SOLUTIONS OF TUT SHEET NO. 6

Q1 (Ans):

Solution From Eq. (11.29),

$$f_\beta = \frac{1}{2\pi r_{b'e}(C_c + C_e)} = \frac{1}{2\pi(1\ \text{K})(1.2\ \text{pF})} = 133\ \text{MHz}$$

And from Eq. (11.30),

$$f_T = \frac{g_m}{2\pi(C_c + C_e)} = \frac{50\ \text{mA/V}}{2\pi(1.2\ \text{pF})} = 6.6\ \text{GHz}$$

f_T represents the highest frequency at which a transistor will provide a gain. The above numbers show that modern bipolar transistors can provide gains upto frequencies in the GHz range.

Q2(Ans):

Solution. (*i*) $V_T = \frac{kT}{q} = \frac{T}{11{,}600}$

Hence $g_m = \frac{|I_C|}{V_T} = \frac{10 \times 10^{-3} \times 11{,}600}{300} = 0.3866\ \text{S}$

(*ii*, $r_{b'e} = \frac{h_{fe}}{g_m} = \frac{100}{0.3866} = 258.6\ \Omega$

(*iii*) $r_{bb}' = h_{ie} - r_{b'e} = 500 - 258.6 = 241.4\ \Omega$

(*iv*) $r_{b'c} = \frac{r_{b'e}}{h_{re}} = \frac{258.6}{10^{-4}} = 258.4 \times 10^4\ \Omega$

(*v*) $g_{ce} = h_{oe} - (1 + h_{fe})\, g_{b'c} = 2 \times 10^{-4} - (1 + 100) \times \frac{1}{258.6 \times 10^4} = S = 1.61 \times 10^{-4}\ \text{S}$

(*vi*) $C_e = \frac{g_m}{2\pi f_T} = \frac{0.3866}{2\pi \times 50 \times 10^6} F = 1.235 \times 10^{-9}\ \text{F}$

(*vii*) $C_c = C_{ob} = 3\ \text{pF}.$

Q3(Ans):

Solution. (*i*)
$$g_m = \frac{|I_C|}{V_T} = \frac{8 \times 10^{-3} \times 11600}{300} = 0.309\ \text{S}$$

$$r_{b'e} = \frac{h_{fe}}{g_m} = \frac{100}{0.309}\ \Omega = 323\ \Omega$$

(*ii*)
$$r_{bb'} = h_{ie} - r_{b'e} = 800 - 323 = 477\ \Omega$$

(*iii*)
$$|A_{IS}| = \frac{h_{fe}}{\sqrt{1 + (f/f_\beta)^2}}$$

Substituting the values, $14 = \dfrac{100}{\sqrt{1 + (8/f_\beta)^2}}$ where f_β is in MHz

$$1 + \left(\frac{8}{f_\beta}\right)^2 = \left(\frac{100}{14}\right)^2 = 51.02$$

Hence
$$f_\beta = \frac{8}{\sqrt{50.02}} = 1.311\ \text{MHz}$$

(*iv*)
$$f_T = h_{fe} \cdot f_\beta = 100 \times 1.311 = 131.1\ \text{MHz}$$

(*v*) But
$$f_T \approx \frac{g_m}{2\pi (C_c + C_e)}$$

Hence
$$C_c + C_e = \frac{g_m}{2\pi f_T} = \frac{0.309}{2\pi \times 131.1 \times 10^6}\ F = 375\ \text{pF}$$

$$C_c = 4\ \text{pF}$$

Hence
$$C_e = (375 - 4) = 371\ \text{pF}.$$

Q4(Ans):

Solution. $I_C \approx I_E = 4$ mA.

$$g_m = \frac{|I_C|}{V_T} = \frac{4 \times 10^{-3} \times 11600}{300} = 0.155 \text{ S}$$

Diffusion constant for holes $D_B = 50 \text{ cm}^2/\text{sec.}$

Base width $W = 2.5 \times 10^{-4}$ cm.

Hence $$C_{De} = g_m \cdot \frac{W^2}{2\,D_B} = \frac{0.155 \times (2.5 \times 10^{-4})^2}{2 \times 50} F = 96.9 \text{ pF}$$

For J_E forward biased, $C_e = C_{De} + C_{Te} \approx C_{De}$

But $$C_e = \frac{g_m}{2\pi f_T}$$

Hence $$f_T = \frac{g_m}{2\pi\, C_e} = \frac{0.155}{2\pi \times 96.9 \times 10^{-12}} \text{ Hz} = 254 \text{ MHz.}$$

Q5 & Q6 (Ans):

Rise Time The response of the low-pass circuit of Fig. 12.2 to a step input of amplitude V is exponential with a time constant R_2C_2. Since the capacitor voltage cannot change instantaneously, the output starts from zero and rises toward the steady-state value V, as shown in Fig. 12.8. The output is given by

$$v_o = V\left(1 - e^{-t/R_2C_2}\right) \qquad (12.19)$$

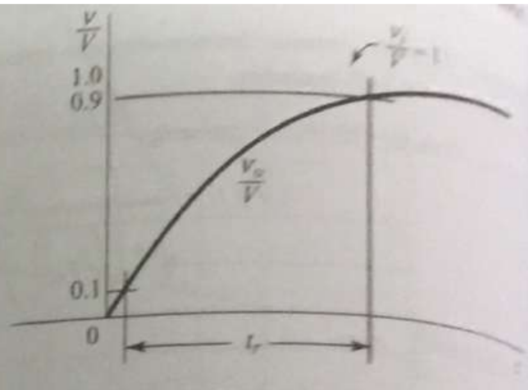

Fig. 12.8 *Step-voltage response of the low-pass RC circuit. The rise time t_r is indicated*

The time required for v_o to reach one-tenth of its final value is readily found to be $0.1R_2C_2$, and the time to reach nine-tenths its final value is $2.3\,R_2C_2$. The difference between these two values is called the *rise time* t_r of the circuit and is shown in Fig. 12.8. The time t_r is an indication of how fast the amplifier can respond to a discontinuity in the input voltage. We have, using Eq. (12.7),

$$t_r = 2.2R_2C_2 = \frac{2.2}{2\pi f_H} = \frac{0.35}{f_H} \qquad (12.20)$$

Note that the rise time is inversely proportional to the upper 3-dB frequency. For an amplifier with 1 MHz bandpass, $t_r = 0.35\ \mu s$.

Consider a pulse of width t_p. What must be the high 3-dB frequency f_H of an amplifier used to amplify this signal without excessive distortion? A reasonable answer to this question is: *Choose f_H equal to the reciprocal of the pulse width, $f_H = 1/f_p$*. From Eq. (12.20) we then have $t_r = 0.35t_p$. Using this relationship, the (shaded) pulse in Fig. 12.9 becomes distorted into the (solid) waveform, which is clearly recognized as a pulse.

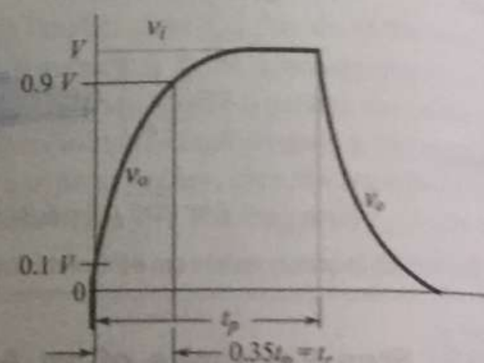

Fig. 12.9 *Pulse response for the case $f_H = 1/t_p$*

Tilt or Sag If a step of amplitude V is impressed on the high-pass circuit of Fig. 12.1, the output is

$$v_o = Ve^{-t/R_1C_1} \qquad (12.21)$$

For times t which are small compared with the time constant R_1C_1, the response is given by

$$v_o \approx V\left(1 - \frac{t}{R_1C_1}\right) \qquad (12.22)$$

From Fig. 12.10 we see that the output is tilted, and the percent tilt, or sag, in time t_1 is given by

$$P \equiv \frac{V - V'}{V} \times 100 = \frac{t_1}{R_1 C_1} \times 100\% \qquad (12.23)$$

It is found[6] that this same expression is valid for the tilt of each half cycle of a symmetrical square wave of peak-to-peak value V and period T provided that we set $t_1 = T/2$. If $f = 1/T$ is the frequency of the square wave, then, using Eq. (12.3), we may express P in the form

$$P = \frac{T}{2R_1 C_1} \times 100 = \frac{1}{2fR_1 C_1} \times 100 = \frac{\pi f_L}{f} \times 100\% \qquad (12.24)$$

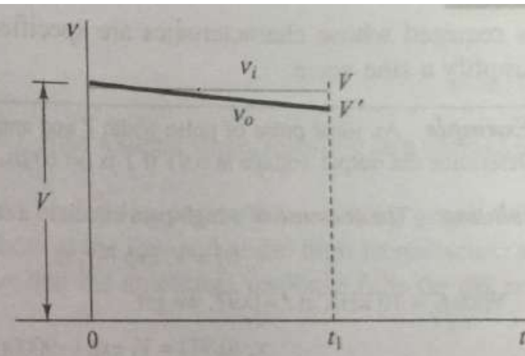

Fig. 12.10 *The response v_o, when a step v_i, is applied to a high-pass RC circuit, exhibits a tilt.*

Note that the tilt is directly proportional to the lower 3-dB frequency. If we wish to pass a 50-Hz square wave with less than 10 percent sag, then f_L must not exceed 1.6 Hz.