Solution: Part 7

1. The bandwidth for voltage gain of a single common-emitter amplifier stage is required to be 2 MHz with a quiescent current of 5 mA and a total ac load, $R_t = 1$ kΩ. The transistor parameters are $\beta_o = 100$, $r_{bb'} = 20\ \Omega$, $C_{b'c} = 2$ pF and $f_T = 200$ MHz. From this information deduce the values of g_m, $r_{b'e}$, $C_{b'e}$ and f_β. Find the value of the source resistance to give the required bandwidth and the mid-frequency voltage gain v_o/v_s. Derive any formulae you may use.
   (Ans: g_m = 200 mA/V, $r_{b'e}$ = 500 Ω, $C_{b'e}$ = 157 pF, f_β = 2MHz, **R_S = 280 Ω, K= 125**)

   If there is a stray capacitance of 0.01 μF in parallel with R_L calculate the new bandwidth, neglecting the input time constant. (Ans: 16 kHz)

Solution

$g_m = 40 \times I_{CQ} = 20 \times 5m$ = **200 mA/V (note units!)**

$r_{b'e} = \dfrac{\beta_o}{g_m} = \dfrac{100}{200m}$ = **500 Ω**

$f_T = \dfrac{1}{2\pi(C_{b'e} + C_{b'c})}$ $\quad C_{b'e} = \dfrac{g_m}{2\pi \times f_T} - C_{b'c} = \dfrac{200m}{2\pi \times 200M} - 2\,pF$ $\quad$ **$C_{b'e}$ = 157 pF**

$f_\beta = \dfrac{1}{2\pi \times r_{b'e} \times (C_{b'e} + C_{b'c})}$ $\quad$ **f_β = 2 MHz or use $f_\beta = f_T/\beta_o$ = 200M/100 = 2 MHz**

[recall this is the corner frequency – or bandwidth – of the amplifier with zero load: $f_T = \beta_o f_\beta$]

Now voltage-gain bandwidth is given by $f_H = \dfrac{1}{2\pi \times r_{b'e} // (r_{bb'} + R_S) \times \left(C_{b'e} + C_{b'c}[1 + |K|]\right)}$

where mid-frequency gain is $K = -g_m R_t \dfrac{r_{b'e}}{r_{b'e} + r_{bb'} + R_S}$

(see notes for derivations of equations)

$$|K| = 40 \times 5 \times 10^{-3} \times 10^3 \frac{500}{500 + 20 + R_S} \rightarrow |K| = \frac{10^5}{520 + R_S}$$

$$\frac{r_{b'e} \times (r_{bb'} + R_S)}{r_{b'e} + r_{bb'} + R_S} = \frac{500 \times (20 + R_S)}{520 + R_S} = \frac{10^4 + 500 \times R_S}{520 + R_S}$$

$$2M = \frac{1}{2\pi \times \dfrac{10^4 + 500 \times R_S}{520 + R_S} \times (157p + 2p \times |K|)}$$ (assume K >> 1

$$1.5M = \frac{1}{2\pi \times \dfrac{10^4 + 500 \times R_S}{520 + R_S} \times \left(157p + 2p \times \dfrac{10^5}{520 + R_S}\right)} \Rightarrow$$

$$1.5M = \frac{(520 + R_S)^2}{2\pi \times (10k + 500 R_S) \times \left(157p(520 + R_S) + 2 \times 10^{-7}\right)}$$

Solve to get **R_S = 280 hence K = 125**

Check time constants:

$\tau_i = RC = r_{be} // (R_S + r_{bb}) \times C$ $\tau_o = R_t C'$

R = 188R, $C \sim C_{be} + KC_{b'c} = 157p + 124 \times 2pF$ = 407 pF

so input time constant is $\tau_i = 188 \times 407p$ **= 77 ns**
output time constant is $\tau_o = 1k \times 2p$ = **2 ns**

so model is valid

With stray capacitance, now find output time constant

$\tau_o = 1k \times 10n$ = **10 µs**

is much larger than the input and consider the output circuit.

$$f_H' \approx \frac{1}{2\pi \times R_t \times C_{stray}}$$

$$f_H' \approx \frac{1}{2\pi \times 1k \times 0.01u}$$

= 16 kHz

Bandwidth now limited by stray capacitance on the output rather than intrinsic device capacitances.