EE210: HW-9 Solution

Date: 06/03/2019

Unless stated otherwise, the BJT in the problems given below has the following characteristics

$I_S = 2.03\text{x}10^{-15}$A; $\beta_F = 100$; $\beta_R = 1$; $V_A = \infty$; r_{bb}=200Ω; V_T=26mV; C_{jeo} =1pF; C_{jco} =0.5pF; C_{jso} =3pF; m= 0.5; V_{bi}=0.85; τ_F=1ns (For simplicity, include r_{bb} only in high frequency analysis and ignore Cjs)

Q.1 Figure.1 shows a common-base amplifier schematic. Determine voltage gain, input and output resistance and upper cutoff frequency for R_S = 0. Determine the voltage gain and upper cutoff frequency again for the case where source has a resistance of 1K.

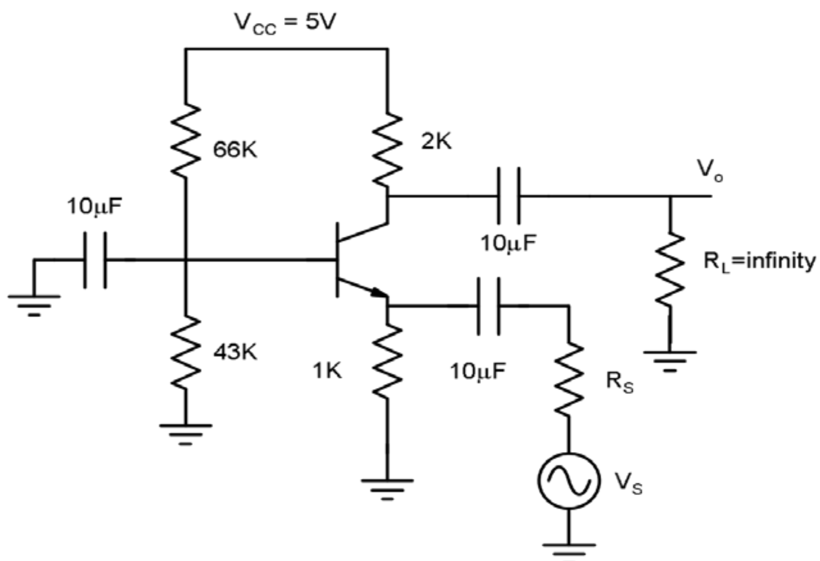


Fig. 1

Sol.

Exact dc analysis (including base current) gives,

$$I_{CQ} = 1mA;\ V_{CEQ} = 2V$$

Small signal analysis gives

$$g_m = 0.038\Omega^{-1};\ r_\pi = 2.6K\Omega$$

$$A_V = +g_m R_C = 77.0$$

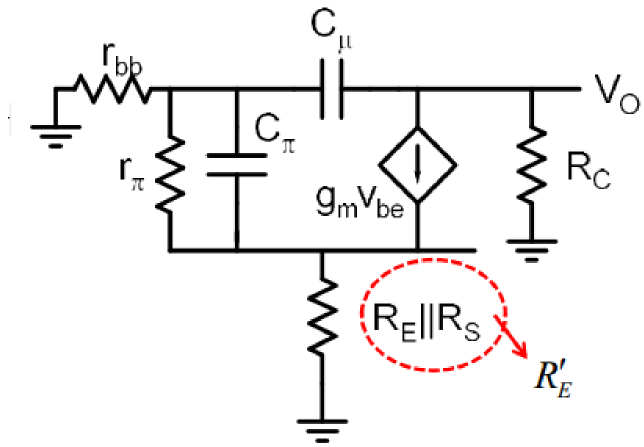
$$R_{in} = \frac{r_\pi}{\beta} \parallel R_E \cong 25\Omega;\ R_0 = R_C = 2k\Omega$$

$$f_L \cong \frac{1}{2\pi * 10 * 10^{-6} * R_{in}} = 634Hz$$

$$V_{BC} = V_{BE} - V_{CE} = -1.3V$$

$$\mathrm{C_{jc}} = \frac{0.5\mathrm{pF}}{\left(1 - \frac{\mathrm{V_{BC}}}{0.85}\right)^{1/2}} = 0.32\mathrm{pF};\ C_{je} = \frac{1pF}{\left(1 - \frac{V_{BE}}{0.85}\right)^{1/2}} = 2.38pF$$

$$C_\pi = g_m\tau_F + C_{je} = 41.21\text{pF};\ C_\mu = 0.3\text{pF}$$



$$R_\pi = \frac{1+\frac{R_E \parallel R_S}{r_{bb}}}{1+\frac{g_m R_E \parallel R_S}{1+\frac{r_{bb}}{r_\pi}}} * (r_{bb} \parallel r_\pi)$$

It is easier to remember as,

$$R_\pi = \left(1+\frac{R'_E}{r_{bb}}\right)\left(r_\pi \parallel \frac{r_{bb}}{1+g_m R'_E}\right)$$

$$R_\mu = r_{bb} + R_C + \frac{(\beta R_C - r_{bb}) * r_{bb}}{r_\pi + r_{bb} + (1+\beta)R_E \parallel R_S}$$

It is easier to remember as,

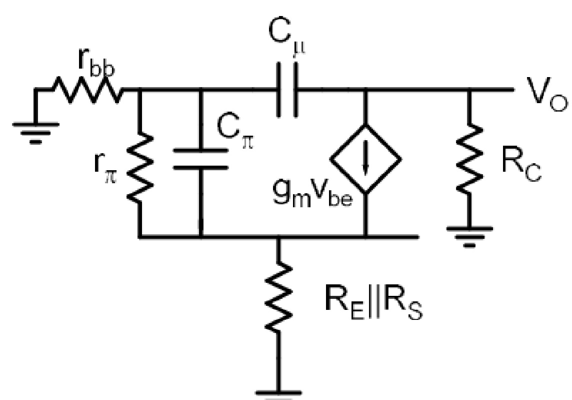
$$R_\mu = r_{bb}(1-x) + R_C * (1 + x\beta)$$
$$x = \frac{r_{bb}}{r_{bb} + r_\pi + \beta R'_E}$$

$$C_\pi = g_m\tau_F + C_{je} = 41.21\text{pF};\ C_\mu = 0.3\text{pF}$$

For $R_S = 0$, we get

$$R_\pi = 185.6\Omega; R_\mu = 16.6\text{k}\Omega$$
$$R_\pi C_\pi = 7.65\text{ns};\quad R_\mu C_\mu = 5.25\text{ns};$$

$$f_H \cong \frac{1}{2\pi * (R_\pi C_\pi + R_\mu C_\mu)} = 12.34\ MHz$$



For R_S =1KΩ, then A_v=1.9

$$R_\pi = 34\Omega; R_\mu = 2.95\text{k}\Omega$$
$$R_\pi C_\pi = 1.4\text{ns};\quad R_\mu C_\mu = 0.93\text{ns}$$
$$f_H \cong \frac{1}{2\pi * (R_\pi C_\pi + R_\mu C_\mu)} = 68MHz$$

Q.2 Determine gain, input resistance, output resistance, voltage swing with HD_2 = 10%, upper and lower cutoff frequencies for the Cascode amplifier shown in Fig. 2.

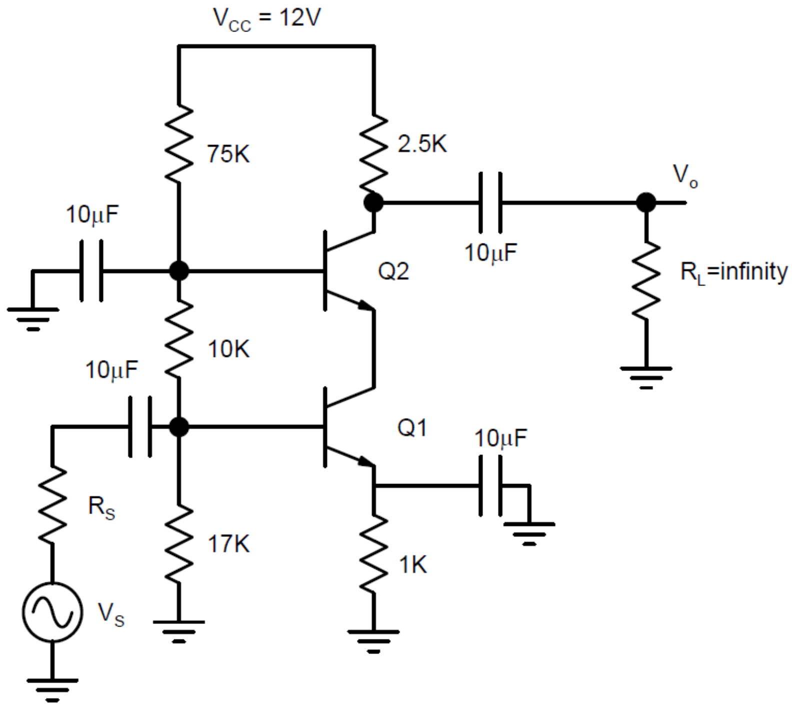


Fig. 2

Sol.
Dc analysis gives

$$I_{CQ} = 1mA;\ V_{CEQ1} = 1.1V;\ V_{CEQ2} = 7.3V$$

Small signal analysis gives

$$g_m = 0.038\Omega^{-1};\ r_\pi = 2.6k\Omega$$

$$A_V = -g_m R_C = 98.7$$

$$R_{in} = r_\pi \parallel 10k \parallel 17k \cong 1.8k\Omega;\ R_0 = R_C = 2k\Omega$$

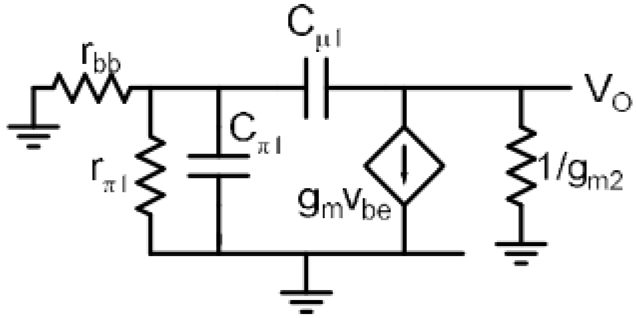
$$f_L \cong \frac{1}{2\pi * 10 * 10^{-6} * \left(\frac{r_\pi}{\beta}||R_E\right)} \cong \frac{1}{2\pi * 10 * 10^{-6} * \left(\frac{r_\pi}{\beta}\right)} = 634Hz$$

$$v_{om} = I_{CQ}R_C * \frac{HD_2}{25} = 1V$$

There are four capacitances, each transistor contributing two,

$$C_{\pi1} = C_{\pi2} = g_m \tau_F + C_{je} = 41.21pF;\ C_{\mu1} = 0.41pF;\ C_{\mu2} = 0.17pF$$

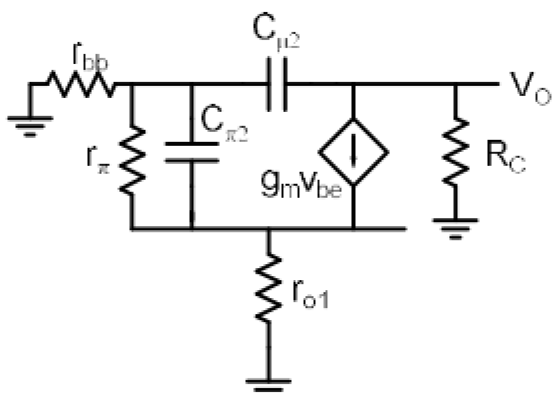
Equivalent circuit for estimating effective resistances seen by capacitances associated with Q1:



$$R_{\pi 1} = \left(1 + \frac{0}{r_{bb}}\right)\left(r_\pi \parallel \frac{r_{bb}}{1+0}\right) = 185.3\Omega$$

$$x_1 = \frac{r_{bb}}{r_{bb} + r_{\pi 1} + 0} = 0.073; \;\; R_{\mu 1} = r_{bb}(1 - x_1) + \frac{1}{g_{m2}} * (1 + x_1\beta) = 0.39K\Omega$$

For CB stage



$$R_{\pi 2} = \left(1 + \frac{r_{o1}}{r_{bb}}\right)\left(r_\pi \parallel \frac{r_{bb}}{1 + g_{m2} r_{o1}}\right) \cong \frac{1}{g_{m2}} = 25.3\Omega$$

$$x_2 = \frac{r_{bb}}{r_{bb} + r_{\pi 1} + \beta r_{o1}} \cong \frac{r_{bb}}{\beta r_{o1}}$$

$$R_{\mu 2} = r_{bb}(1 - x_2) + R_C * (1 + x_2\beta) \cong r_{bb} + R_C = 2.7k\Omega$$

$$f_H \cong \frac{1}{2\pi * \left(R_{\pi 1}C_{\pi 1} + R_{\pi 2}C_{\pi 2} + R_{\mu 1}C_{\mu 1} + R_{\mu 2}C_{\mu 2}\right)} = 16.87MHz$$

*Note that f_H in Cascode amplifier is dominated by CE stage.
For CE stage only, the upper cutoff frequency comes out to be,

$$f_{H1} \cong \frac{1}{2\pi * \left(R_{\pi 1}C_{\pi 1} + R_{\mu 1}C_{\mu 1}\right)} \cong 20MHz$$

While for CB stage only, the upper cutoff frequency comes out to be,

$$f_{H2} \cong \frac{1}{2\pi * \left(R_{\pi 2}C_{\pi 2} + R_{\mu 2}C_{\mu 2}\right)} \cong 106MHz$$