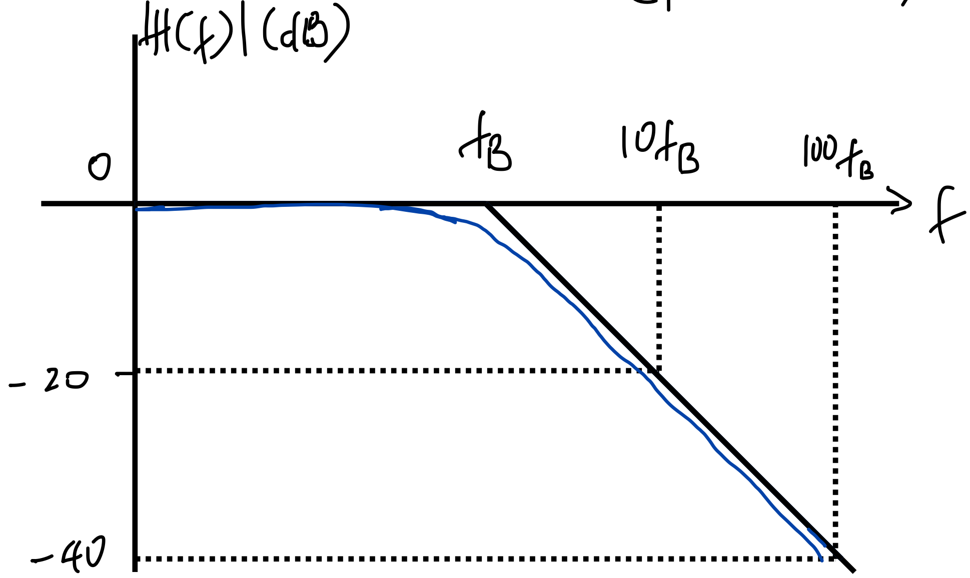
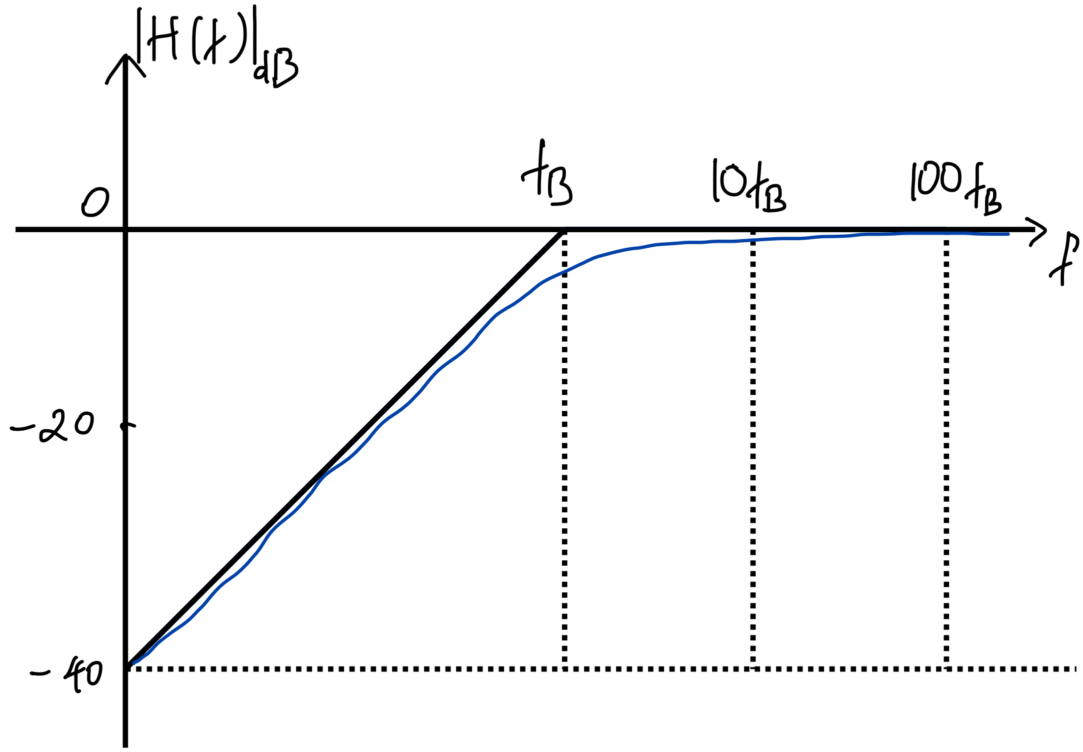
Nhat Ho - HW 7

Problem 1:

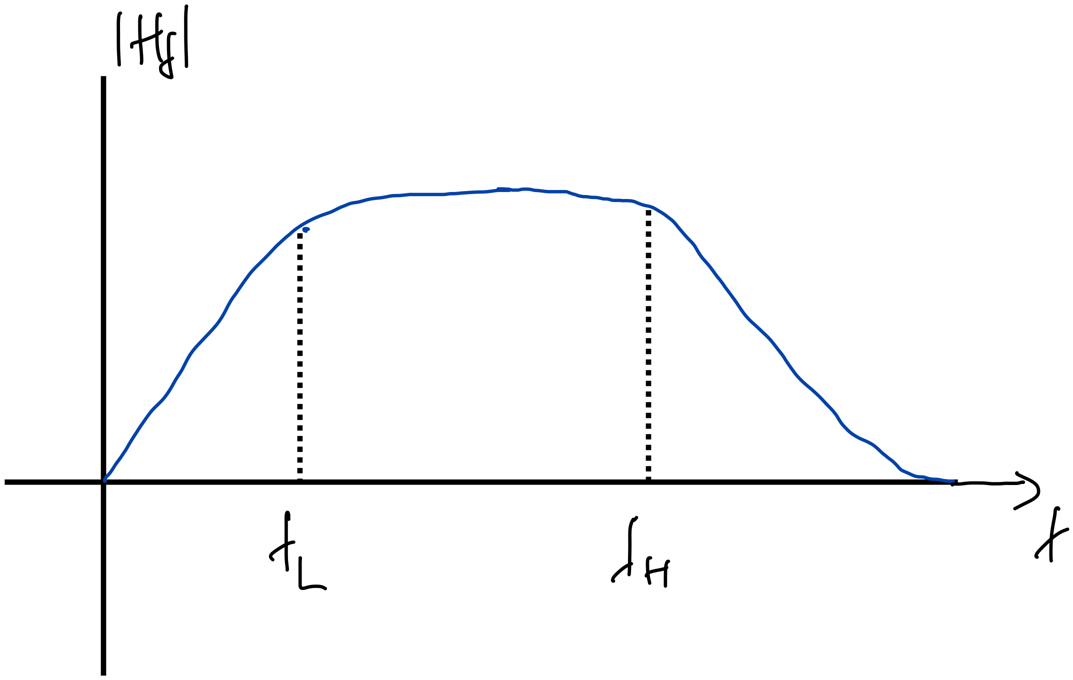
a) i) low-pass: Example expected frequency:
(first-order)



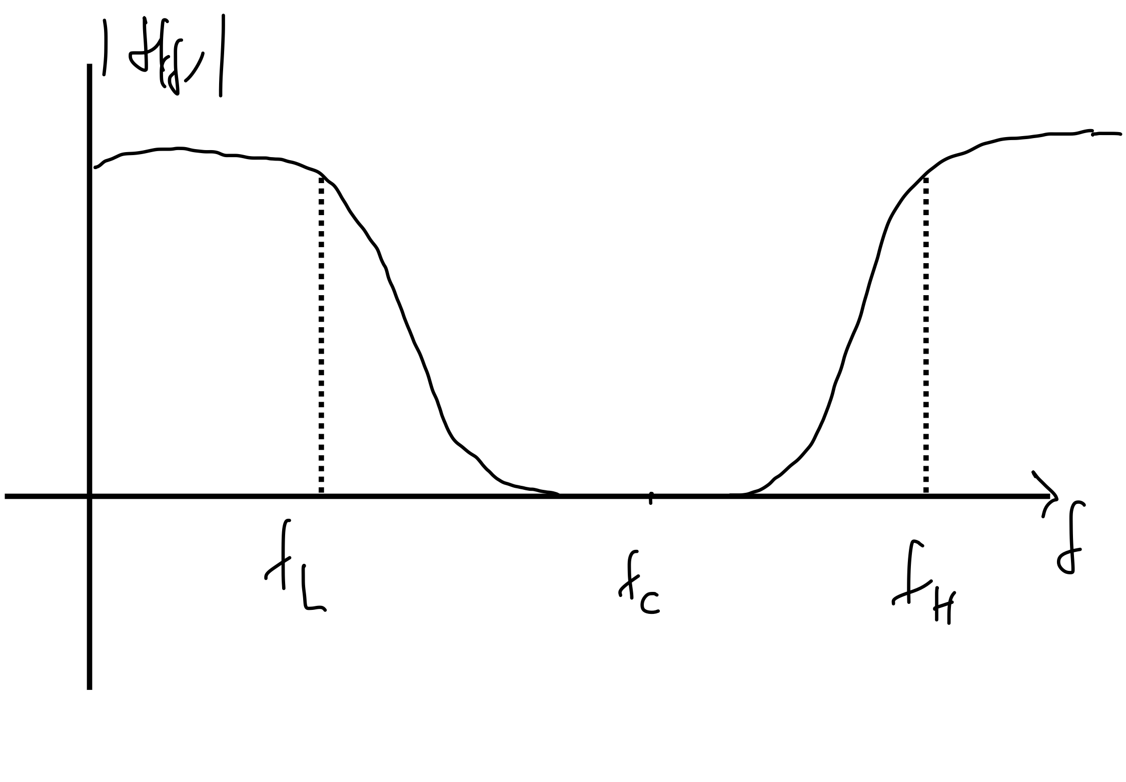
ii) High pass: Example expected frequency: (first-order)



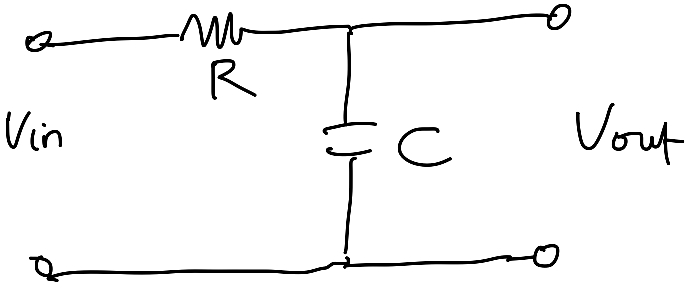
iii) band pass: Example expected frequency



iv) band Stop: Example expected frequency.



b) (Next page)



$$Z_C = \frac{1}{jwC}$$

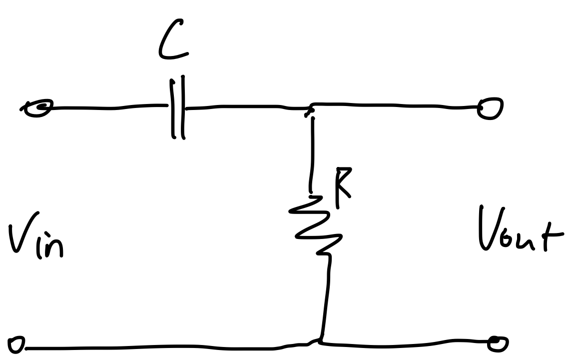
$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{\frac{1}{jwC}}{R + \frac{1}{jwC}}$$

$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{1}{1 + Rjwc}.$$

Since $w \to 0 \Rightarrow 1 + RjwC \to 1 \Rightarrow \frac{V_{out}}{V_{in}} \sim 1$

While $w \to \infty \Rightarrow 1 + RjwC \to \infty \Rightarrow \frac{V_{out}}{V_{in}} \to 0$

$\Rightarrow$ this circuit is $\boxed{\text{low pass}}$

c) 

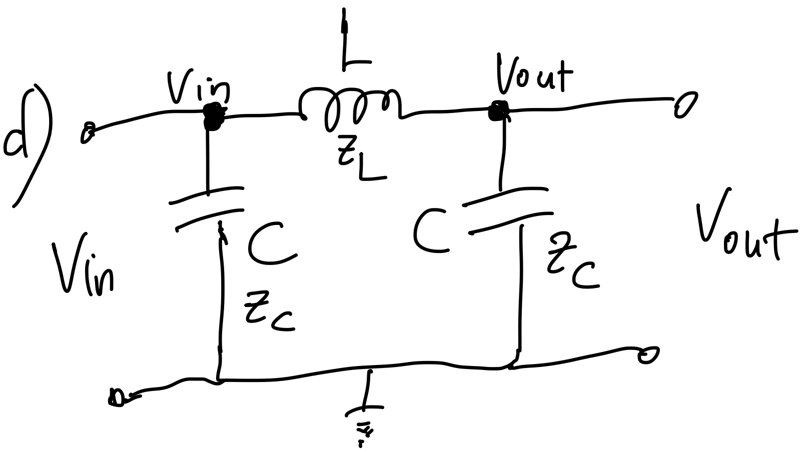
$$\frac{V_{out}}{V_{in}} = \frac{R}{R + \frac{1}{jwC}}$$

$$= \frac{1}{1 + \frac{1}{jwRC}}$$

Since $w \to 0 \Rightarrow \frac{1}{jwRC} \to \infty$

$\Rightarrow \frac{V_{out}}{V_{in}} \to 0$. While $w \to \infty \Rightarrow \frac{1}{jwRC} \to 0$

$$\Rightarrow \frac{V_{out}}{V_{in}} \to 1 \Rightarrow \text{this circuit is } \boxed{\text{high-pass.}}$$

d) 

$$\begin{cases} Z_L = j\omega L \\ Z_C = \dfrac{1}{j\omega C} \end{cases}$$

We have : $\dfrac{V_{out}}{V_{in}} = \dfrac{Z_C}{Z_C + Z_L} = \dfrac{1}{1 + \dfrac{Z_L}{Z_C}}$

also : $\dfrac{Z_L}{Z_C} = \dfrac{j\omega L}{\dfrac{1}{j\omega C}} = j\omega L \, j\omega C = -\omega^2 LC$

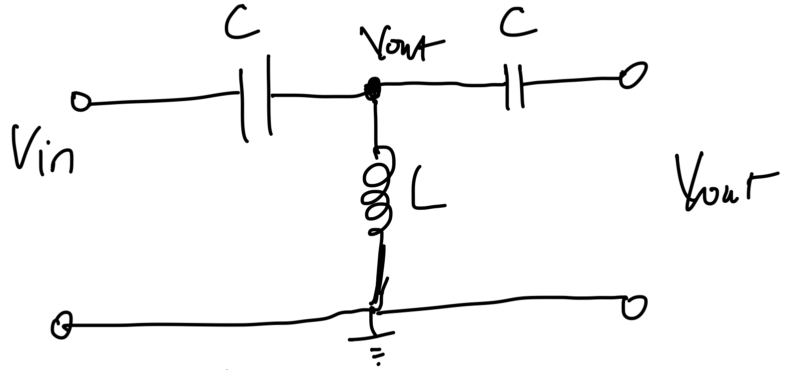
$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{1}{1 - \omega^2 LC}.$$

When $\omega \to 0 \Rightarrow \dfrac{V_{out}}{V_{in}} \to 1$

When $\omega \to \infty \Rightarrow \dfrac{V_{out}}{V_{in}} \to 0$

$\Rightarrow$ this circuit is $\boxed{\text{low-pass}}$

e)



Since $\frac{V_{out}}{V_{in}} = \frac{Z_L}{Z_C + Z_L}$

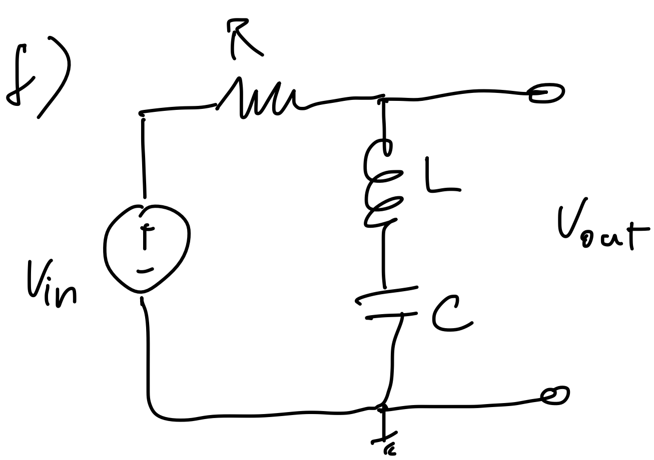
$= \frac{1}{1 + \frac{Z_C}{Z_L}}$. Also $\frac{Z_C}{Z_L} = \frac{\frac{1}{j\omega C}}{j\omega L} = \frac{1}{-\omega^2 CL}$

$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{1}{1 - \frac{1}{\omega^2 CL}}$.

When $\omega \to 0 \Rightarrow \frac{V_{out}}{V_{in}} \to 0$

$\omega \to \infty \Rightarrow \frac{V_{out}}{V_{in}} \to 1 \Rightarrow$ this circuit is $\boxed{\text{high-pass}}$

f)



$Z_L + Z_C = j\omega L - \frac{j}{\omega C}$

$= j\left(\omega L - \frac{1}{\omega C}\right)$

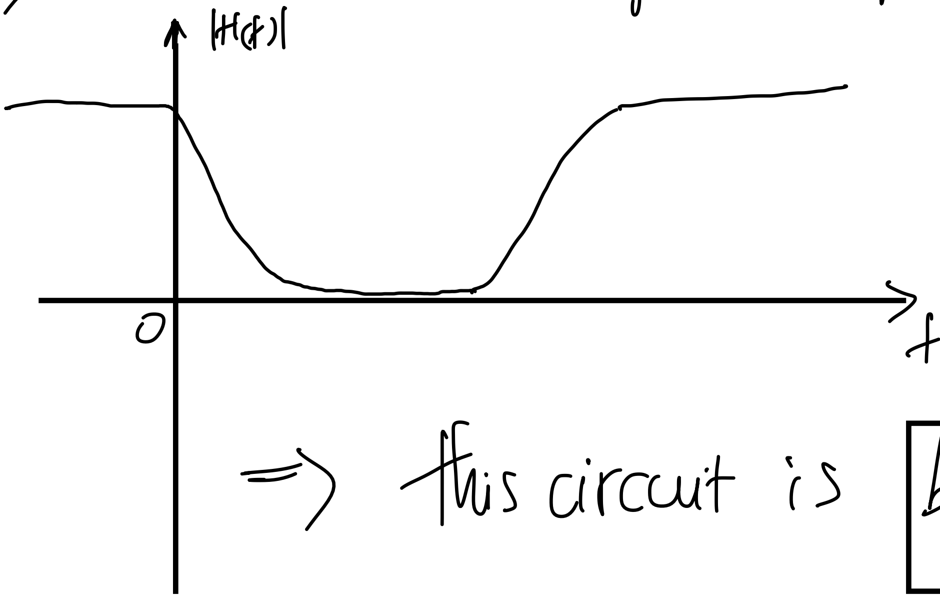
$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{Z_L + Z_C}{R + Z_L + Z_C} = \frac{1}{1 + \frac{R}{Z_L + Z_C}}$

$$\frac{V_{out}}{V_{in}} = \frac{1}{1 + \frac{R}{j\left(\omega L - \frac{1}{\omega C}\right)}}$$

When $\omega \to 0 \Rightarrow \begin{cases} \omega L \to 0 \\ \frac{1}{\omega C} \to \infty \end{cases} \Rightarrow \frac{V_{out}}{V_{in}} \to 1$

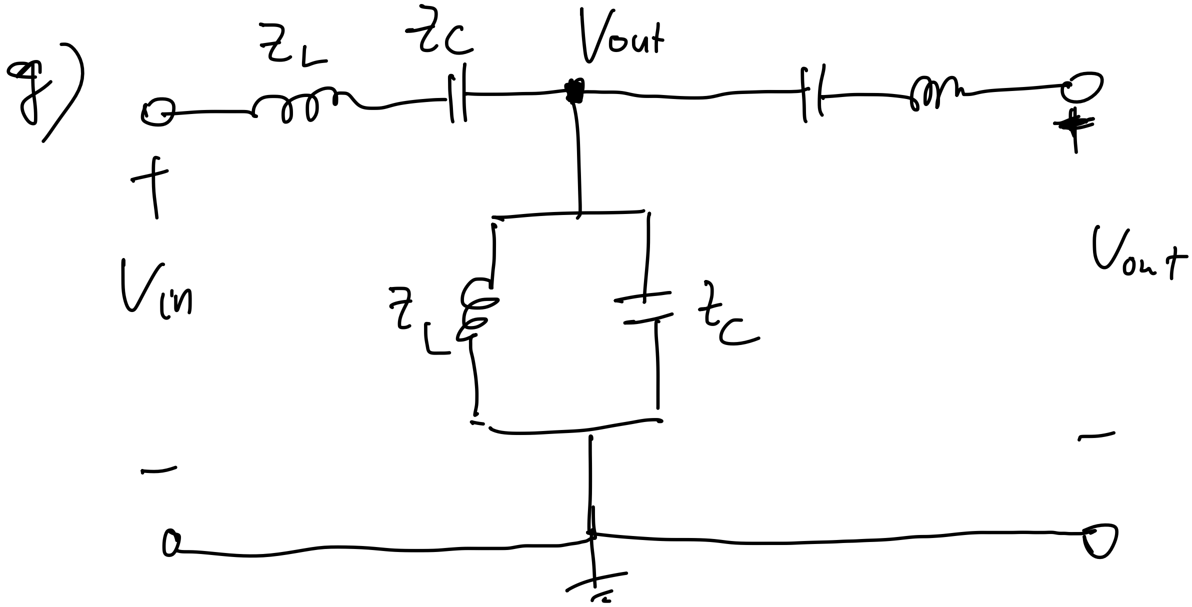
When $\omega \to \infty \Rightarrow \begin{cases} \omega L \to \infty \\ \frac{1}{\omega C} \to 0 \end{cases} \Rightarrow \frac{V_{out}}{V_{in}} \to 1$

$\Rightarrow$ We can have the general diagram for this circuit:



$\Rightarrow$ this circuit is $\boxed{\text{band Stop.}}$

g)



$C \parallel L \Rightarrow Z_{CL} = \dfrac{Z_C \times Z_L}{Z_C + Z_L}$.

Also: $\begin{cases} Z_C = \dfrac{1}{j\omega C} \\ Z_L = j\omega L \end{cases} \Rightarrow \begin{cases} Z_C \times Z_L = \dfrac{j\omega L}{j\omega C} = \dfrac{L}{C} \\ Z_C + Z_L = \dfrac{1}{j\omega C} + j\omega L \end{cases}$

$$= j\left(\omega L - \frac{1}{\omega C}\right)$$

Beside, we have: $\dfrac{V_{out}}{V_{in}} = \dfrac{Z_{CL}}{Z_L + Z_C + Z_{CL}}$

$$= \frac{1}{1 + \dfrac{Z_L + Z_C}{Z_{CL}}} = \frac{1}{1 + \dfrac{(Z_L + Z_C)(Z_C + Z_L)}{Z_C \times Z_L}}$$

$$= \frac{1}{1 + \left(1 + \frac{Z_L}{Z_C}\right)\left(1 + \frac{Z_C}{Z_L}\right)}$$

Since: $\frac{Z_L}{Z_C} = \frac{j\omega L}{\frac{1}{j\omega C}} = j\omega L j\omega C = -\omega^2 LC$

$$\frac{Z_C}{Z_L} = \frac{\frac{1}{j\omega C}}{j\omega L} = \frac{1}{-\omega^2 CL}$$

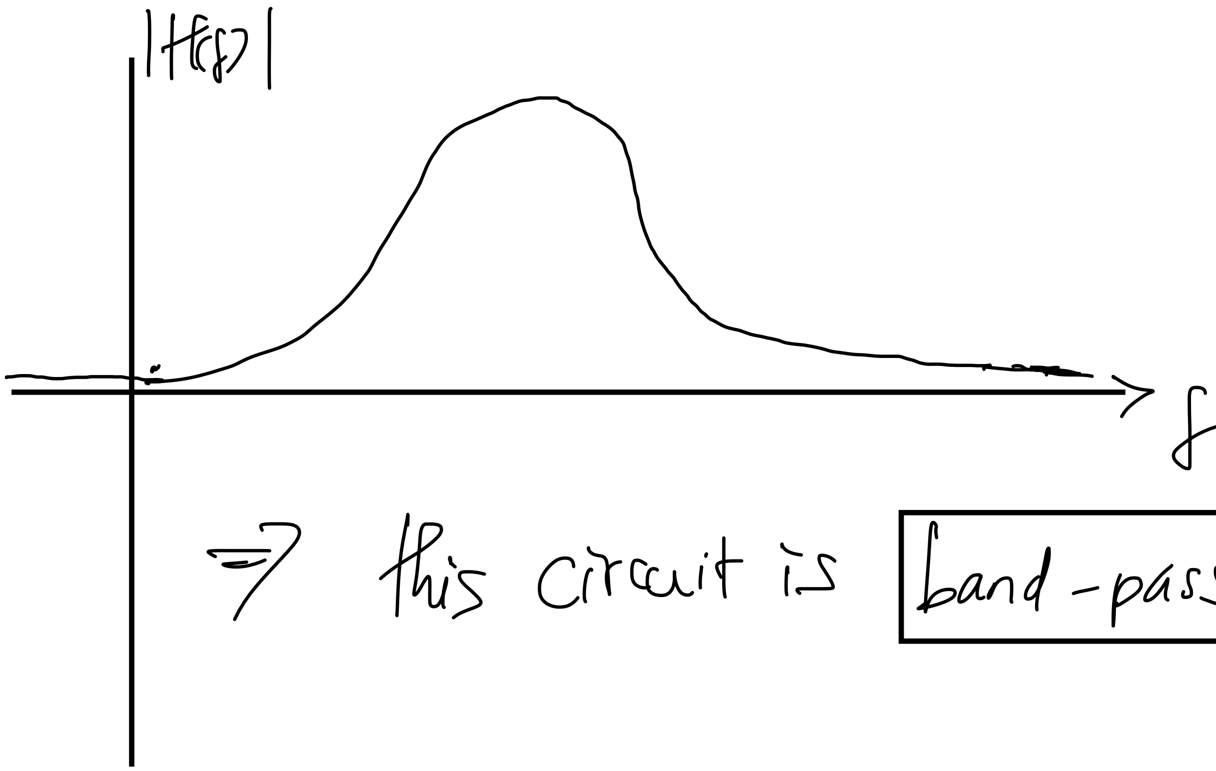
$$\Rightarrow \frac{V_{out}}{V_{in}} = \frac{1}{1 + (1 - \omega^2 LC)\left(1 - \frac{1}{\omega^2 CL}\right)}$$

So, <u>checking:</u> $\omega \to 0 \quad \begin{cases} \omega^2 LC \to 0 \\ \frac{1}{\omega^2 LC} \to \infty \end{cases}$

$$\Rightarrow \frac{V_{out}}{V_{in}} \longrightarrow 0$$

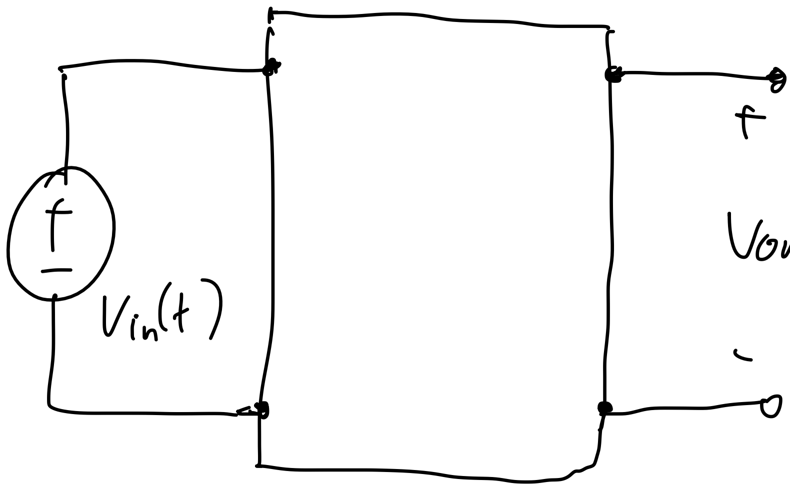
$\omega \to \infty \quad \begin{cases} \omega^2 LC \to \infty \\ \frac{1}{\omega^2 LC} \to 0 \end{cases} \quad \Rightarrow \frac{V_{out}}{V_{in}} \longrightarrow 0$

$\Rightarrow$ we can have the general diagram of this circuit:



$\Rightarrow$ this circuit is $\boxed{\text{band-pass}}$

Problem 2:



$$V_{out}(t) = \frac{dV_{in}(t)}{dt}$$

$$v_{in}(t) = V_{max} \cos(2\pi f t)$$

$$V_{out}(t) = \frac{dV_{in}(t)}{dt} = V_{max}\left[\cos(2\pi f t)\right]'$$

$$= -V_{max} \cdot 2\pi f \sin(2\pi f t)$$

$$\Rightarrow \boxed{v_{out}(t) = -2\pi f V_{max} \sin(2\pi f t)}$$

<u>We have:</u> $V_{in}(t) = V_{max} \cos(2\pi f t)$

$$\Rightarrow V_{in} = V_{max} \angle 0^\circ \quad (V)$$

$$V_{out}(t) = -2\pi f V_{max} \sin(2\pi f t)$$

$= 2\pi f V_{max} \sin(-2\pi f t) = 2\pi f V_{max} \cdot \cos(2\pi f t + 90^\circ)$

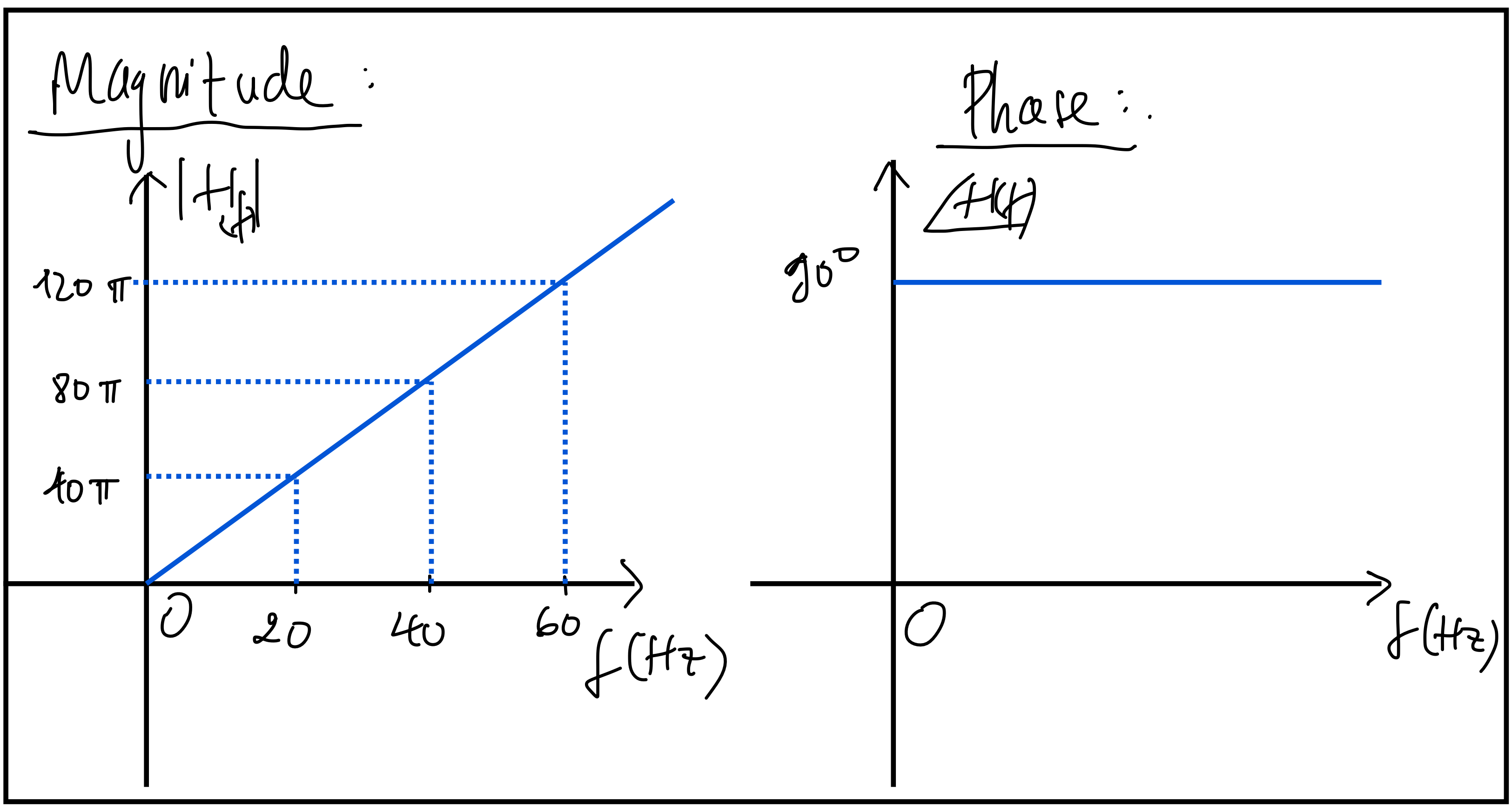
$\Rightarrow V_{out} = 2\pi f V_{max} \angle 90^\circ \quad (V)$

The transfer function:

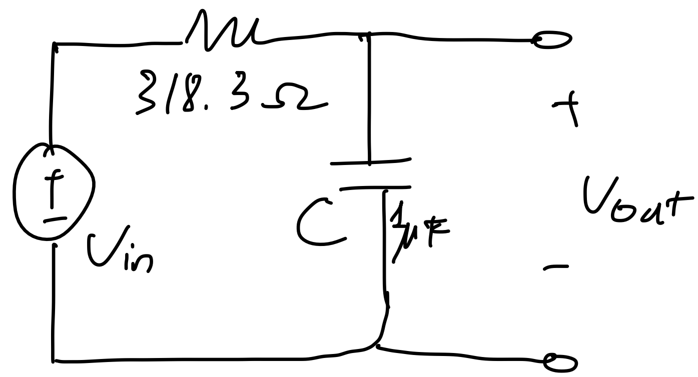
$$H = \frac{V_{out}}{V_{in}} = \frac{2\pi f V_{max} \angle 90^\circ}{V_{max} \angle 0^\circ} = \boxed{2\pi f \angle 90^\circ}$$

$\Rightarrow \boxed{H_{(f)} = j2\pi f}$.

Plot:



Problem 3:



$V_{in}(t) = 5\cos(500\pi t)$
$+ 5\cos(1000\pi t)$
$+ 5\cos(2000\pi t)$

We have: $$\frac{V_{out}}{V_{in}} = \frac{Z_C}{R + Z_C} = \frac{1}{1 + \frac{R}{Z_C}}$$

$$= \frac{1}{1 + j\omega RC}$$

$$\Rightarrow V_{out} = V_{in} \cdot \frac{1}{1 + j\omega RC}$$

* When $V_{in}(t) = 5\cos(500\pi t) \Rightarrow \omega = 500\pi$ (rad/s)

$$\Rightarrow j\omega RC = j \times 500\pi \times \frac{1000}{\pi} \times 10^{-6}$$

$$= 0.5j$$

$$\Rightarrow V_{out} = \frac{5\cos(500\pi t)}{1 + 0.5j} = \frac{5\angle 0^\circ}{1 + 0.5j}$$

$= 4.472 \angle -26.565^\circ$

$\Rightarrow V_{out} = 4.472 \cos(500\pi t - 26.565^\circ)$ (V) 1

+ When $V_{in}(t) = 5\cos(1000\pi t) \Rightarrow \omega = 1000\pi$ (Rad/s)

$\Rightarrow j\omega RC = j \times 1000\pi \times \frac{1000}{\pi} \times 10^{-6} = j$

$\Rightarrow V_{out} = \frac{5\cos(1000\pi t)}{1 + j} = \frac{5\angle 0^\circ}{1+j} = 3.536 \angle -45^\circ$

$\Rightarrow V_{out}(t) = 3.536 \cos(1000\pi t - 45^\circ)$ (V) 2

+ When $V_{in}(t) = 5\cos(2000\pi t) \Rightarrow \omega = 2000\pi$ (Rad/s)

$\Rightarrow j\omega RC = j \times 2000\pi \times \frac{1000}{\pi} \times 10^{-6} = 2j$

$\Rightarrow V_{out} = \frac{5\cos(2000\pi t)}{1 + 2j} = \frac{5\angle 0^\circ}{1+2j}$

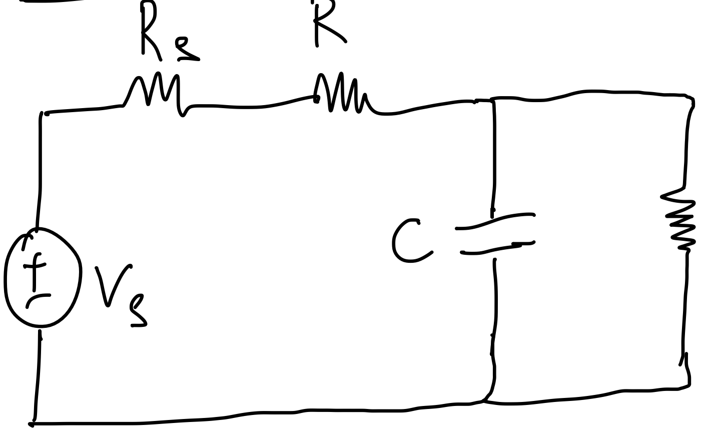
$= 2.236 \angle -63.435$ (V) 3

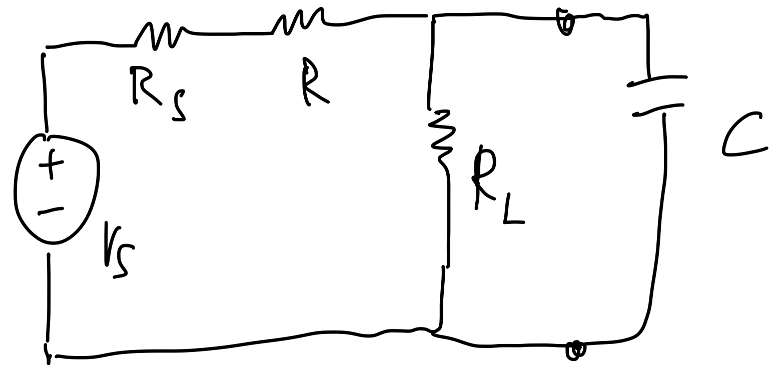
$\Rightarrow V_{out}(t) = 2.236 \cos(2000\pi t - 63.435)$ (V) 3

From above analysis, we have:

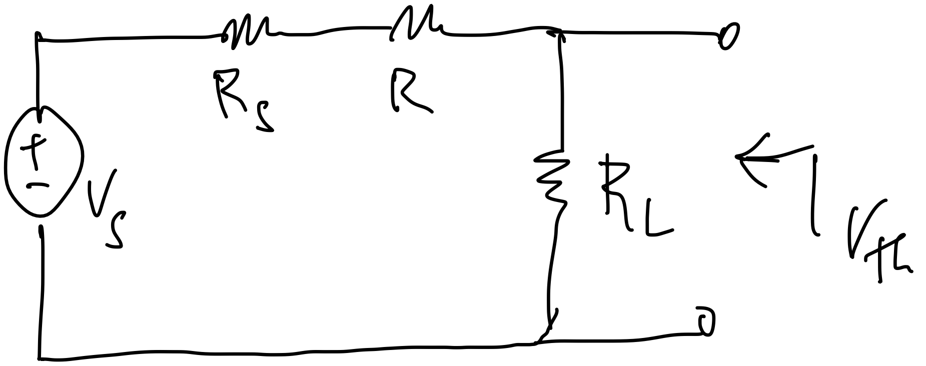
$$\boxed{\begin{aligned} V_{out}(t) &= 4.472\cos(500\pi t - 26.565^\circ) \\ &+ 3.536\cos(1000\pi t - 45^\circ) \\ &+ 2.236\cos(2000\pi t - 63.435^\circ) \end{aligned}}$$

Problem 5:





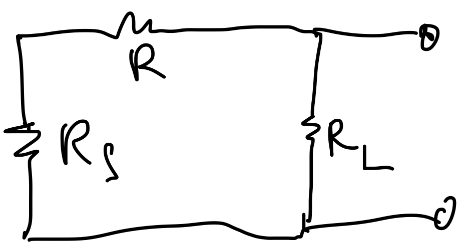
Need to find Thevenin equivalent for:



Using voltage divider, we have:

$$V_{th} = \frac{R_L}{R_s + R + R_L} V_s .$$

Now, find Z_{th}, short the voltage source:

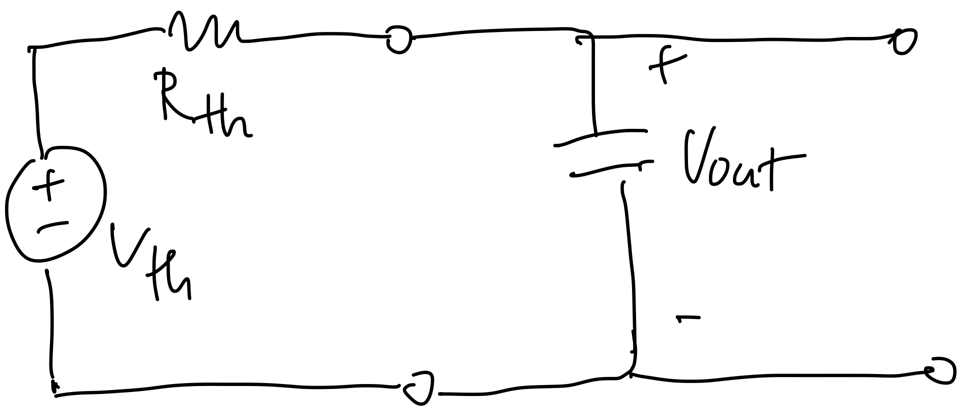


Since $R_L \parallel (R \text{ series } R_s)$

$$\Rightarrow R_{th} = \frac{R_L \times (R + R_s)}{R_L + R + R_s}$$

$$\Rightarrow R_{th} = \frac{R_L(R+R_S)}{R_L+R+R_S}$$

$\Rightarrow$ We have:



$$Z_C = \frac{1}{j\omega C}$$

$$\Rightarrow H(f) = \frac{V_{out}}{V_{th}} = \frac{Z_C}{R_{th}+Z_C} = \frac{1}{1+\frac{R_{th}}{Z_C}}$$

Since $V_{th} = \frac{R_L}{R_S+R+R_L} V_s$

$$\Rightarrow \frac{V_{out}}{V_s} = \frac{1}{1+\frac{R_{th}}{Z_C}} \cdot \frac{R_L}{R_S+R+R_L} = \frac{R_L}{R_S+R+R_L} \cdot \frac{1}{1+R_{th}j\omega C}$$

$$= \frac{R_L}{R_S+R+R_L} \cdot \frac{1}{1+jR_{th}2\pi f C}$$

$$= \frac{R_L}{R_S + R + R_L} \cdot \frac{1}{1 + j\dfrac{f}{\dfrac{1}{2\pi R_{th} C}}} \quad \text{. with } f_B = \frac{1}{2\pi R_{th} C}$$

$$\Rightarrow \boxed{H(f) = \frac{R_L}{R_S + R + R_L} \cdot \frac{1}{1 + j(f/f_B)}}$$

$$\text{With } f_B = \frac{1}{2\pi R_{th} C} \quad \& \quad R_{th} = \frac{R_L(R + R_S)}{R_L + R + R_S}$$

(Q.E.D)

b) $C = 0.2\,\mu F$, $R_S = 2\,K\Omega$, $R = 47\,K\Omega$

$R_L = 1\,k\,\Omega$

$$\Rightarrow R_{th} = \frac{R_L(R + R_S)}{R_L + R + R_S} = \frac{1(2+47)}{1+2+47} = \frac{49}{50}\ (K\Omega)$$

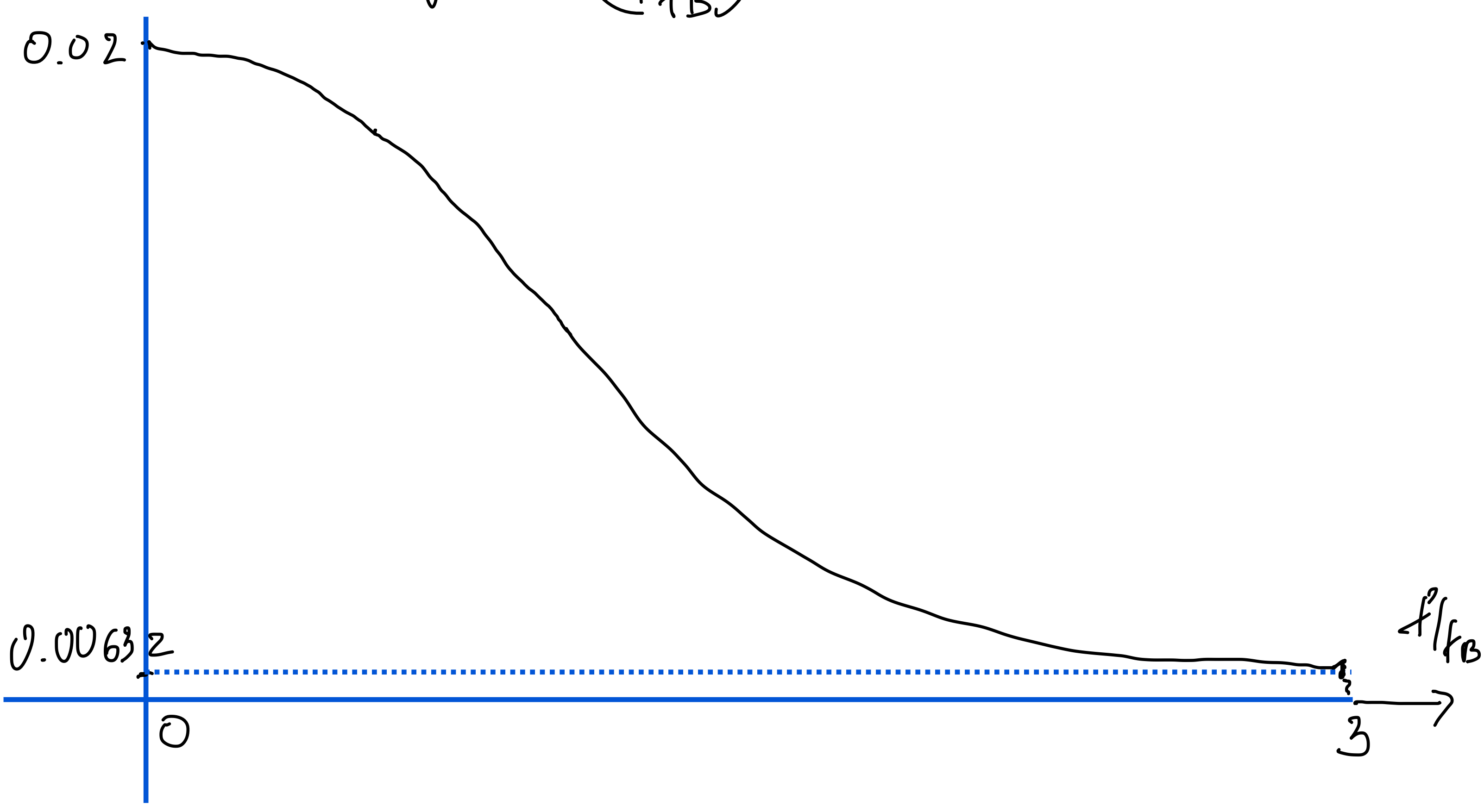
$$= 0.98\,(K\Omega)$$

$$\Rightarrow f_B = \frac{1}{2\pi \times 0.98 \times 1000 \times 0.2 \times 10^{-6}} = 812\,(Hz)$$

<u>Also</u>: $$\frac{R_L}{R_S + R + R_L} = \frac{1}{1+47+2} = \frac{1}{50}$$

$$\Rightarrow H(f) = \frac{1}{50} \cdot \frac{1}{1 + j\left(f/812\right)} = \frac{0.02}{1 + j\left(f/812\right)}$$

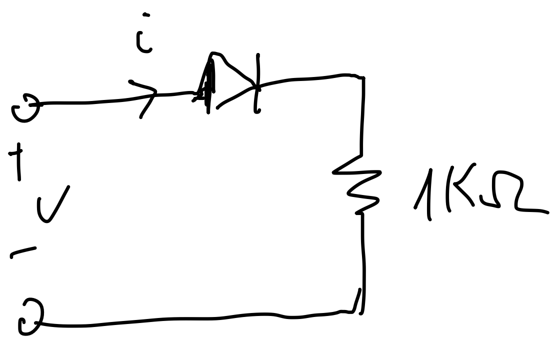
$$\Rightarrow |H(f)| = \frac{0.02}{\sqrt{1 + \left(f/f_B\right)^2}}$$



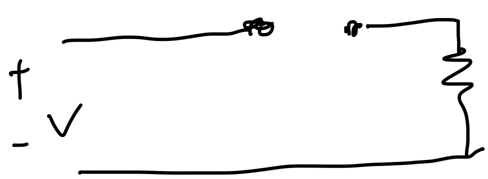
Problem 10: Sketch i vs v.

Assume diode ideal & v: $-10 \to 10V$

a)

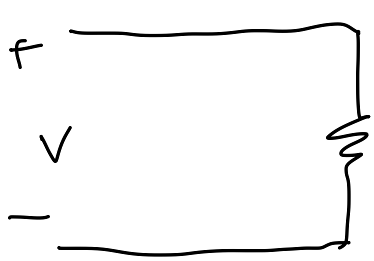


⊕ When $v: -10 \to 0V$, diode is off, then we have:



$\Rightarrow i = 0$

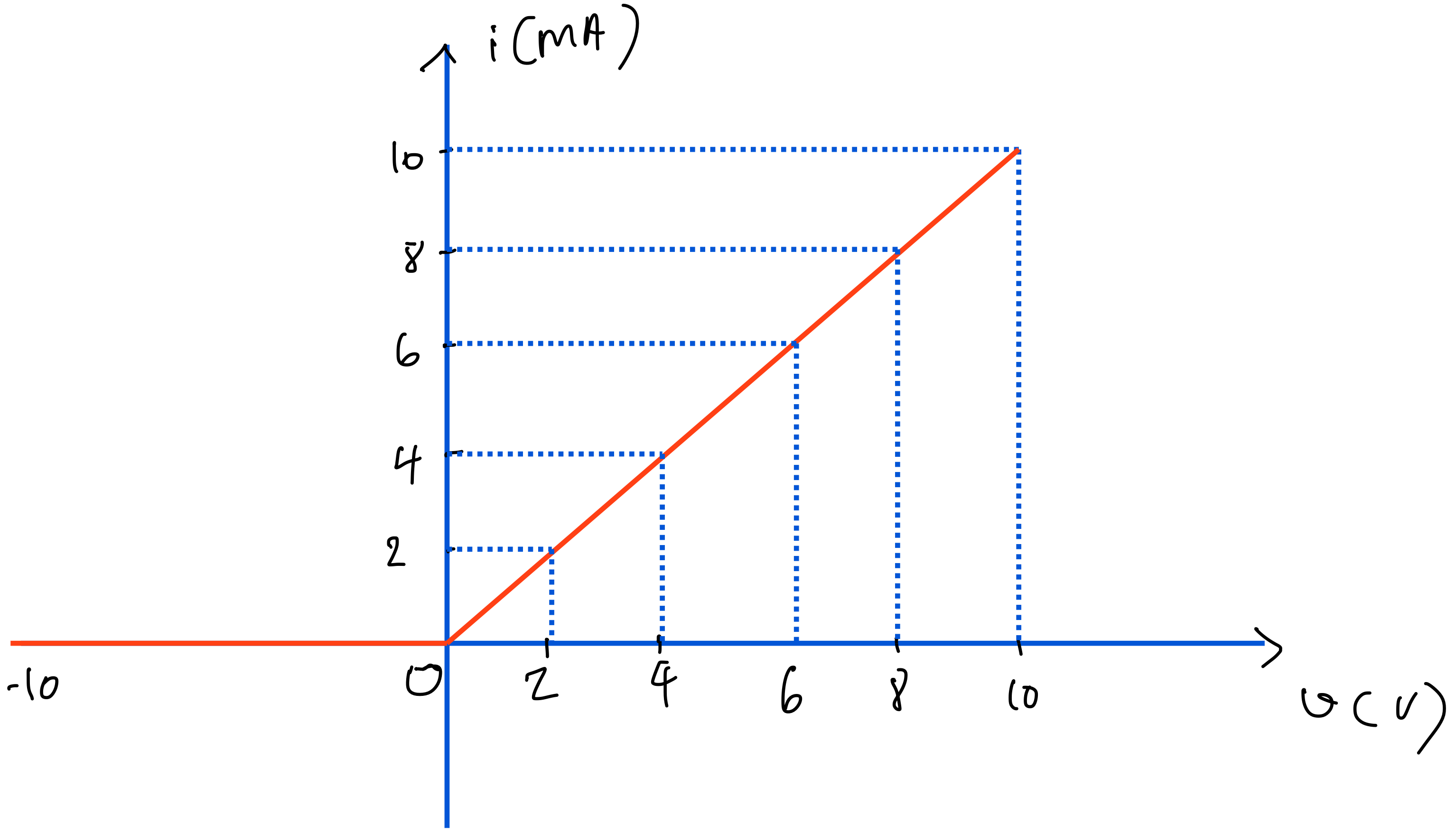
⊕ when $v: 0 \to 10V$, diode is on, then we have:



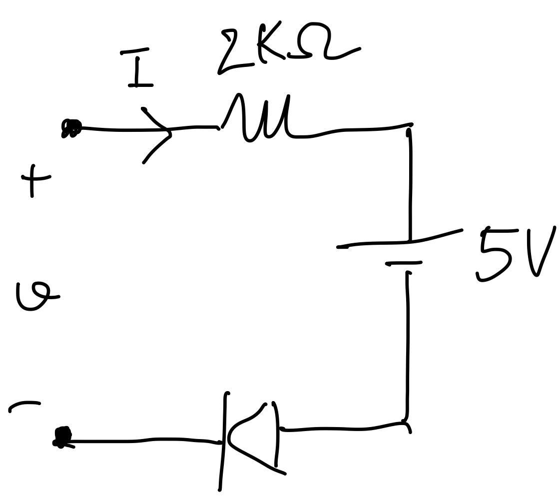
$$\Rightarrow i = \frac{v}{R} = \frac{v}{1000\,\Omega}\ (A)$$

Then, we have a diagram:

v(V)	≤0	2	4	6	8	10
i(mA)	0	2	4	6	8	10

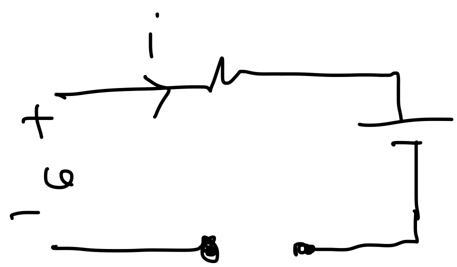


b)



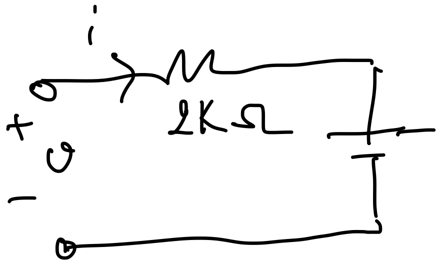
⊕ When the voltage $v: -10 \to 5V$ the current $i < 0$ ⇒ diode is off, then

we have:



$\Rightarrow i = 0$

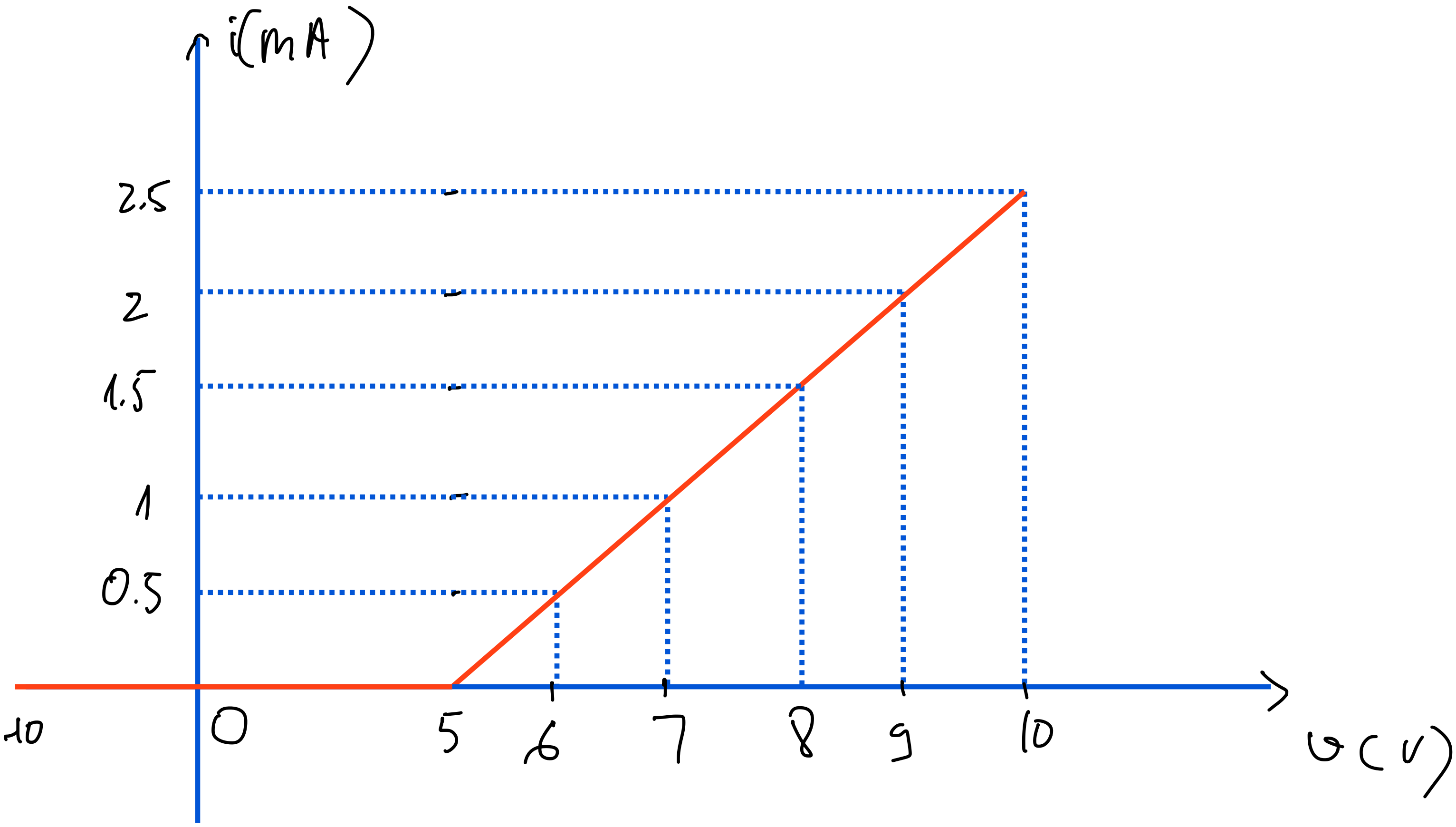
⊕ When voltage $v: 5 \to 10\ V$, we have the diode is on.



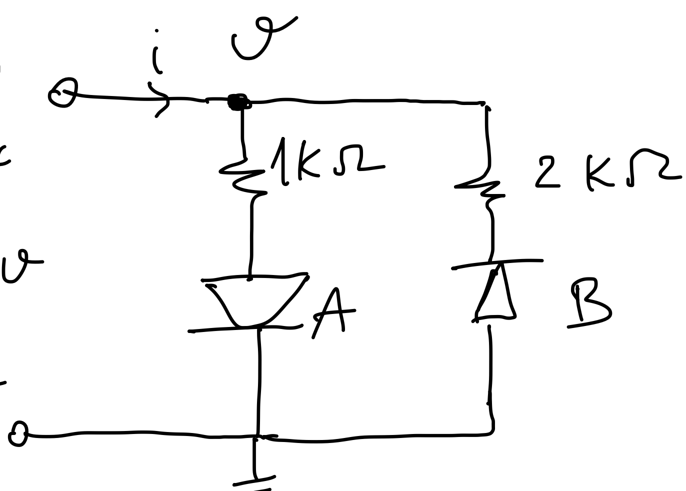
$\Rightarrow -v + iR + 5V = 0$

$\Rightarrow i = \dfrac{v-5}{2K\Omega} \geq 0$ (mA)

v(V)	≤ 5	6	7	8	9	10
i(mA)	0	0.5	1	1.5	2	2.5



c)

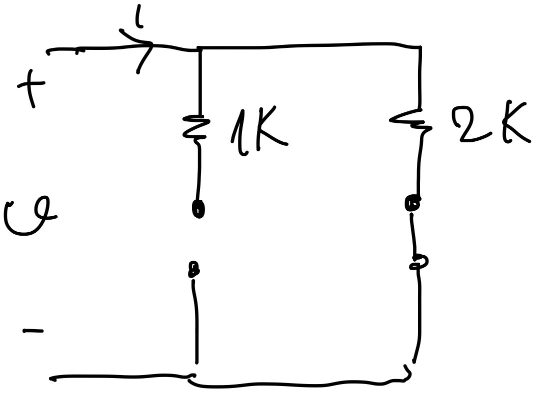


When $v: -10 \rightarrow 0$

$\Rightarrow$ the diode A is off

diode B is on

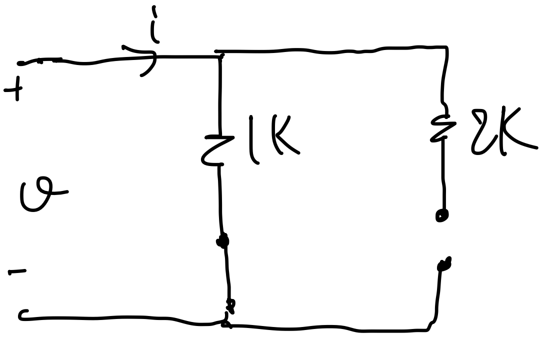
⇒ We have:



$\Rightarrow i = \frac{v}{2k}$ (mA)

When voltage $v: 0 \to 10V$.
the diode A is on while diode B is of.

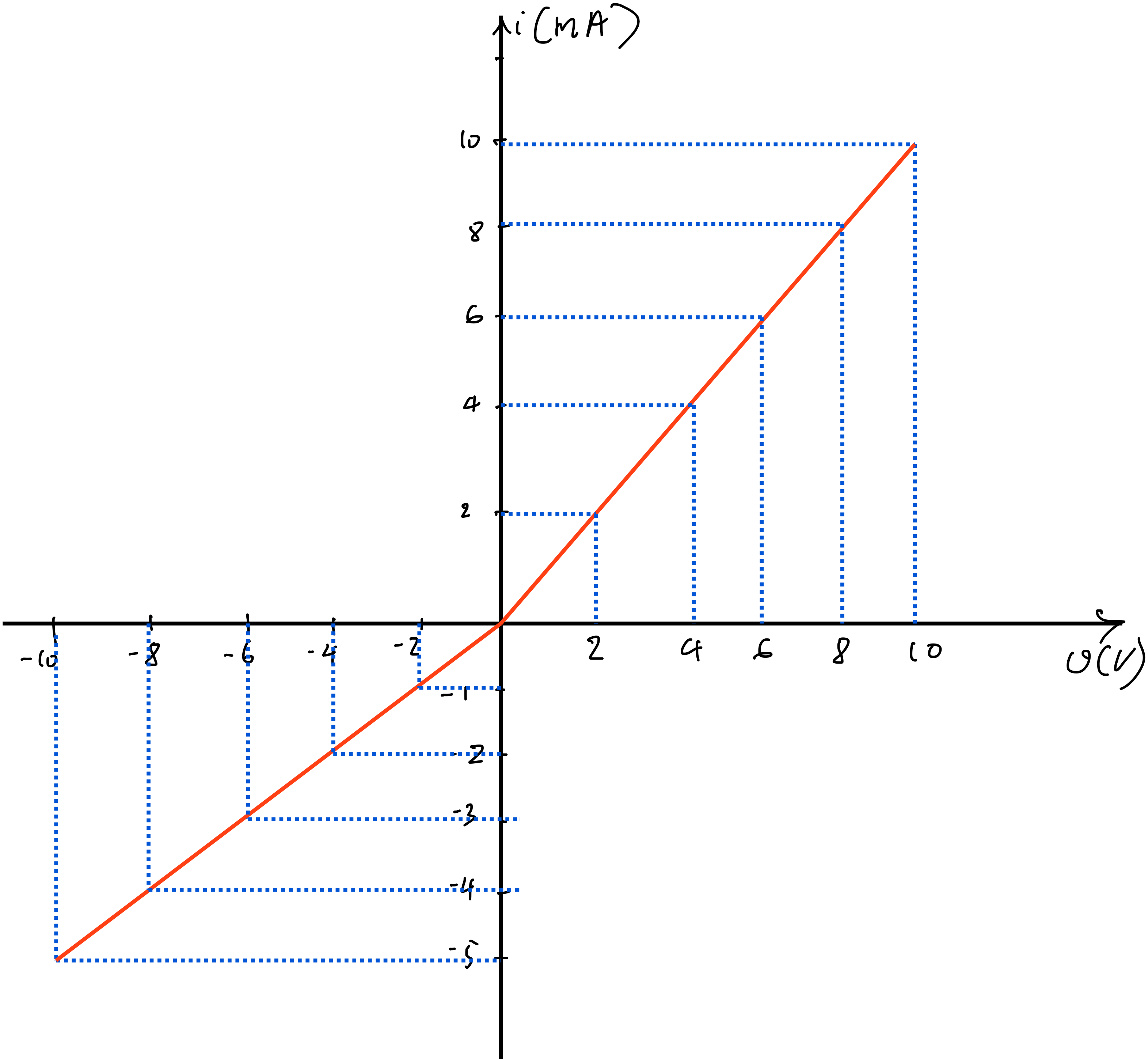
<u>We have:</u>



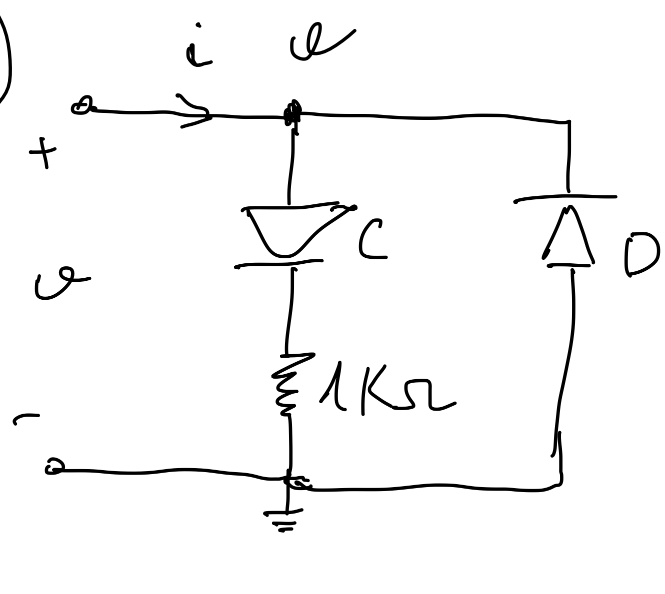
$\Rightarrow i = \frac{v}{1K}$ (mA)

v(V)	-10	-8	-6	-4	-2	0
i(mA)	-5	-4	-3	-2	-1	0

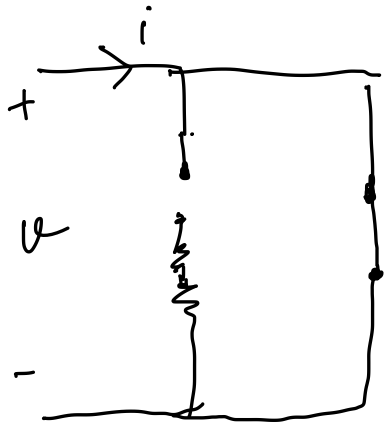
v(V)	0	2	4	6	8	10
i(mA)	0	2	4	6	8	10



d)



+ When voltage v : $-10 \to 0\,V$, the diode C is off & D is on so we have:



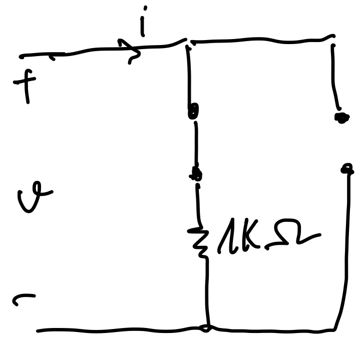
$\Rightarrow$ no resistance

$\Rightarrow v = i \times 0$

$\Rightarrow i$ is undefined

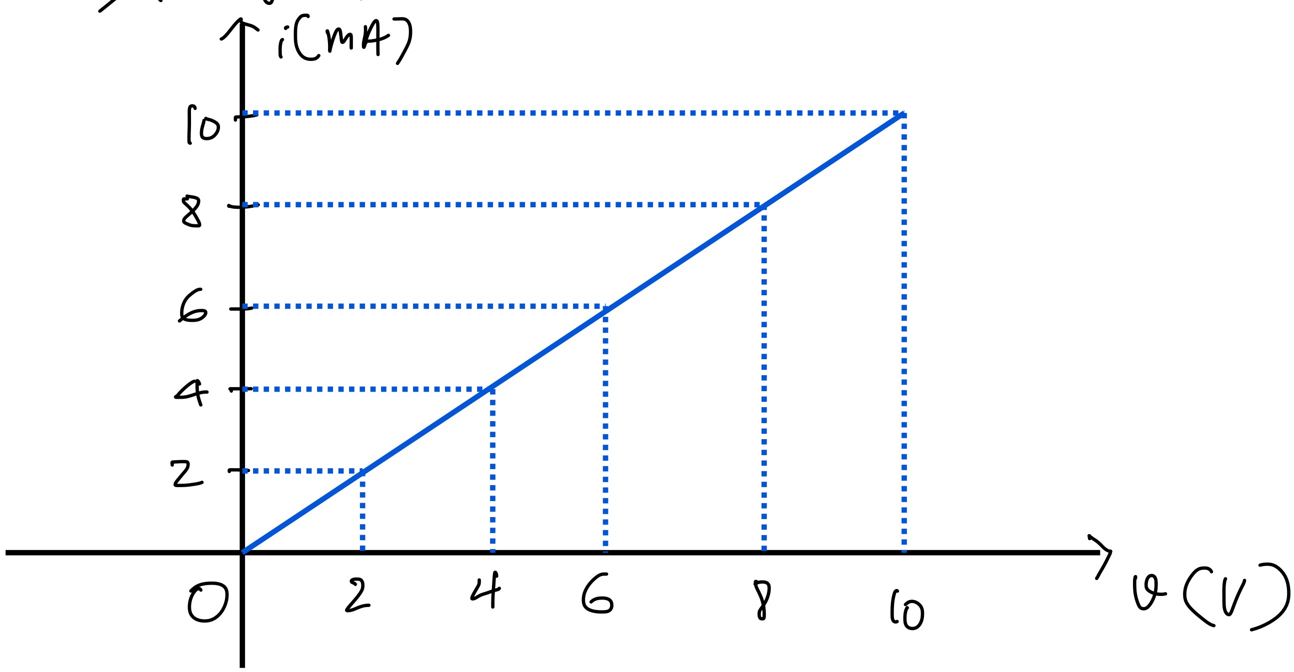
(f) When voltage v : $0 \rightarrow 10\,V$, we have diode C is on & D is off

$\Rightarrow$



$\Rightarrow i = \dfrac{v}{1K\Omega}$ (mA)

v(V)	≤ 0	2	4	6	8	10
i(mA)	undefined	2	4	6	8	10



Problem 13:

a) Design a half-wave rectifier.

+ Average voltage 9V with a peak-to peak ripple at 2V to a load.

+ current load 100mA

+ ideal diode & 60Hz, ac voltage

$\Rightarrow V_L = 9V, \; V_r = 2V, \; I_L = 100\,mA = 0.1A$

$f = 60Hz \Rightarrow T = \frac{1}{f} = \frac{1}{60}\,(s)$

$\Rightarrow C = \frac{I_L T}{V_r} = \frac{0.1 \times 1/60}{2V} = \frac{0.1}{120}\,(F)$

$= 833.33\,(\mu F)$

And $\omega = 2\pi f = 120\pi$

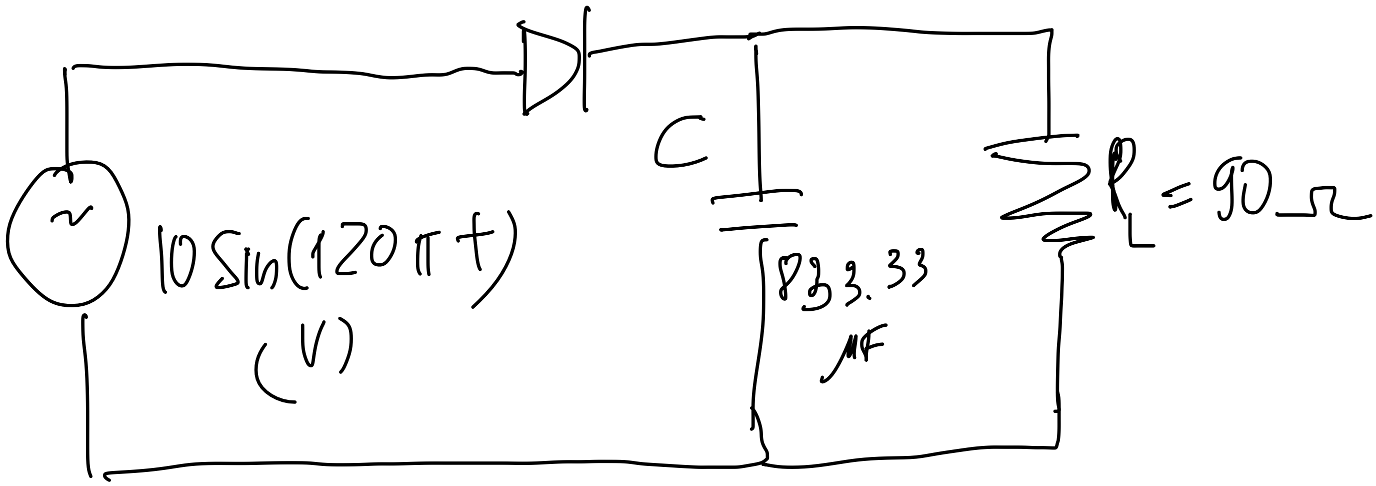
Since $V_L = V_m - \frac{V_r}{2} \Rightarrow V_m = V_L + \frac{V_r}{2} = 9 + \frac{2}{2}$

$= 10V$

$\Rightarrow v_s(t) = 10 \sin(120\pi t)$

Also $V_L = I_L R_L \Rightarrow R_L = \frac{V_L}{I_L} = \frac{9V}{0.1A} = 90\,\Omega$

⇒ the fully circuit:



b) Repeated With full-Wave bridge rectifier.

We also have $V_L = 9V$, $V_r = 2V$, $I_L = 100\,mA$

$f = 60\,Hz$, $W = 120\pi$

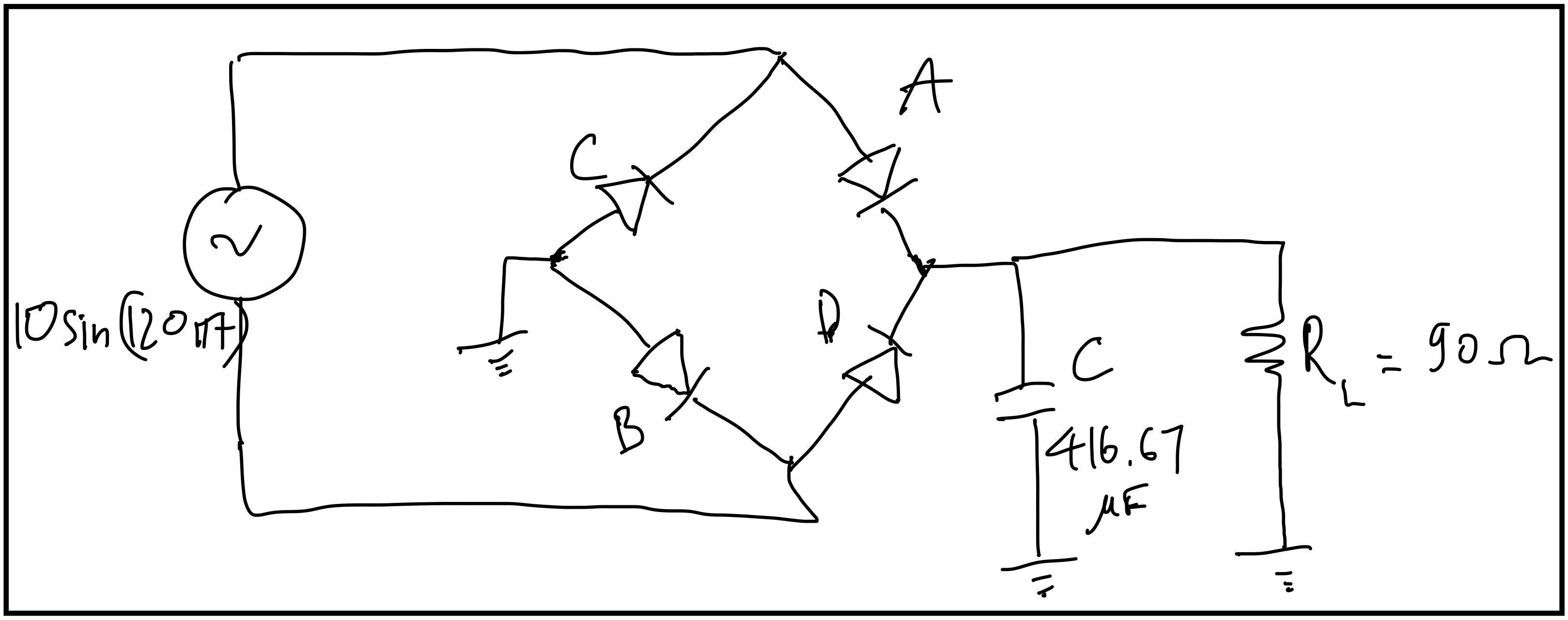
$V_m = V_L + \frac{V_r}{2} = 9 + \frac{2}{2} = 10\,V$

But for C, we have: $C = \frac{I_L T}{2 V_r} = \frac{0.1 \times 1/60}{2 \times 2}$

$\Rightarrow C = \frac{0.1}{240} = 416.67\,(\mu F)$

$$R_L = \frac{V_L}{I_L} = \frac{9}{0.1A} = 90(\Omega)$$

So, we have the circuit diagram for full wave bridge rectifier :



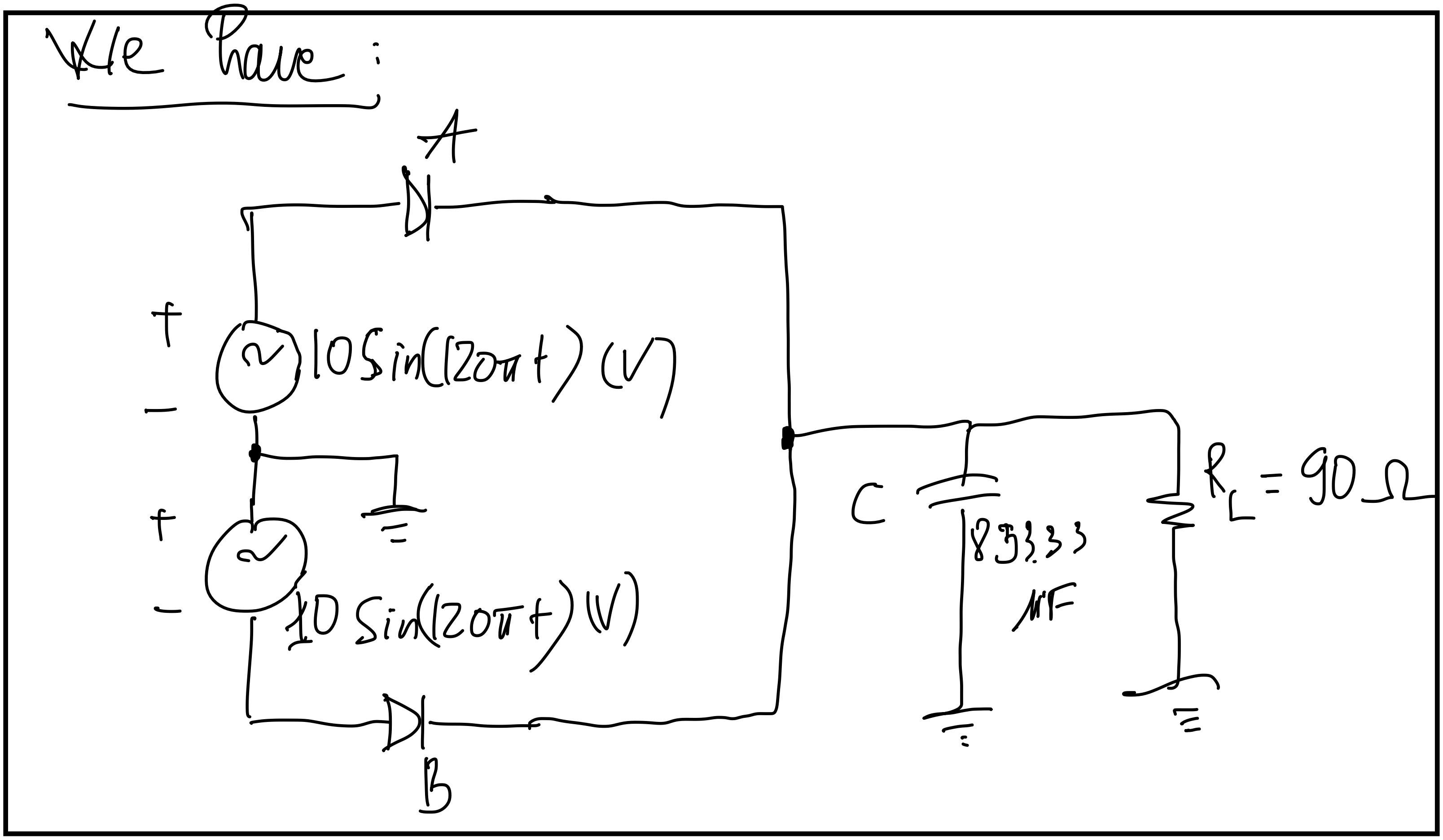
c) Repeat with two diode & out of phase voltage to form a full wave rectifier.

Given: $V_L = 9V$, $i_L = 100mA$, $f = 60Hz$

$\Rightarrow \omega = 120\pi$, $V_r = 2V$, $V_m = 10V$

$$C = \frac{I_L T}{V_r} = \frac{0.1 \times 1/60}{2V} \Rightarrow C = 833.33(\mu F)$$

$$R = \frac{V_L}{i_L} = \frac{9\,V}{0.1\,A} = 90(\Omega)$$



d) Repeat with assuming that the diodes have forward drop of 0.8V. (design a half wave rectifier).

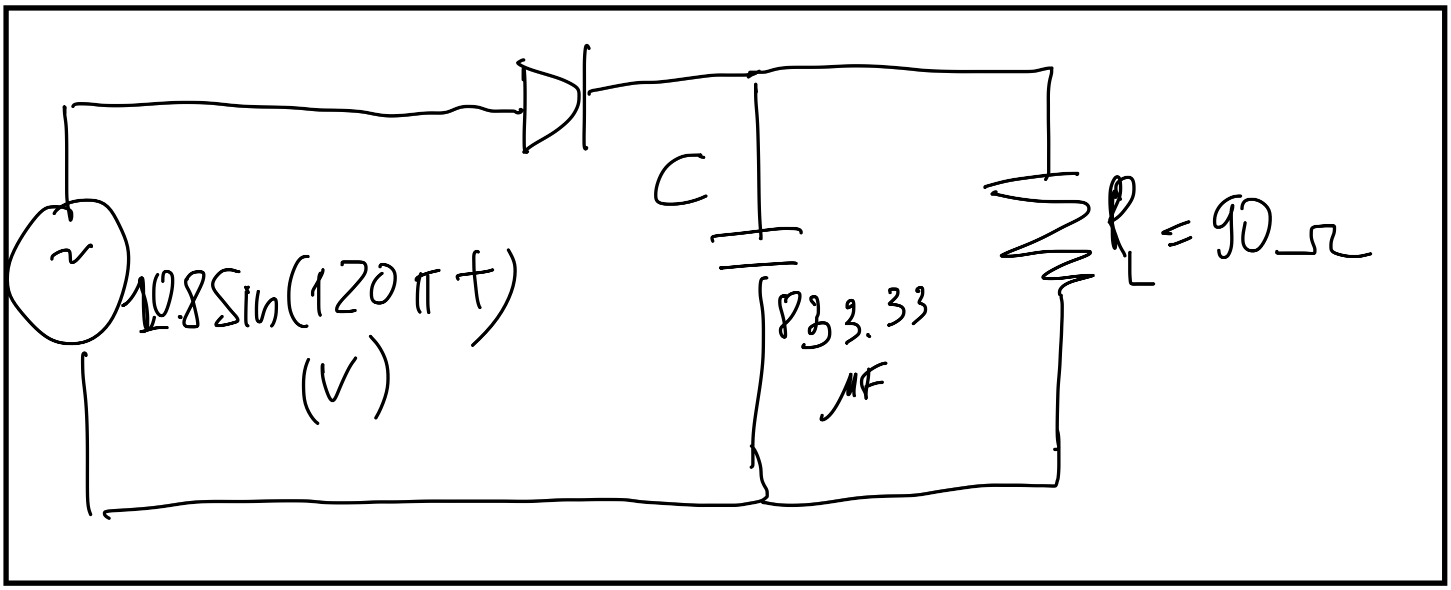
As the a, we have already had:

$V_L = 9V$, $V_r = 2V$, $\omega = 120\pi$, $C = 833.33\mu F$

$R = 90\,\Omega$, and $V_m = 10(V)$

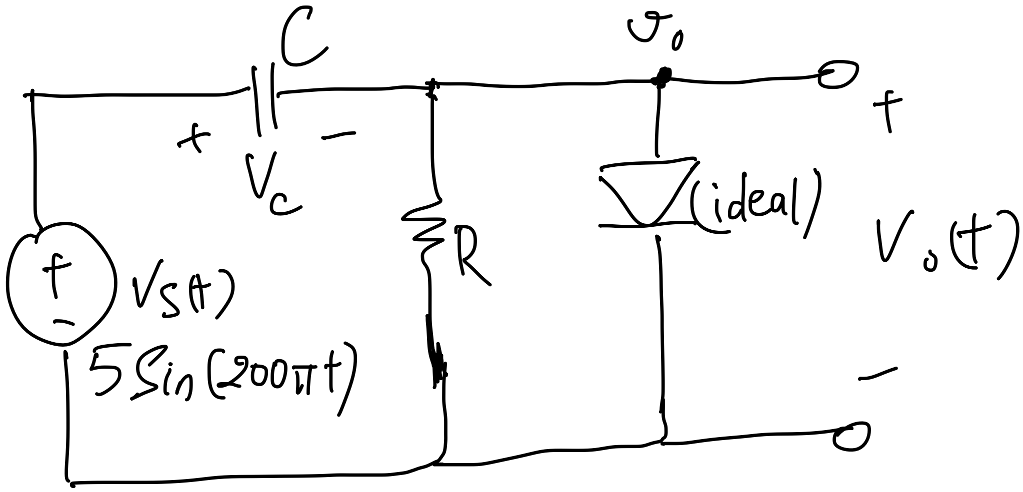
Since in this case, diode is not ideal, & has forward drop of 0.8V $\Rightarrow V_m = 10 + 0.8 = 10.8$ (V)

$\Rightarrow$ We have a design:

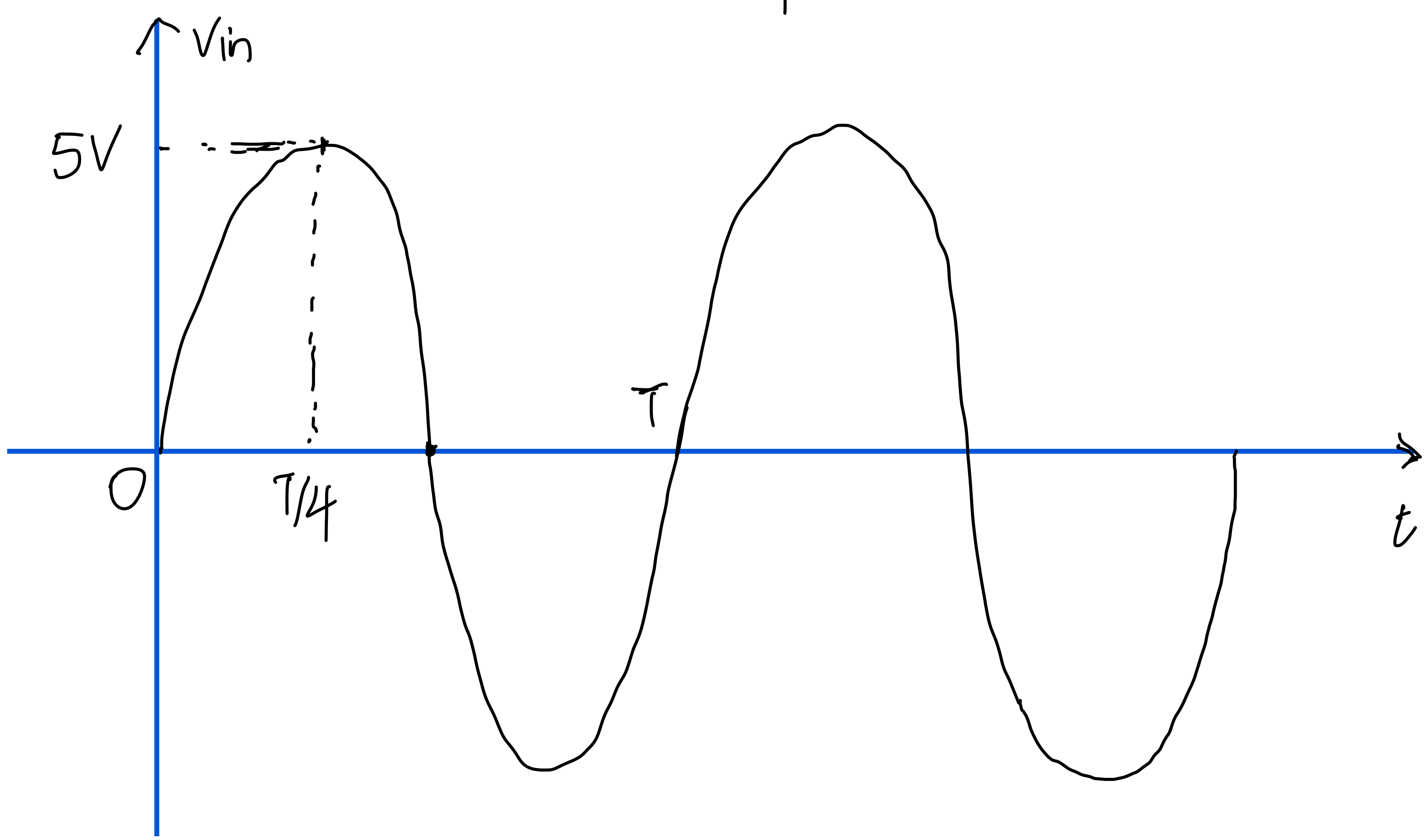


Problem 14:

Given: the RC is very long compared with the period of input, diode is ideal.



* We have the wave form for V_{in}:



When $t: 0 \to T/4$, assump the capacitor has already in steady state, the $v_{in} \leq V_c$

Due to $RC \gg T$ => the capacitor will not discharged quickly, in this time $V_C = V_m \Rightarrow V_{out} = V_{in} - V_m$ and the diode will never go into forward.

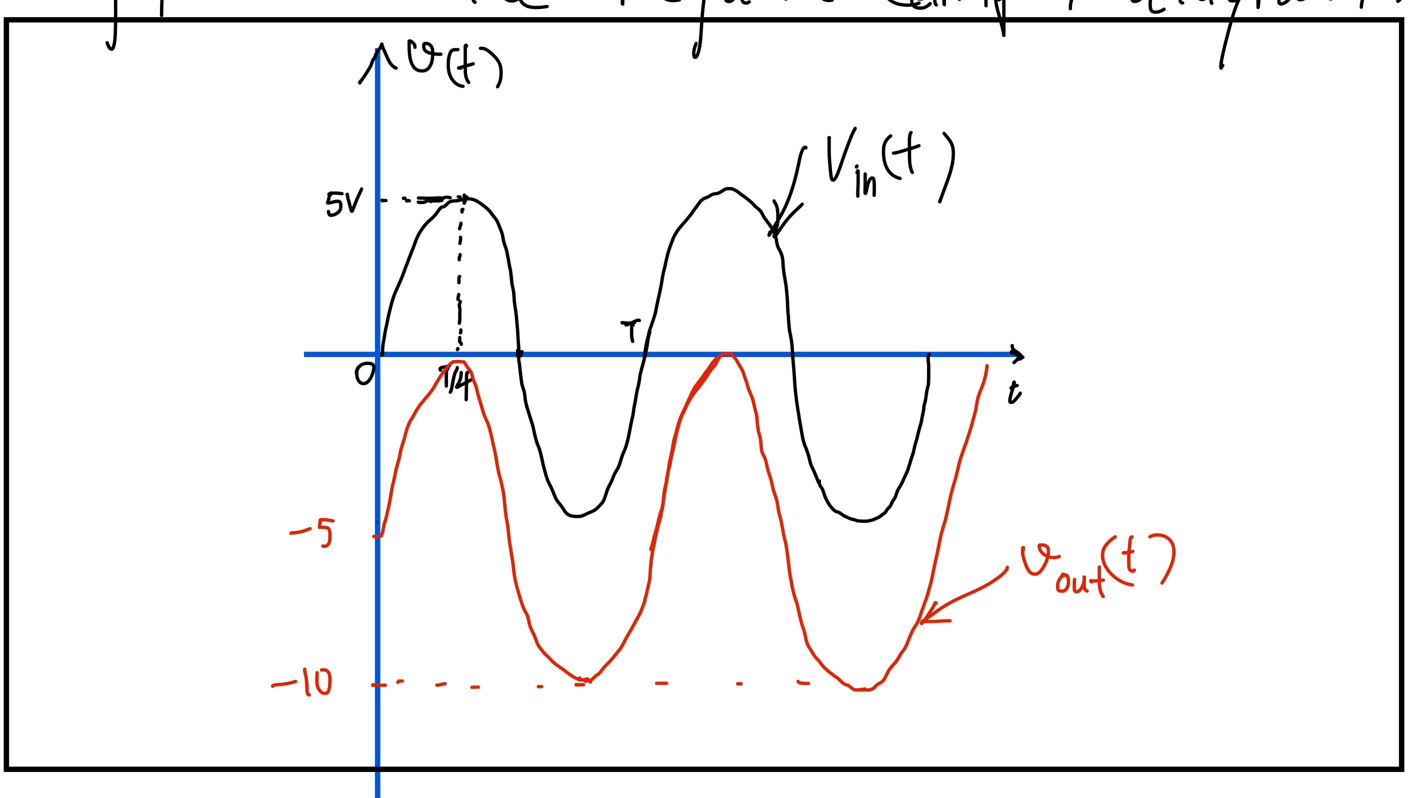
at $t = T/4$, $v_{in} = V_{max} \Rightarrow v_o = 0V$

$t = 0 \Rightarrow v_{in} = 0 \Rightarrow v_o = -V_m$.

When $t: T/4 \to T$, $v_{OUT} = -V_m + V_{in}$

$\Rightarrow v_{out} = -5 + 5\sin(200\pi t)$,

Finally, we have the negative clamper diagram:



Problem 16 : All device are NMOS mosfet. & $v_{th} = 0.7V$

[redacted]

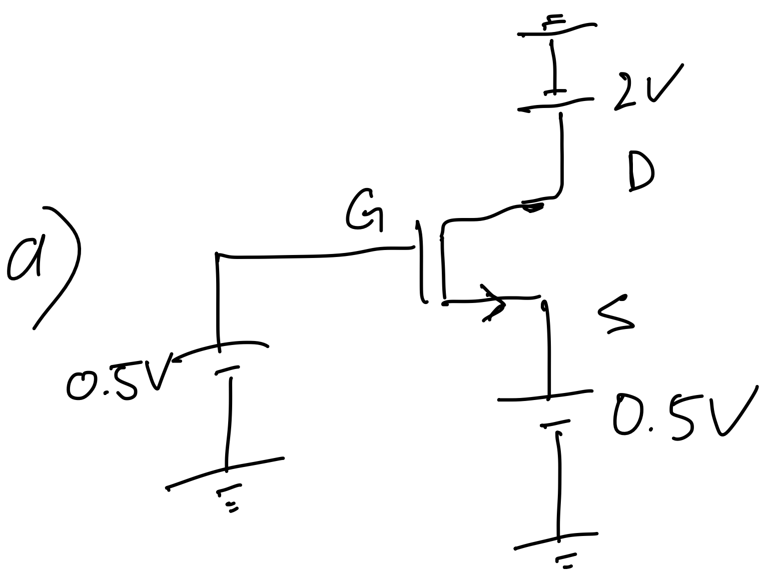
So, we have:

+ cut off region : $V_{GS} \leq V_{th}$

+ Triode $\Leftrightarrow$ Resistor : $\begin{cases} V_{gs} \geq V_{th} \\ 0 \leq v_{ds} \leq v_{gs} - v_{th} \end{cases}$

+ saturation : $\begin{cases} v_{gs} \geq v_{th} \\ v_{ds} \geq v_{gs} - v_{th} \end{cases}$

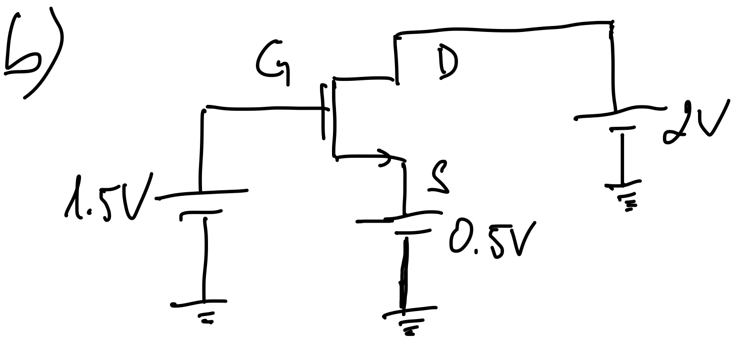
a)



Since $V_{GS} = 0.5 - 0.5 = 0(V) < V_{th}$

$\Rightarrow$ $\boxed{\text{Cut of region}}$

b)

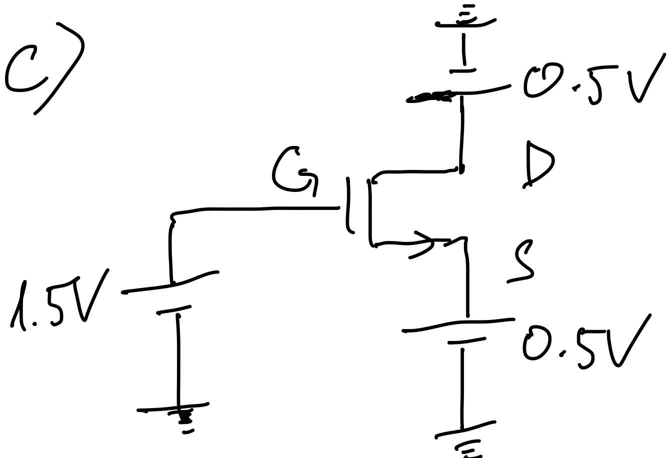


$v_{gs} = 1.5 - 0.5 = 1V \geq V_{th} = 0.7V$

$v_{ds} = 2 - 0.5 = 1.5V > v_{gs} - v_{th} = 1 - 0.7 = 0.3$

$\Rightarrow \begin{cases} v_{gs} \geq V_{th} \\ v_{ds} \geq v_{gs} - v_{th} \end{cases}$ $\Rightarrow$ $\boxed{\text{Saturation region or neither off nor resistor}}$

c)



$V_{gs} = 1.5 - 0.5 = 1 > V_{th}$

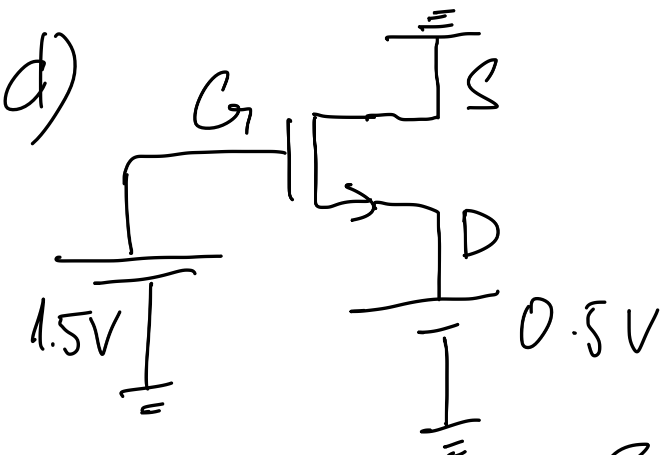
$\Rightarrow$ on condition.

$v_{ds} = 0.5 - 0.5 = 0$

Since $v_{ds} = 0 < V_{gs} - V_{th}$
$= 1 - 0.7 = 0.3$

$\Rightarrow v_{ds} < v_{gs} - V_{th} \Rightarrow$ $\boxed{\text{act as resistor}}$

d)



$v_{gs} = 1.5 - 0 = 1.5 > V_{th}$

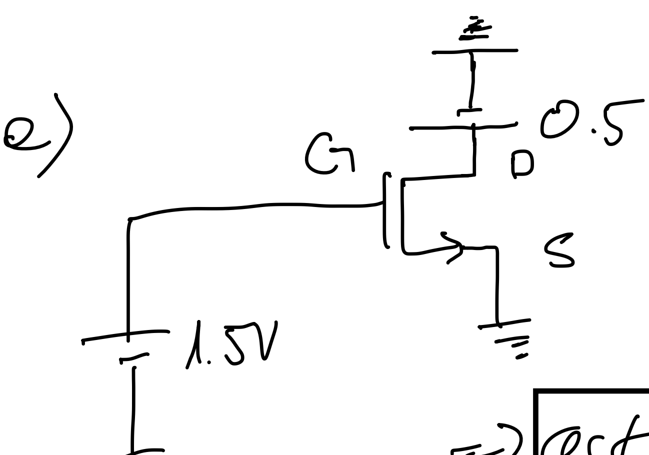
$\Rightarrow$ on condition.

$v_{ds} = 0.5 - 0 = 0.5$

Since $v_{ds} = 0.5 < v_{gs} - v_{th}$
$= 1.5 - 0.7 = 0.8$

$\Rightarrow$ $\boxed{\text{act as resistor}}$

e)



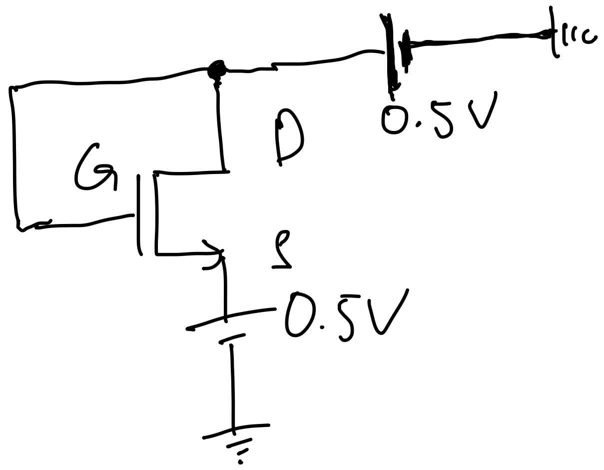
$v_{gs} = 1.5 - 0 = 1.5 > V_{th}$

$\Rightarrow$ on condition

$v_{ds} = 0.5 (V) < v_{gs} - V_{th}$
$= 1.5 - 0.7$
$= 0.8$

$\Rightarrow$ $\boxed{\text{act as resistor}}$

f)

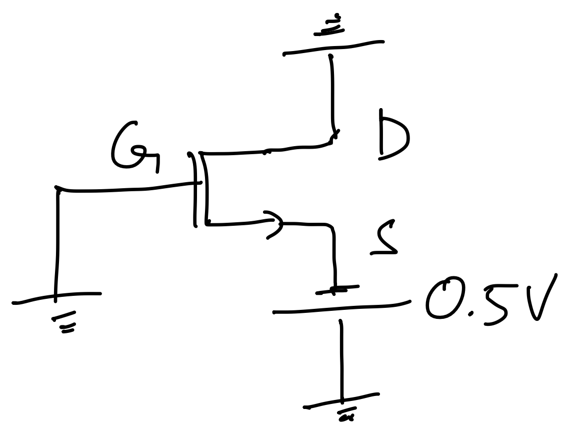


$v_{gs} = 0.5 - 0.5 = 0$

$< V_{th} = 0.7V$

$\Rightarrow$ $\boxed{\text{Cut off region}}$

g)

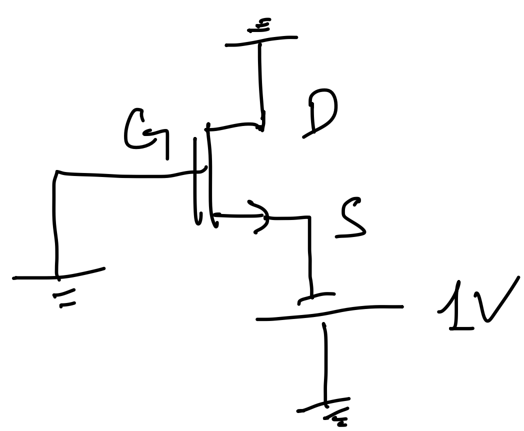


$V_{gs} = 0 - (-0.5) = 0.5(V)$

$< V_{th} = 0.7V$

$\Rightarrow$ $\boxed{\text{Cut off region}}$

h)



$v_{gs} = 0 - (-1) = 1(V)$

$> V_{th} = 0.7(V)$

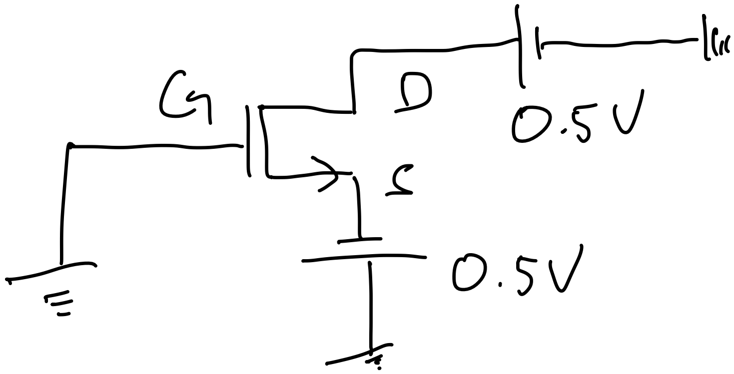
$\Rightarrow$ on condition.

$v_{ds} = 0 - (-1) = 1V$

$> v_{gs} - V_{th} = 1 - 0.7 = 0.3V$

$\Rightarrow$ $\boxed{\text{in saturation region or neither cut off nor resistor}}$

i)



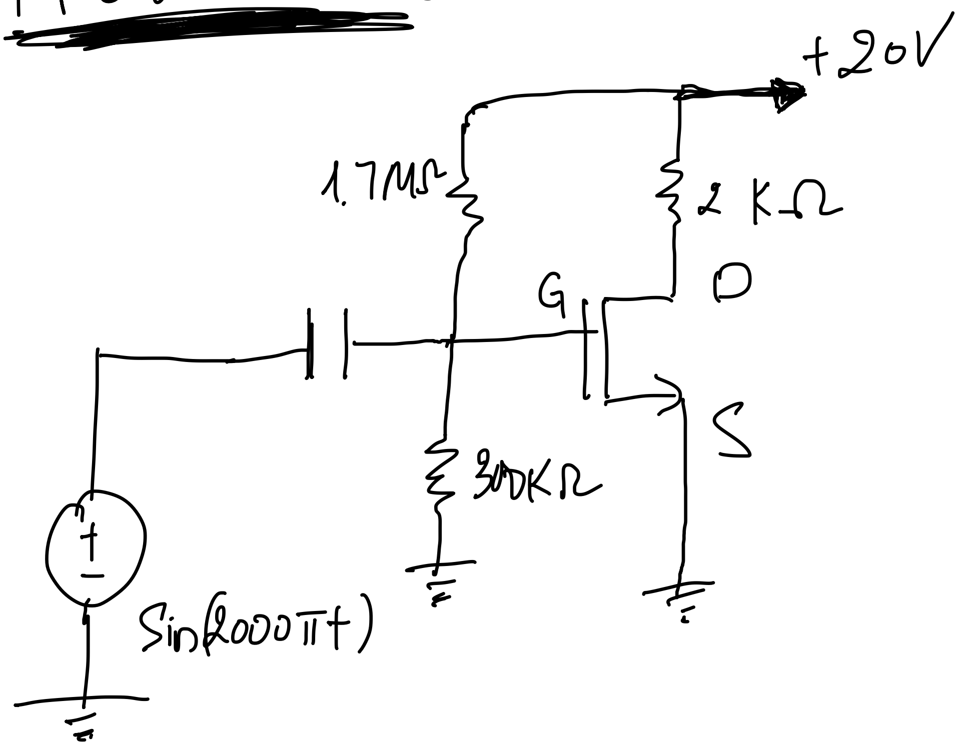
$v_{gs} = 0 - (-0.5)$

$= 0.5 < 0.7V$

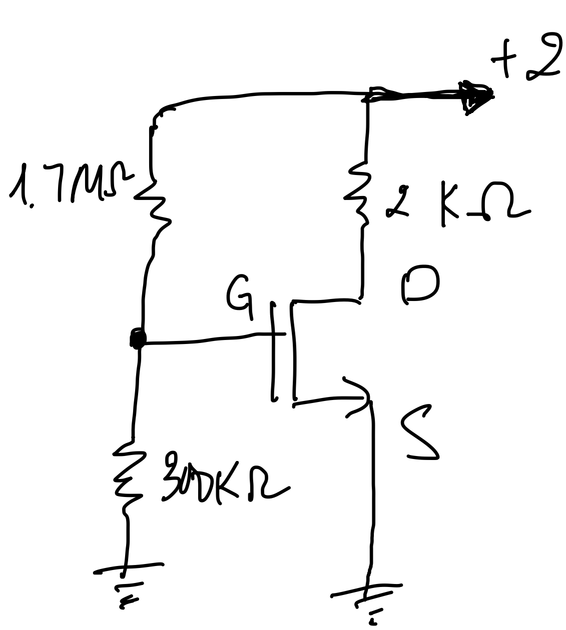
$= v_{th}$

$\Rightarrow$ $\boxed{\text{off region}}$

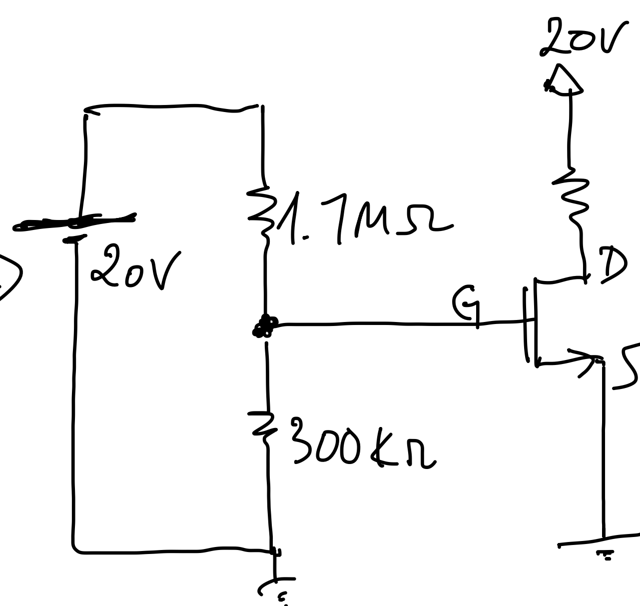
Problem 19



a) Apply the suppersposition for DC sources:
(the coupling is open circuit for DC)



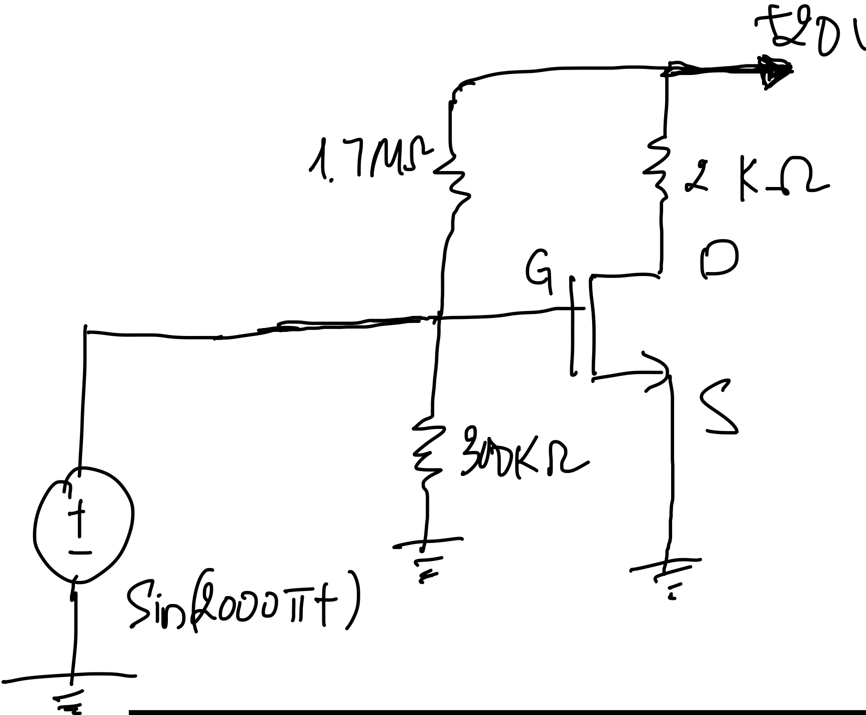
$\Longleftrightarrow$



Apply the divide voltage :

$$V_G = V_{GSQ} = \frac{300\times10^3}{300\times10^3 + 1.7\times10^6} \times 20 = 3(V) \quad (1)$$

For the ac circuit, the coupling capacitor is a Short circuit, we have:



We can see,

$$v_{GS}(t) = v_{in}(t) = \sin(2000\pi t) \quad (2)$$

From (1) & (2), the voltage of $v_{GS}(t)$.

$$\boxed{v_{GS}(t) = 3 + \sin(2000\pi t)\ (V)}$$

b) $V_{th} = 1V$ & $K = 0.5 (mA/V^2)$

Need to sketch its drain characteristics to scale for $v_{GS} = 1, 2, 3, \& 4V$.

With saturation region, we have:

$$i_D = k(V_{GS} - V_{th})^2 = 0.5(V_{GS} - 1)^2 \text{ (mA)}$$

⊕ $V_{GS} = 1\,V$

$\Rightarrow i_D = 0 \text{ (mA)}$

⊕ $V_{GS} = 2\,V$

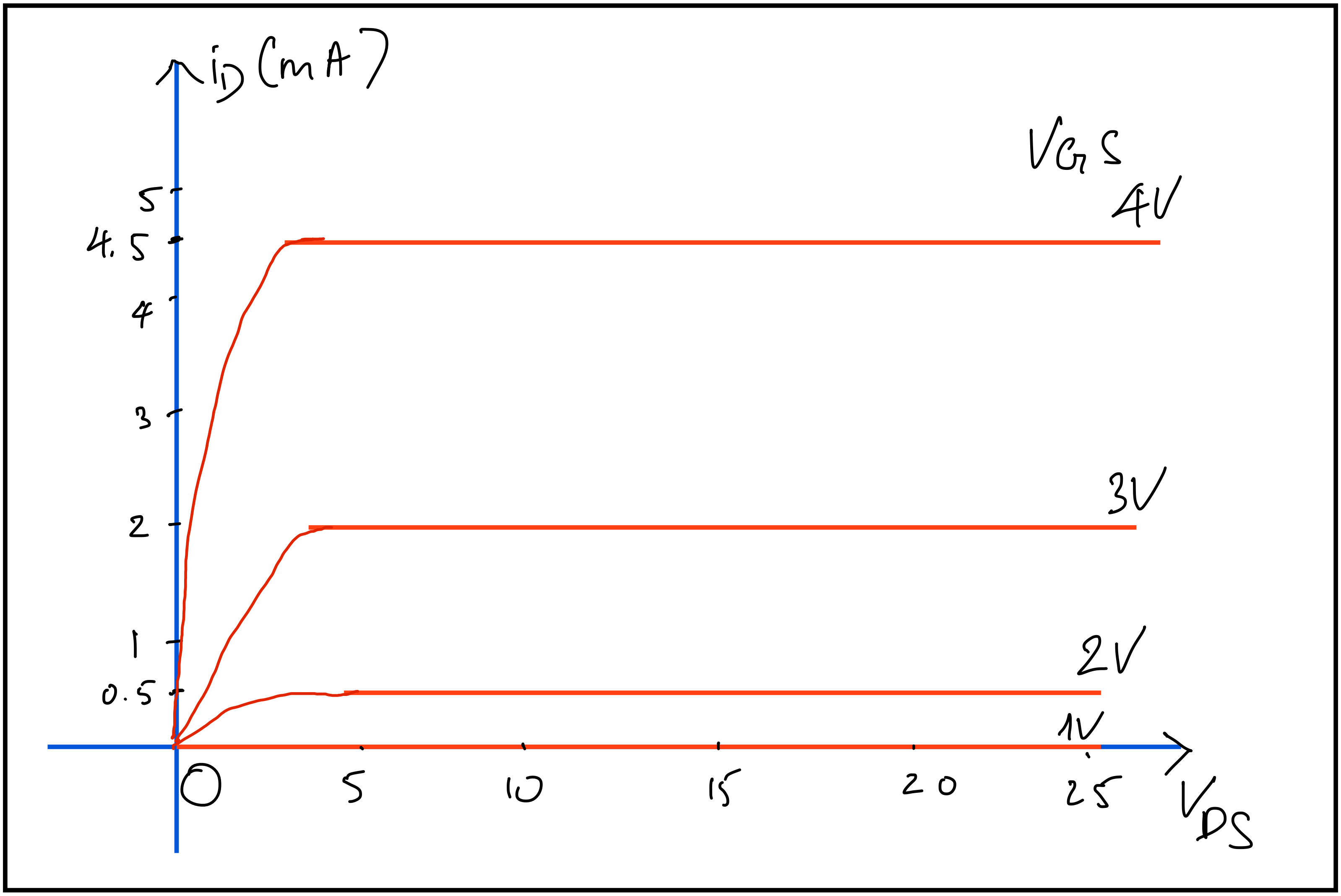
$\Rightarrow i_D = 0.5(2-1)^2 = 0.5 \text{ (mA)}$

⊕ $V_{GS} = 3\,V$

$\Rightarrow i_D = 0.5(3-1)^2 = 2 \text{ (mA)}$

⊕ $V_{GS} = 4\,V$

$\Rightarrow i_D = 0.5(4-1)^2 = 4.5 \text{ (mA)}$



c) Find the load line:

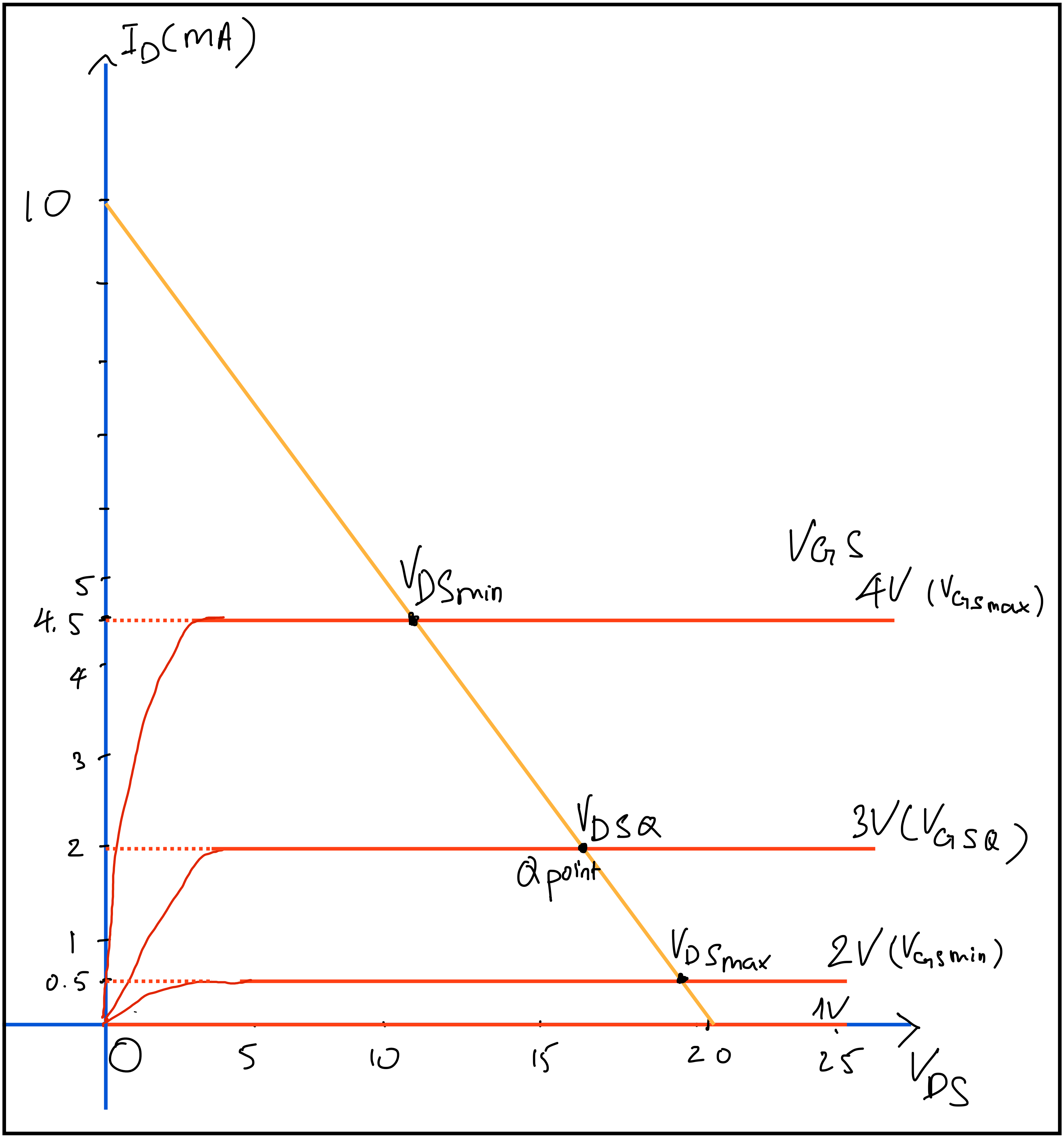
We have:

$$20 = i_D \times 2K\Omega + V_{DS}$$

+ Assuming $i_D = 0 \Rightarrow V_{DS} = 20V$

+ Assuming $V_{DS} = 0 \Rightarrow i_D = 10mA$

We have:



Since $20 = i_D \times 2K\Omega + V_{DS}$

+ With $i_D = 4.5 mA \Rightarrow V_{DSmin} = 20 - 4.5 \times 2$

$$\Rightarrow \boxed{V_{DS_{min}} = 11(V)}$$

+ With $i_D = 2mA \Rightarrow V_{DSQ} = 20 - 2 \times 2 = 16\ V$

$$\Rightarrow \boxed{V_{DSQ} = 16(V)}$$

+ With $i_D = 0.5mA \Rightarrow V_{DS_{max}} = 20 - 0.5 \times 2 = 19V$

$$\Rightarrow \boxed{V_{DS_{max}} = 19(V)}$$