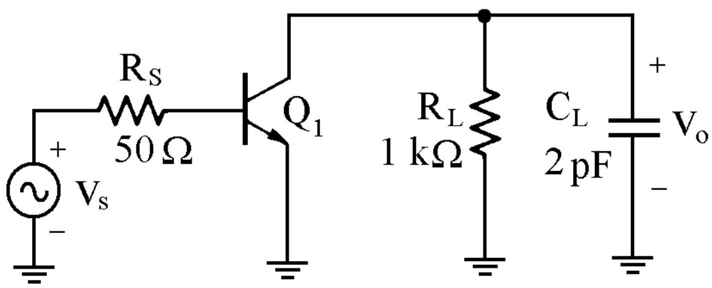
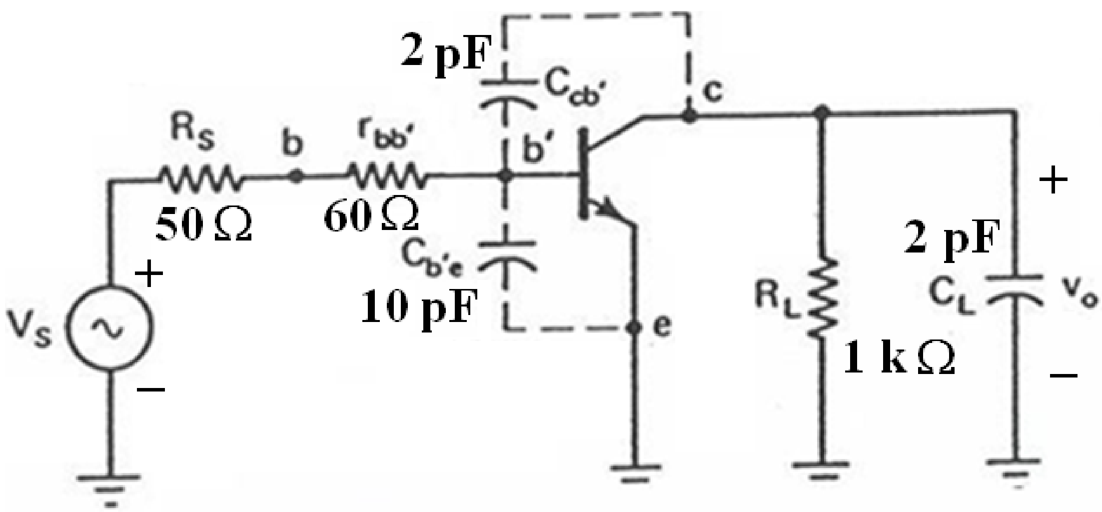
EE4341 TUTORIAL 5 SOLUTION

1.



Q$_1$: β = 60, $C_{cb'}$ = 2 pF, $C_{b'e}$ = 10 pF and $r_{bb'}$ = 60 Ω, V_T = 25 mV.



Mid-band voltage gain v_o/v_s is given by:

$$v_o = -g_m v_s \left(\frac{r_\pi}{R_s + r_{bb'} + r_\pi} \right) R_L$$

$$-\frac{v_o}{v_s} = g_m R_L \left(\frac{r_\pi}{R_s + r_{bb'} + r_\pi} \right)$$

$$\because r_\pi = \frac{\beta}{g_m}$$

$$-\frac{v_o}{v_s}=\frac{\beta R_L}{R_s+r_{bb'}+\dfrac{\beta}{g_m}}$$

$$55=\frac{60\times 1k}{110+\dfrac{60}{g_m}}\Rightarrow g_m=61.2mS$$

$$I_c=g_m V_T=61.2mS\times 25mV=1.53mA$$

Two critical frequencies where roll-off of voltage gain happen:

$$f_1=\frac{1}{2\pi\left[\left(R_s+r_{bb'}\right)//\,r_\pi\right]C_i}$$

$$C_i=C_{b'e}+C_{cb'}\left(1+g_m R_L\right)=10\,pF+2\,pF\left(1+61.2\right)=134.3\,pF$$

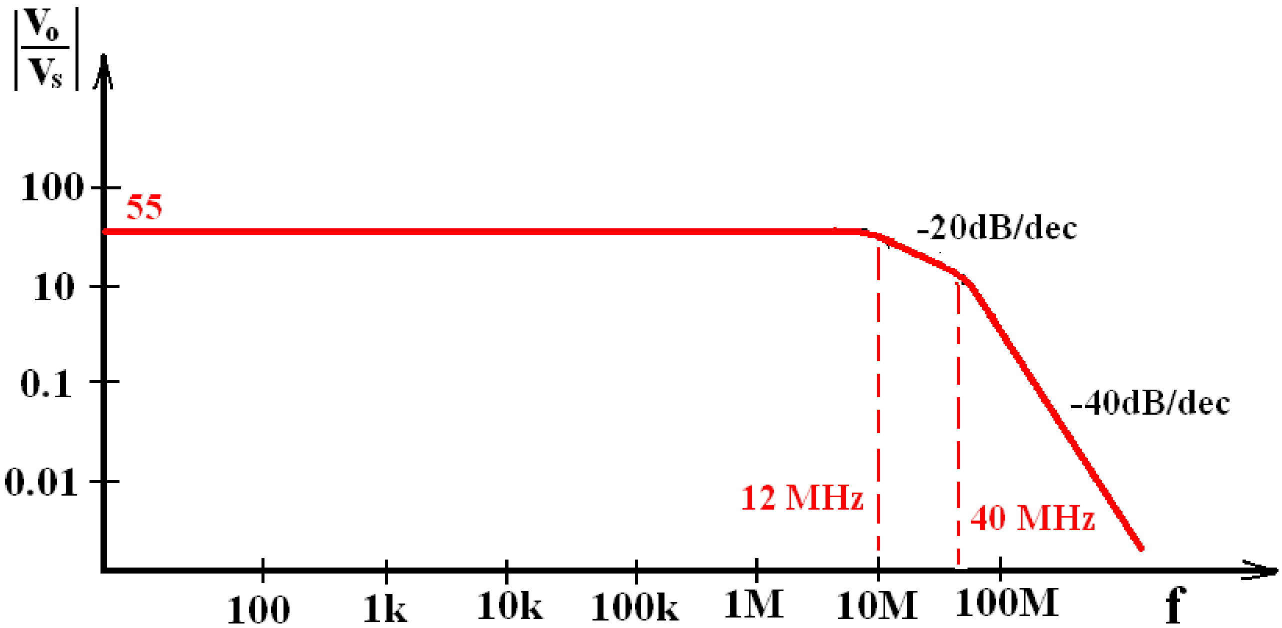
$$\therefore\ f_1=\frac{1}{2\pi\times 99\times 134.3\,p}=12MHz$$

$$f_2=\frac{1}{2\pi\left(R_L\,//\,r_o\right)C_o}\approx\frac{1}{2\pi R_L C_o},\quad \because r_o>>R_L$$

$$C_o=C_L+C_{cb'}\left(1+\frac{1}{g_m R_L}\right)=2\,pF+2\,pF\left(1+\frac{1}{61.2}\right)\approx 4\,pF$$

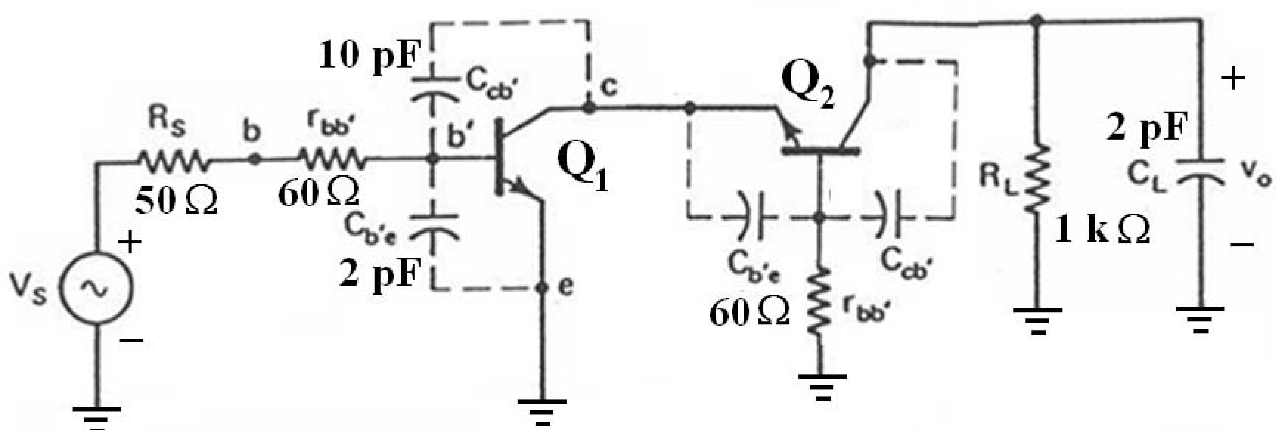
$$\therefore\ f_2=\frac{1}{2\pi\times 1k\times 4\,p}=40MHz$$

$$\frac{v_o}{v_s}=\frac{-55}{\left(1+\dfrac{jf}{f_1}\right)\left(1+\dfrac{jf}{f_2}\right)}$$



The -3dB bandwidth is dominated by f_1, which is about 12 MHz.

2.



$$I_{C1} = I_{E2} = 1.53mA$$

$$r_{e2} = \frac{V_T}{I_{E2}} = \frac{1060}{61} = 16.3\,\Omega$$

Mid-band voltage gain for the first stage:

$$A_{v1} = \frac{-v_{c1}}{v_s} = \left(\frac{-r_{\pi 1}}{R_s + r_{bb'} + r_{\pi 1}} \right) g_m r_{e2} = \left(\frac{-980}{110+980} \right) (61.2m \times 16.3) = -0.9$$

Mid-band voltage gain for the second stage:

$$A_{v2} = \frac{i_{c2} R_L}{i_{e2} r_{e2}} = \frac{\alpha R_L}{r_{e2}} = \left(\frac{60}{61} \right) \left(\frac{1k}{16.3} \right) = 60.2$$

Overall mid-band voltage gain:

$$A_v = \frac{v_o}{v_s} = A_{v1} \times A_{v2} = -0.9 \times 60.2 = -54.2$$

Three critical frequencies where roll-off of voltage gain happen:

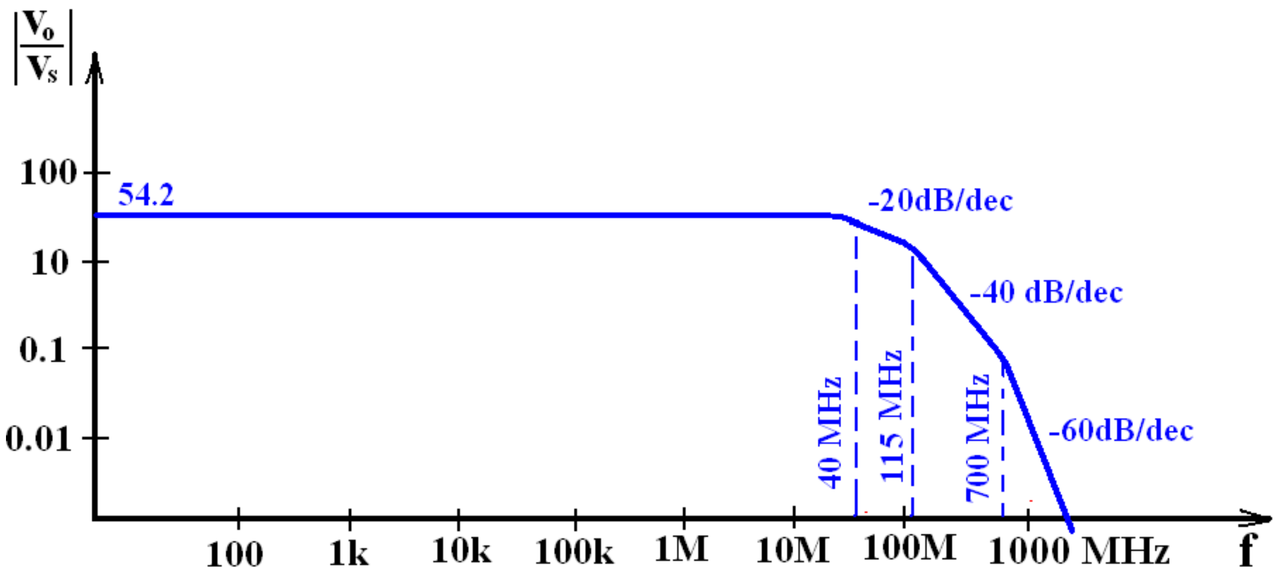
$$C_i = C_{b'e} + C_{cb'} \left(1 + g_m r_{e2} \right) = 10\,pF + 2\,pF \times 2 \approx 14\,pF$$

$$\therefore\ f_1 = \frac{1}{2\pi \left[\left(R_s + r_{bb'} \right) // \, r_{\pi 1} \right] C_i} = \frac{1}{2\pi \times 99 \times 14\,p} \approx 115 MHz$$

$$f_2 = \frac{1}{2\pi r_{e2} \left[C_{b'e} + C_{cb'} \left(1 + \frac{1}{g_m r_{e2}} \right) \right]} = \frac{1}{2\pi r_{e2} \left(C_{b'e} + 2C_{cb'} \right)} = \frac{1}{2\pi \times 16.3 \times 14\,p} \approx 700 MHz$$

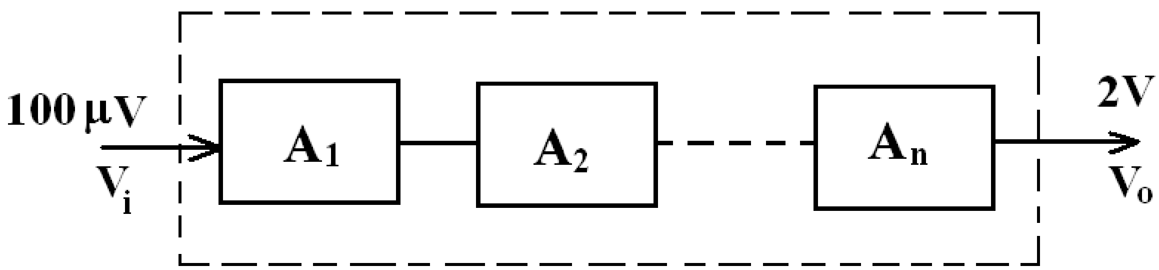
$$f_3 = \frac{1}{2\pi R_L \left[C_L + C_{cb'} \cancel{\left(1 + \frac{1}{A_{v2}} \right)} \right]} = \frac{1}{2\pi \times 1k \left[2\,p + 2\,p \cancel{\left(1 + \frac{1}{56.5} \right)} \right]} \approx 40 MHz$$

$$\frac{v_o}{v_s} = \frac{-54.2}{\left(1+\frac{jf}{f_1}\right)\left(1+\frac{jf}{f_2}\right)\left(1+\frac{jf}{f_3}\right)}$$



The -3dB bandwidth is dominated by f_3, which is about 40 MHz.

3.



For n-stage of identical amplifiers, the overall gain response will be:

$$A_T = \frac{v_o}{v_i} = \frac{A^n}{\left(1+\frac{jf}{f_p}\right)^n}$$

$$\left|A_T\right| = \frac{A^n}{\left(\sqrt{1+\left(\frac{f}{f_p}\right)^2}\right)^n} = \frac{A^n}{\left(1+\left(\frac{f}{f_p}\right)^2\right)^{\frac{n}{2}}}$$

If the -3dB bandwidth of the overall gain is f_1, then:

$$\frac{A^n}{\left(1+\left(\frac{f_1}{f_p}\right)^2\right)^{\frac{n}{2}}} = \frac{A^n}{2^{\frac{1}{2}}}$$

$$\therefore \left(1+\left(\frac{f_1}{f_p}\right)^2\right)^n = 2$$

$$1+\left(\frac{f_1}{f_p}\right)^2 = 2^{1/n} \Rightarrow f_1 = f_p\sqrt{2^{1/n}-1}$$

The required overall mid-band gain:

$$A_T = \frac{2V}{100\mu V} = 20{,}000$$

If n =2,

$$f_p = \frac{f_1}{\sqrt{2^{1/n}-1}} = \frac{30MHz}{\sqrt{2^{1/2}-1}} = 46.6MHz$$

$$A = \frac{GBW}{f_p} = \frac{600}{46.6} = 12.9$$

$$\therefore A_T = (12.9)^2 = 166 < 20{,}000$$

If n =4,

$$f_p = \frac{f_1}{\sqrt{2^{1/n}-1}} = \frac{30MHz}{\sqrt{2^{1/4}-1}} = 69MHz$$

$$A = \frac{GBW}{f_p} = \frac{600}{69} = 8.7$$
$$\therefore A_T = (8.7)^4 = 5{,}728 < 20{,}000$$

If n =5,

$$f_p = \frac{f_1}{\sqrt{2^{1/n}-1}} = \frac{30MHz}{\sqrt{2^{1/5}-1}} = 78MHz$$

$$A = \frac{GBW}{f_p} = \frac{600}{78} = 7.7$$
$$\therefore A_T = (7.7)^5 = 27{,}280 > 20{,}000$$

Therefore, 5 stages are needed with 4 stages of identical gain = 7.7 and

the last stage gain = 5.7.