HW 1

01 April 2020 17:36

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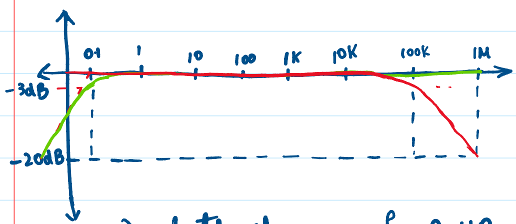

— HPF $\Rightarrow f_{3dB,HP} = 0.1Hz$

— LPF $\Rightarrow f_{3dB,LP} = 100.5KHz$

a) Lets choose $f_{3dB,HP}$ to be equal to 0.1Hz $\Rightarrow \tau_{HP} = \frac{1}{2\pi \times 0.1} = 1.59155$

At $f = 1Hz$

$$\left|\frac{V_o}{V_s}\right|_{dB} = 20\log \frac{\omega\tau}{\sqrt{1+(\omega\tau)^2}} = 20\log \frac{(1/0.1)}{\sqrt{1+(1/0.1)^2}} = -0.043dB < 0.1dB \text{ (Meets spec)}$$

LPF needs to meet 20dB attenuation at 1MHz

$$\left|\frac{V_o}{V_s}\right|_{dB} = -20dB = 20\log \frac{1}{\sqrt{1+(\omega\tau)^2}}$$

$$-1 = \log \frac{1}{\sqrt{1+(2\pi \times 10^6 \times \tau_{LP})^2}} \Rightarrow \log \sqrt{1+(2\pi 10^6 \times \tau_{LP})^2} = 1$$

$$1+(2\pi 10^6 \times \tau_{LP})^2 = 10^2$$

$$\tau_{LP} = \sqrt{10^2 - 1} \cdot \frac{1}{2\pi 10^6}$$

$$\tau_{LP} = 1.58357\mu$$

$f_{3dB,LP} = 100.5037815$ KHz

At $f = 10KHz$,

$$\left|\frac{V_o}{V_s}\right|_{dB} = 20\log \frac{1}{\sqrt{1+(\omega\tau)^2}} = 20\log \frac{1}{\sqrt{1+(2\pi 10K \times 1.58357\mu)^2}} = -0.04dB < 0.1dB \text{ (Meets spec)}$$

Choose $f_{3dB,LP} = 100.5KHz$

& $f_{3dB,HP} = 0.1Hz$

b) $R_s = 100\Omega$, $R_L = 10M\Omega$, $R_1 = ?$, $R_2 = ?$, $C_1 = ?$ & $C_2 = ?$

$$f_{3dB,HP} = \frac{1}{2\pi R_1 C_1} = 0.1$$

To minimize loading $\Rightarrow R_1$ must be large compared to R_s

Choose $R_1 = 1000 R_s$ [0.1dB $\Rightarrow$ 1%. Lets target 0.1%]

$R_1 = 100K\Omega$

$C_1 = 15.9155\mu F$

$$f_{3dB,LP} = \frac{1}{2\pi R_2 C_2} = 1005KHz$$

To minimize loading $\Rightarrow R_L \gg 1000 R_2$

Let $R_2 = R_L/1000$

$R_2 = 10K\Omega$

$C_2 = 0.15836nF$

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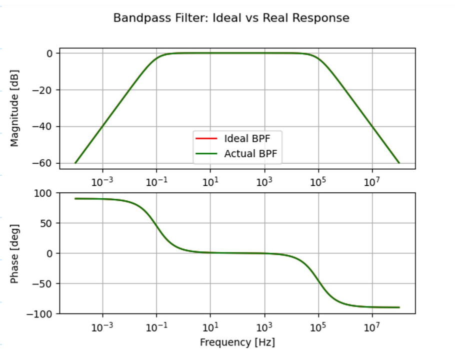
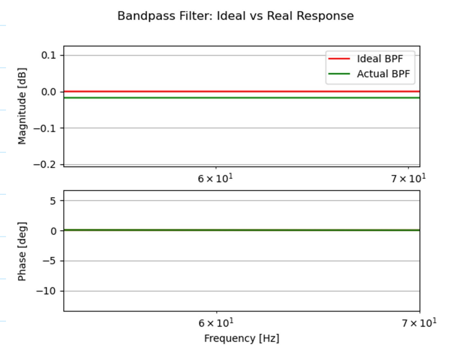
$C_2 = \underline{0.15836nF}$

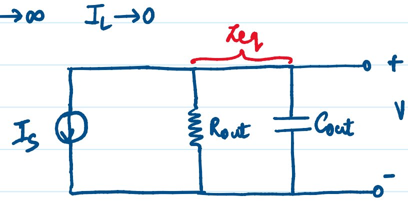
c) LTspice Simulation & python



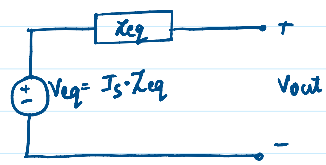


Zoomed in at $f = 60Hz$.

2 a) $\frac{V_{out}}{I_s} = ?$ $\quad Z_L \to \infty \quad I_L \to 0$



$\Rightarrow$

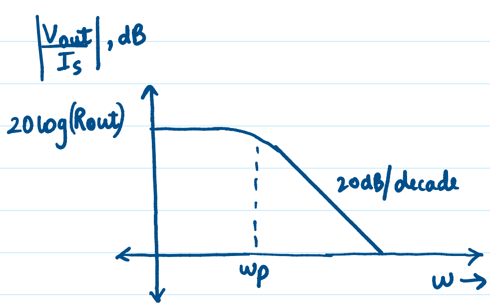


$$Z_{eq} = Z_{out} = R_{out} \parallel C_{out} = \frac{R_{out} \frac{1}{sC_{out}}}{R_{out} + \frac{1}{sC_{out}}} = \frac{R_{out}}{sR_{out}C_{out}+1}$$

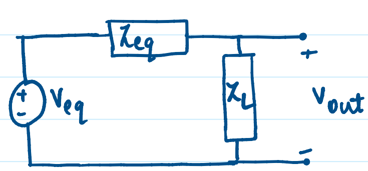
$$\frac{V_{out}}{I_s} = \frac{I_s \cdot Z_{eq}}{I_s} = Z_{eq} = \frac{R_{out}}{sR_{out}C_{out}+1} \quad \text{—— (1)}$$

$$\omega_p = \frac{1}{R_{out}C_{out}} \quad \text{—— (2)}$$

$$|Z_{eq}| \text{ at DC} = R_{out} \quad \text{—— (3)}$$



b)



$$V_{eq} = -I_s Z_{eq} \quad \text{—— (4)}$$

$$V_{out} = \frac{Z_L}{Z_L + Z_{eq}} V_{eq} \Rightarrow \frac{V_{out}}{I_s} = -\frac{Z_L \cdot Z_{eq}}{Z_L + Z_{eq}}$$

$$= -Z_L \parallel Z_{eq} \quad \text{—— (5)}$$

1) $Z_L = C_L \Rightarrow C_{eff} = C_{out} \parallel C_L = C_{out} + C_L$

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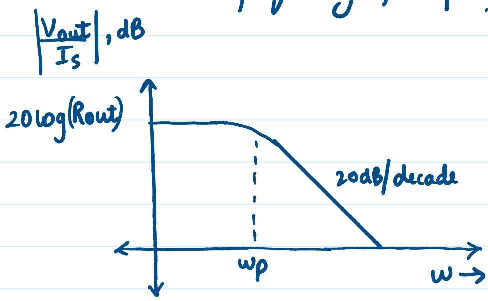
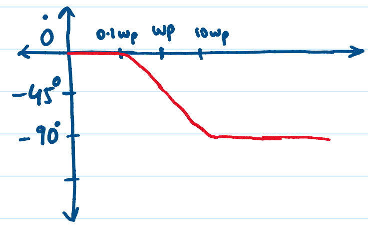
Pole frequency, $\omega_p = \dfrac{1}{R_{out} C_{eff}} = \dfrac{1}{R_{out}(C_{out} + C_L)}$ —— (6)

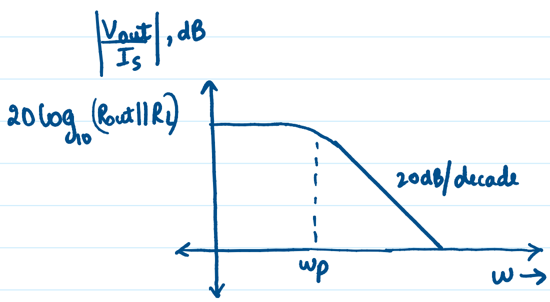


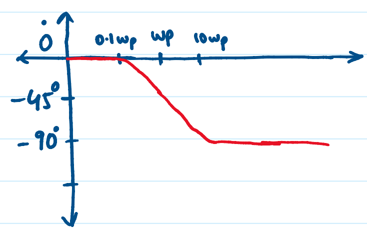


2) $Z_L = R_L \Rightarrow R_{eff} = R_{out} \| R_L = \dfrac{R_{out} R_L}{R_{out} + R_L}$

Pole frequency, $\omega_p = \dfrac{1}{C_{out} R_{eff}} = \dfrac{1}{C_{out}(R_{out} \| R_L)}$ —— (7)

Also $\left|\dfrac{Z_{out}}{I_s}\right|$ at DC $= R_{out} \| R_L$





c) Transient response of Vout $I_s \to 0$ to I_{max} & $Z_L \to \infty$

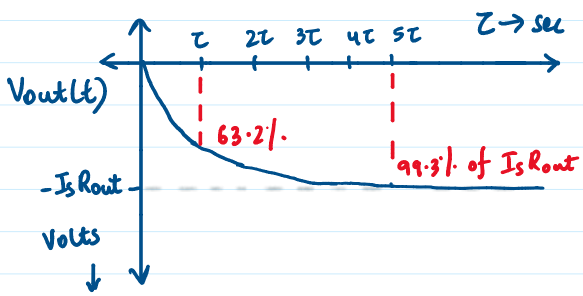
for $Z_L \to \infty$, $V_{out} = V_{eq}$

$V_{out} = -I_s Z_{eq}$

$V_{out}(s) = -I_s \dfrac{R_{out}}{s R_{out} C_{out} + 1}$

Time domain,

$$V_{out}(t) = -I_s R_{out}\left(1 - e^{-t/\tau}\right) \quad \text{—— (8)} \quad \Big| \ \tau = R_{out} C_{out}$$



③ $R = 100\Omega$, $C = 10pF$

$\tau = RC = \underline{\underline{1ns}}$

a) For 0.1% settling precision.

$$T_{ON} \geq 6.9\tau$$

$$T_{CLK} = T_{ON} + T_{OFF} \geq 13.8\tau$$

$$f_{CLK} \leq \frac{1}{13.8\tau}$$

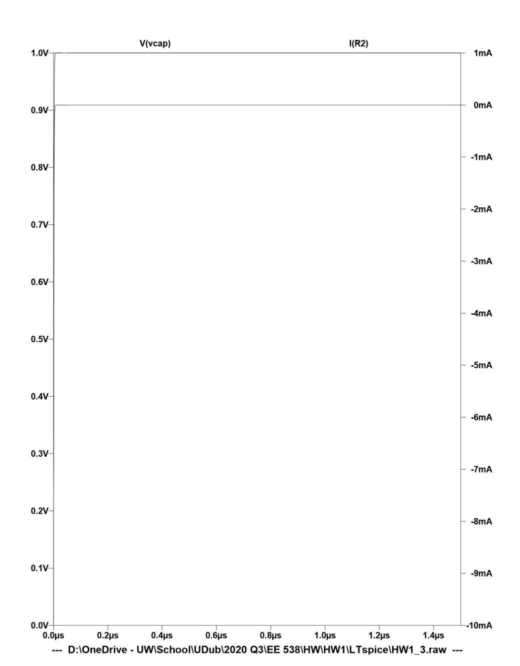
$$f_{CLK(max)} = \frac{1}{13.8 \times 10^{-9}} = \underline{\underline{72.4637\, MHz}}$$

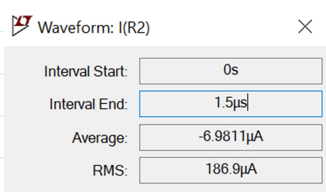
b) $I_{avg} = \frac{\Delta q}{\Delta t}$

Charge delivered to capacitor $Q = CV_{in}$

$$I_{avg} = \frac{CV_{in}}{\text{Simulation time}} = \frac{10pF \times 1V}{1.5\mu} = 6.67\mu s.$$ (Ideally the steady state average current is zero)

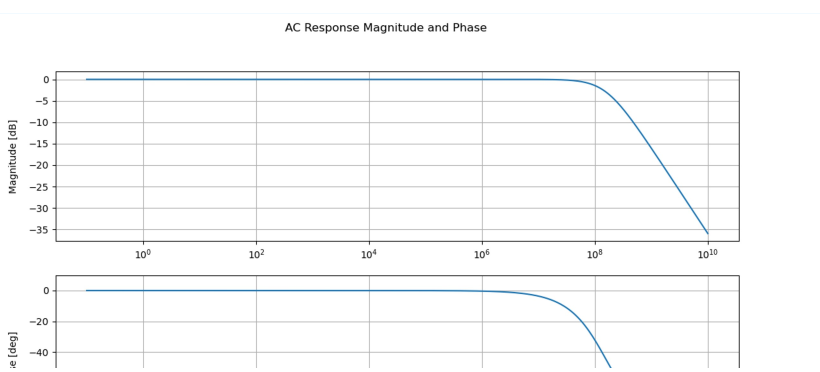
c)





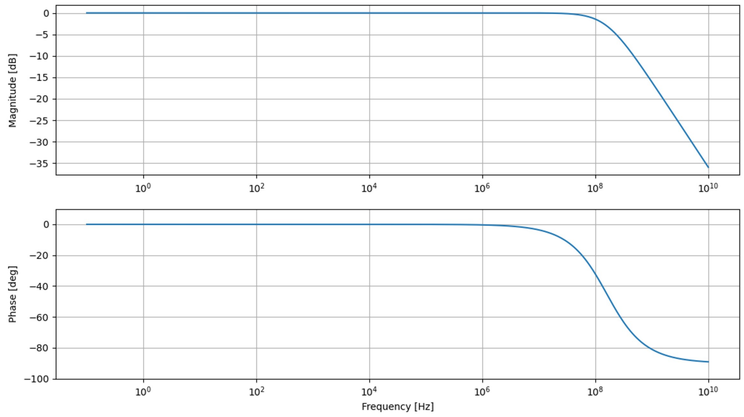
Average current = $\underline{\underline{6.98\,\mu A}}$

d)



d)

AC Response Magnitude and Phase



$f_{3dB} = \underline{\underline{159 MHz}}$

$\tau = \frac{1}{2\pi f_{3dB}} = \underline{\underline{1ns}}$

Settling time $= 6.9\tau = \underline{\underline{6.9ns}}$