduct in either direction, the voltage drop will always consist of a forward turn-on voltage and a reverse breakdown voltage, which is 4.3 + 0.7 = 5 V. Thus V_o is clamped to ±5 V when the diodes conduct, and $-5 \text{ V} < V_o < 5$ V when the diodes do not conduct.

When V_{in} = 10 V, assuming that the op am does not saturate, V_o would like to go to −10 V but this is not allowed. So the op amp must saturate. Furthermore, with $-5 \text{ V} \le V_o \le 5$ V, $V_+ = (V_{in} + V_o)/2$ is definitely positive. Therefore, the op amp output must saturate high at 15 V.

Now the diodes must conduct. Otherwise, V_o would be over 10 V, which is not allowed. The only remaining question is whether is V_o at 5 V or −5 V. The latter possibility, however, can be ruled out since all three branches of current would then be draining toward V_o, a clear violation of KCL.

In conclusion, V_o = 5 V and $V_+ = (V_{in} + V_o)/2$ = 7.5 V.

(b) Find V_o and V_+ when V_{in} = −10 V.

Using similar argument, when V_{in} = −10 V, V_o = −5 V and $V_+ = (V_{in} + V_o)/2$ = −7.5 V.

(c) Plot V_o alongside with V_+ as a function of V_{in} as V_{in} increases from −10 V to 10 V, showing the exact coordinates of the starting point, the end point, and all the turning points.

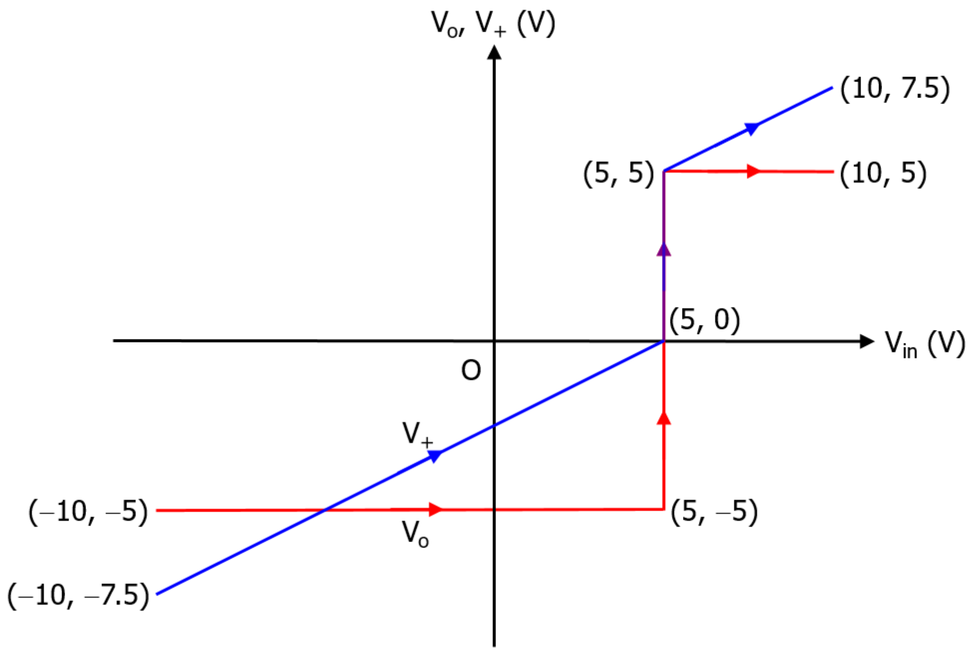
In general, when V_{in} increases from −10 V, V_o = −5 V and

$$V_+ = (V_{in} + V_o)/2 = V_{in}/2 - 2.5 \text{ V}$$

This is true until V_+ increases above 0 V at which point V_o will switch to 5 V. This happens when

$$V_+ = V_{in}/2 - 2.5 \text{ V} > 0 \text{ V or when } V_{in} > 5 \text{ V}$$

Below is the plot:



(d) Plot V_o alongside with V_+ as a function of V_{in} as V_{in} decreases from 10 V to −10 V, showing the exact coordinates of the starting point, the end point, and all the turning points.

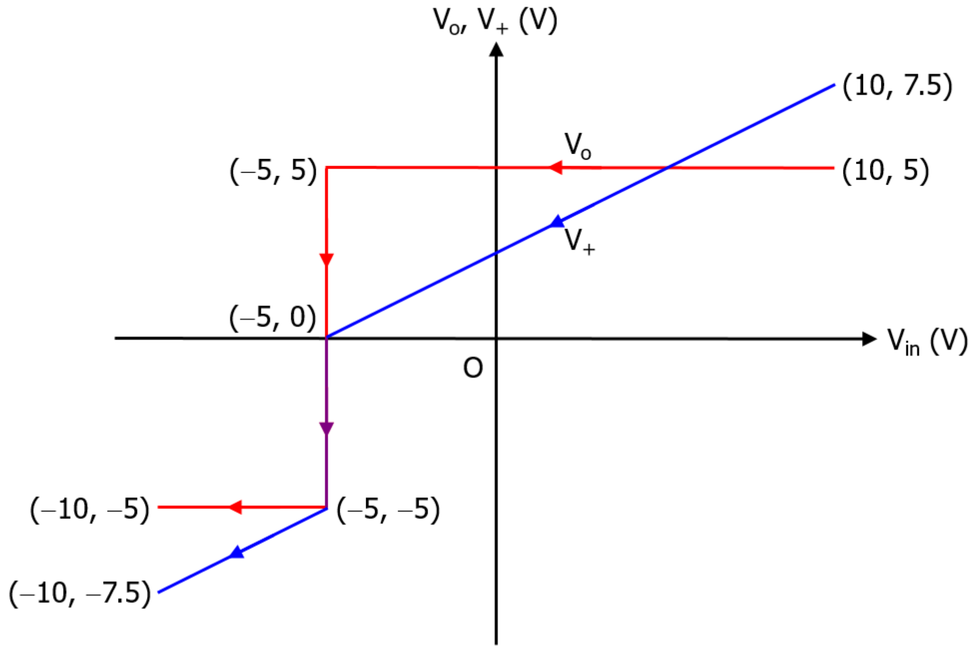
In general, when V_{in} decreases from 10 V, V_o = 5 V and

$$V_+ = (V_{in} + V_o)/2 = V_{in}/2 + 2.5\text{ V}$$

This is true until V_+ decreases below 0 V at which point V_o will switch to −5 V. This happens when

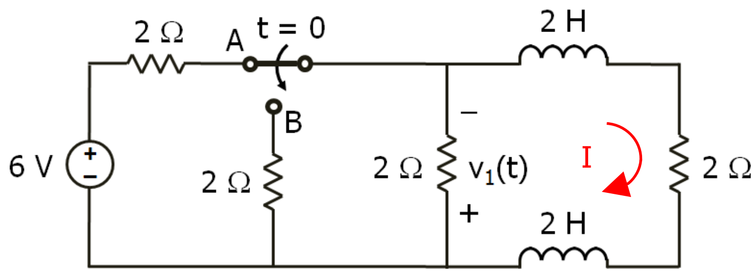
$$V_+ = V_{in}/2 + 2.5\text{ V} < 0\text{ V or when } V_{in} < -5\text{ V}$$

Below is the plot:



(e) What is the name for this type of circuit? Schmitt trigger

9. Assuming that the switch has been switched to position "A" for a long time, the switch is then switched to position "B" at t = 0.



(a) What is the value of $v_1(t)$ for $t < 0$?

At $t < 0$, the inductors behave as a short circuit. Hence

$$v_1 = -6\left(\frac{2 \parallel 2}{2 + 2 \parallel 2}\right) = -2\ \text{V}$$

Moreover, the inductor current

$$I = \frac{-v_1}{2} = 1\ \text{A}$$

(b) What is the value of $v_1(t)$ at $t = 0^+$, right after the switch is switched to the "B" position?

The inductor current I = 1 A remains momentarily unchanged at $t = 0^+$. This current is split between the two 2 Ω resistors in the middle. Hence

$$v_1 = \frac{I}{2} \times 2 = 1\ \text{V}$$

(c) What is the value of the time constant for the transients that occur after t = 0?

The two 2 H inductors in series is equivalent to a single 4 H inductor.

Time constant is $\tau = L/R$ where $L = 2 + 2 = 4\ \mathrm{H}$ and $R = 2 + 2 \parallel 2 = 3\ \Omega$.

Therefore

$$\tau = \frac{4}{3} = 1.33\ \mathrm{s}$$

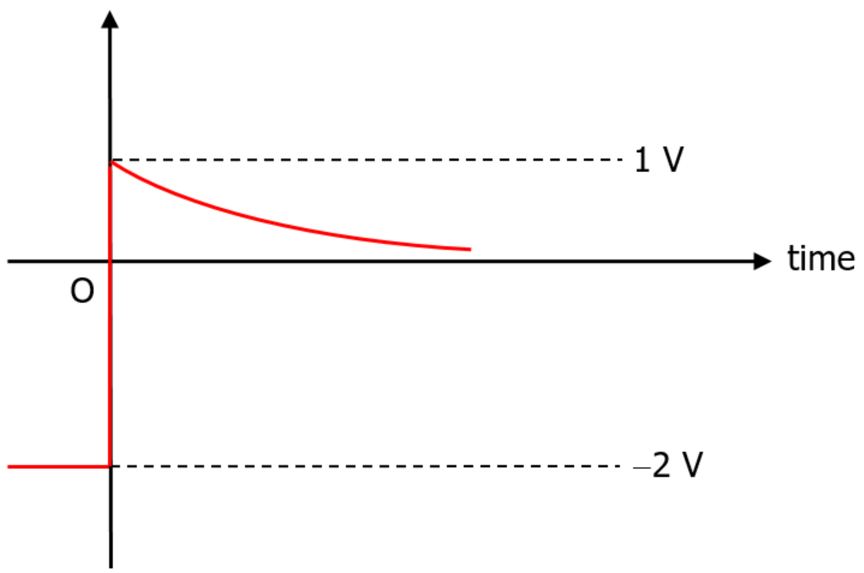
(d) Find the equation for $v_1(t)$ that is valid for $t > 0$.

The final value for $v_1(t)$ is zero after the stored energy in the inductors is all dissipated.

The equation for $v_1(t)$ is therefore

$$v_1(t) = v_1(0^+)e^{-t/\tau} = e^{-t/1.33}\ \mathrm{V}$$

(e) Plot the voltage $v_1(t)$ as a function of time starting from $t < 0$.

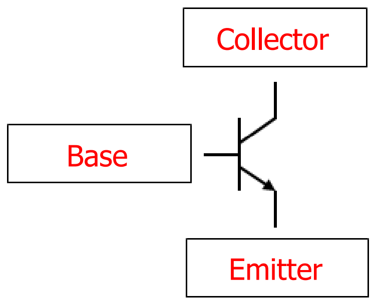


10. Shown in below are the symbols for the NPN and NMOS transistors and their I-V characteristics plotted in the usual manner.

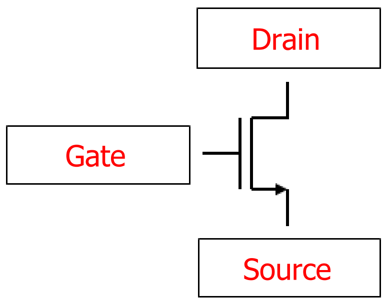
(a) Fill in the blank boxes by choosing from among the words provided below (reuse if necessary):

Accumulation, Active, Base, Body, Breakdown, Collector, Common, Cutoff, Depletion, Drain, Emitter, Enhancement, Forward, Gate, Inversion, Linear, Nonlinear, Passive, Quiescent, Reverse, Saturation, Source, Substrate.

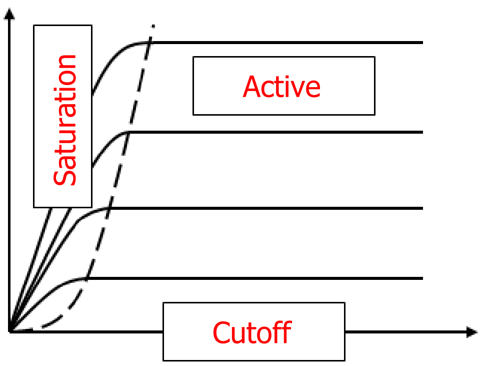
NPN Transistor



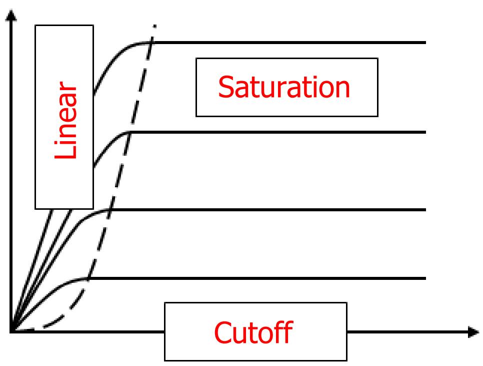
NMOS Transistor



NPN Transistor



NMOS Transistor

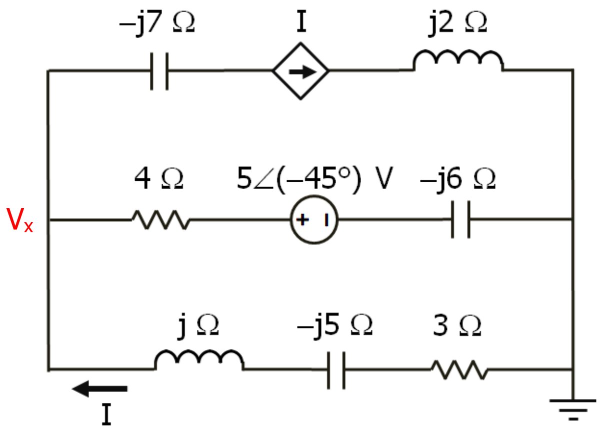


Modes of Operation

(b) Name 4 advantages of the MOS transistors over the bipolar transistors for digital logic applications.

Any 4 of the following:
- Low Power
- High speed
- Small size or high circuit density
- Low cost
- High noise immunity or low noise
- High input impedance or zero gate/input current
- High fan-in and fan-out
- Simple design

11. The circuit below contains a current-dependent current source.



(a) Compute the average power (with the proper sign for power) for each element in the circuit, and write the answers in below.

–j5 Ω Capacitor: 0 W –j6 Ω Capacitor: 0 W –j7 Ω Capacitor: 0 W

j Ω Inductor: 0 W j2 Ω Inductor: 0 W

3 Ω Resistor: 1.5 W 4 Ω Resistor: 0 W

Independent Voltage Source: 0 W Dependent Current Source: –1.5 W

The average power for all the capacitors and inductors are zero.

The current in the top branch matches that in the bottom branch. Hence there is no current going through the middle branch. As a result, the 4 Ω resistor and the independent voltage source both consume zero power. Moreover, V_x = 5∠(–45°) V.

Consider the bottom branch

$$\mathrm{I} = -\frac{5\angle(-45°)}{\mathrm{j} - \mathrm{j}5 + 3} = -\frac{5\angle(-45°)}{5\angle(-53.13°)} = 1\angle(188.13°)\ \mathrm{A}$$

Average power in the top branch is

$$\frac{|V_x||\mathrm{I}|\cos(\angle V_x - \angle \mathrm{I})}{2} = \frac{5 \times 1 \cos(-45° - 188.13°)}{2} = -1.5\ \mathrm{W}$$

This is all coming from the dependent current source, since the capacitor and inductor consume zero average power.

Average power for the 3 Ω resistor is

$$\frac{|\mathrm{I}|^2\mathrm{R}}{2} = \frac{1 \times 1 \times 3}{2} = 1.5\ \mathrm{W}$$

(continue)

(b) Show that the conservation of power holds for the circuit.

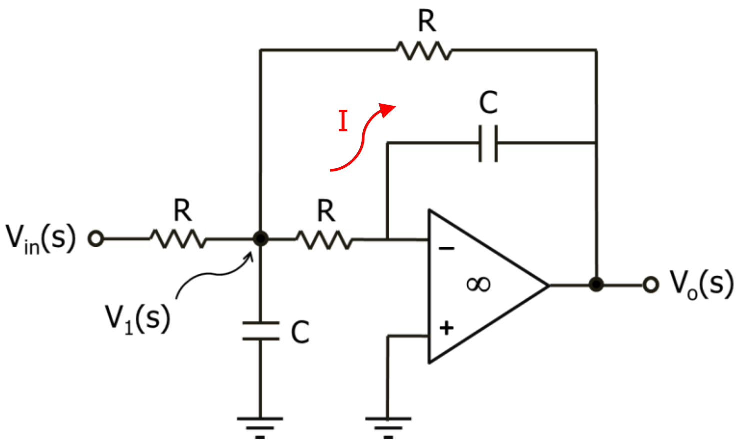
This is evident from the results summary in (a), as the total sum of average power is zero for the circuit.

(c) Which circuit element(s) are generating power? Where is the power coming from?

The dependent current source is generating all the power.

Most likely, the dependent source is a partial model of an op amp or transistor circuit in which additional power supplies, i.e., voltage or current sources, are present but not shown here.

12. For the op amp circuit shown in below:



(a) Derive and simplify an expression relating $V_1(s)$ to $V_o(s)$.

V_- is a virtual ground. The same current I goes through R and C. Hence

$$\frac{V_1(s)}{R} = -\frac{V_o(s)}{\frac{1}{sC}}$$

or

$$V_1(s) = -sRCV_o(s)$$

(b) Derive and simplify the transfer function $H(s)= \frac{V_o(s)}{V_{in}(s)}$.

Apply KCL to the node containing $V_1(s)$

$$\frac{V_1 - V_{in}}{R} + \frac{V_1}{\frac{1}{sC}} + \frac{V_1}{R} + \frac{V_1 - V_o}{R} = 0$$

$$V_1 - V_{in} + sRCV_1 + V_1 + V_1 - V_o = 0$$

$$V_{in} = (3 + sRC)V_1 - V_o$$

Using the result from (a)

$$V_{in} = -(3 + sRC)(sRCV_o) - V_o$$

$$= -(1 + 3sRC + s^2R^2C^2)V_o$$

The transfer function is therefore

$$H(s) = \frac{V_o(s)}{V_{in}(s)} = -\frac{1}{1 + 3sRC + s^2R^2C^2}$$

(c) How many poles and zeros are in H(s)? What is the order of this system?

2 poles and no zeros Second order system

(d) What type of circuit is this? Low-pass filter

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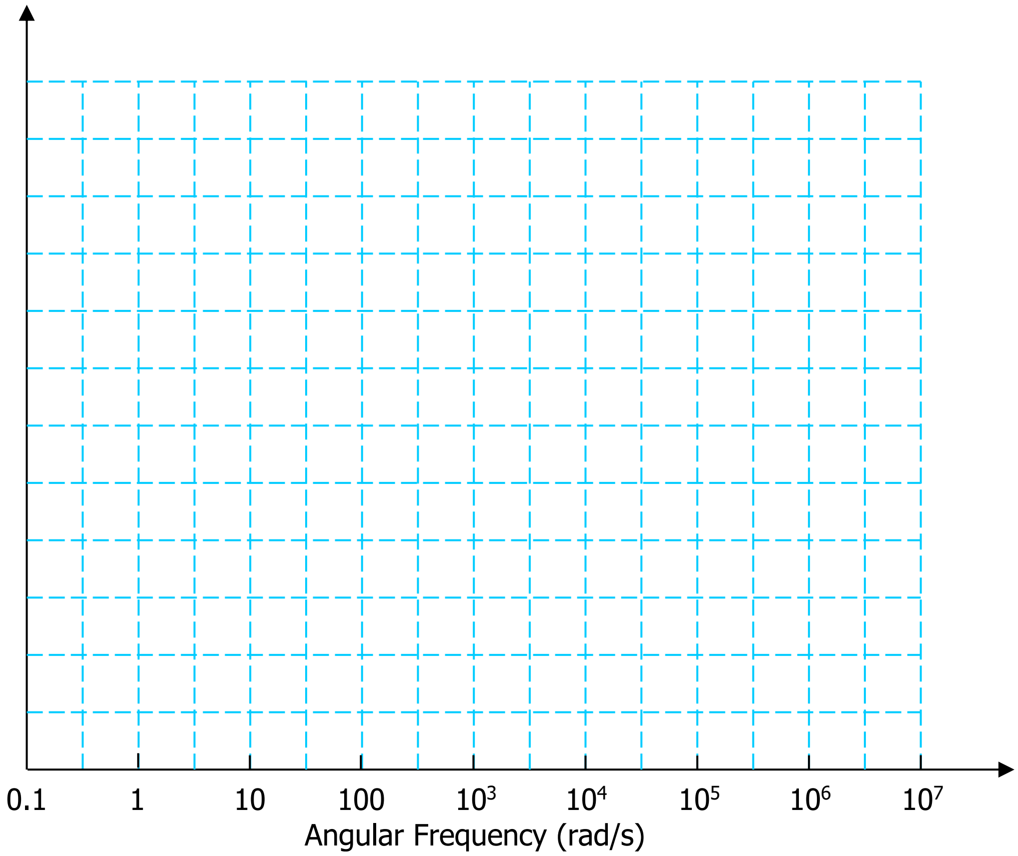

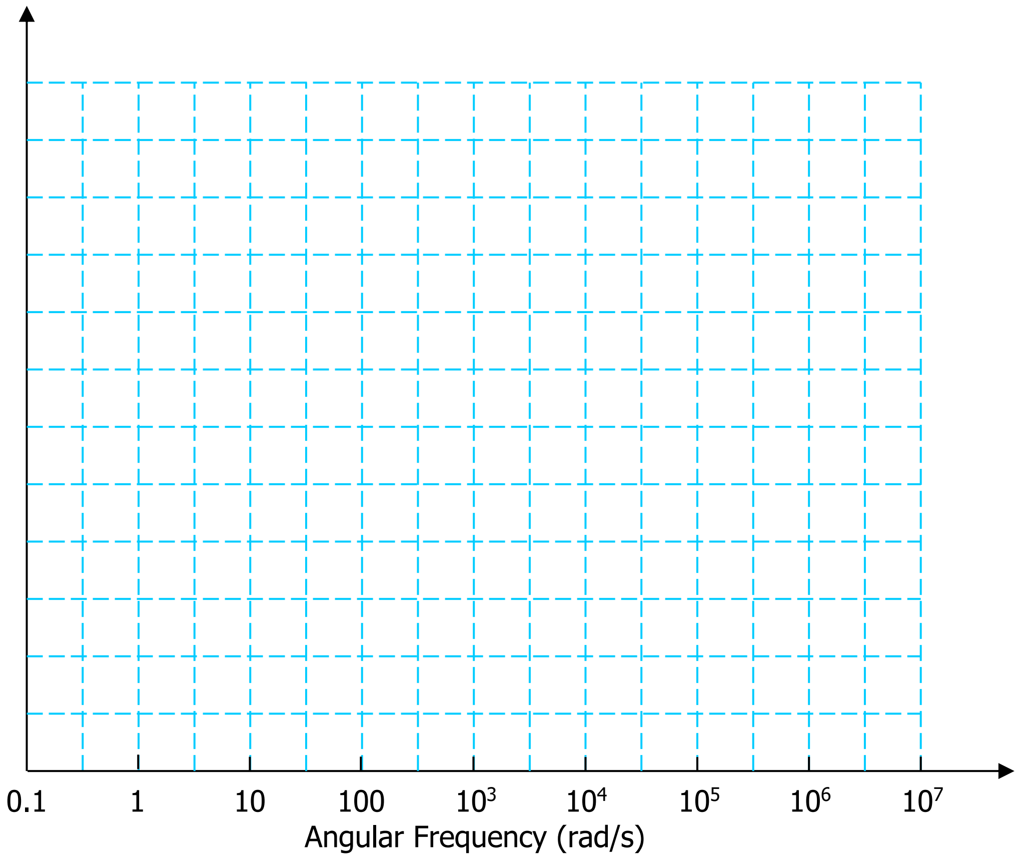

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