7.34 Consider a transistor biased to operate in the active mode at a dc collector current I_C. Calculate the collector signal current as a fraction of I_C (i.e., i_c/I_C) for input signals v_{be} of +1 mV, −1 mV, +2 mV, −2 mV, +5 mV, −5 mV, +8 mV, −8 mV, +10 mV, −10 mV, +12 mV, and −12 mV. In each case do the calculation two ways:

(a) using the exponential characteristic, and
(b) using the small-signal approximation.

Present your results in the form of a table that includes a column for the error introduced by the small-signal approximation. Comment on the range of validity of the small-signal approximation.

7.35 An *npn* BJT with grounded emitter is operated with $V_{BE} = 0.700$ V, at which the collector current is 0.5 mA. A 5-kΩ resistor connects the collector to a +5-V supply. What is the resulting collector voltage V_C? Now, if a signal applied to the base raises v_{BE} to 705 mV, find the resulting total collector current i_C and total collector voltage v_C using the exponential i_C–v_{BE} relationship. For this situation, what are v_{be} and v_c? Calculate the voltage gain v_c/v_{be}. Compare with the value obtained using the small-signal approximation, that is, $-g_m R_C$.

7.36 A transistor with $\beta = 100$ is biased to operate at a dc collector current of 0.5 mA. Find the values of g_m, r_π, and r_e. Repeat for a bias current of 50 μA.

7.37 A *pnp* BJT is biased to operate at $I_C = 1.0$ mA. What is the associated value of g_m? If $\beta = 100$, what is the value of the small-signal resistance seen looking into the emitter (r_e)? Into the base (r_π)? If the collector is connected to a 5-kΩ load, with a signal of 5-mV peak applied between base and emitter, what output signal voltage results?

D 7.38 A designer wishes to create a BJT amplifier with a g_m of 30 mA/V and a base input resistance of 3000 Ω or more. What collector-bias current should he choose? What is the minimum β he can tolerate for the transistor used?

7.39 A transistor operating with nominal g_m of 40 mA/V has a β that ranges from 50 to 150. Also, the bias circuit, being less than ideal, allows a ±20% variation in I_C. What are the extreme values found of the resistance looking into the base?

7.40 In the circuit of Fig. 7.20, V_{BE} is adjusted so that $V_C =$ 1 V. If $V_{CC} = 3$ V, $R_C = 2$ kΩ, and a signal $v_{be} = 0.005 \sin \omega t$ volts is applied, find expressions for the total instantaneous quantities $i_C(t)$, $v_C(t)$, and $i_B(t)$. The transistor has $\beta = 100$. What is the voltage gain?

D *7.41 We wish to design the amplifier circuit of Fig. 7.20 under the constraint that V_{CC} is fixed. Let the input signal $v_{be} = \hat{V}_{be} \sin \omega t$, where $\hat{V}_{be}$ is the maximum value for acceptable linearity. For the design that results in the largest signal at the collector, without the BJT leaving the active region, show that

$$R_C I_C = (V_{CC} - 0.3) \Big/ \left(1 + \frac{\hat{V}_{be}}{V_T}\right)$$

and find an expression for the voltage gain obtained. For $V_{CC} = 3$ V and $\hat{V}_{be} = 5$ mV, find the dc voltage at the collector, the amplitude of the output voltage signal, and the voltage gain.

7.42 The table below summarizes some of the basic attributes of a number of BJTs of different types, operating as amplifiers under various conditions. Provide the missing entries. (*Note:* Isn't it remarkable how much two parameters can reveal?)

7.43 A BJT is biased to operate in the active mode at a dc collector current of 1 mA. It has a β of 100 and V_A of 100 V. Give the four small-signal models (Figs. 7.25 and 7.27) of the BJT complete with the values of their parameters.

Transistor	**a**	**b**	**c**	**d**	**e**	**f**	**g**
α	1.000					0.90	
β		100		∞			
I_C (mA)	1.00		1.00				
I_E (mA)		1.00				5	
I_B (mA)			0.020				1.10
g_m (mA/V)							700
r_e (Ω)				25	100		
r_π (Ω)					10.1 kΩ		

than 10 mV). Find appropriate values for R_E and R_C. What is the value of voltage gain realized from signal source to output?

***7.58** The transistor in the circuit shown in Fig. P7.58 is biased to operate in the active mode. Assuming that β is very large, find the collector bias current I_C. Replace the transistor with the small-signal equivalent-circuit model of Fig. 7.26(b) (remember to replace the dc power supply with a short circuit). Analyze the resulting amplifier equivalent circuit to show that

$$\frac{v_{o1}}{v_i} = \frac{R_E}{R_E + r_e}$$

$$\frac{v_{o2}}{v_i} = \frac{-\alpha R_C}{R_E + r_e}$$

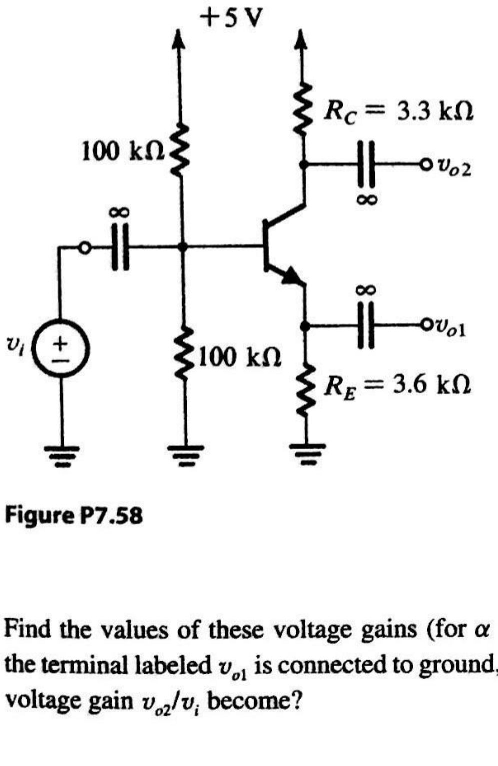

Figure P7.58

Find the values of these voltage gains (for $\alpha \simeq 1$). Now, if the terminal labeled v_{o1} is connected to ground, what does the voltage gain v_{o2}/v_i become?

Section 7.3: Basic Configurations

7.59 An amplifier with an input resistance of 100 kΩ, an open-circuit voltage gain of 100 V/V, and an output resistance of 100 Ω is connected between a 20-kΩ signal source and a 2-kΩ load. Find the overall voltage gain G_v. Also find the current gain, defined as the ratio of the load current to the current drawn from the signal source.

D 7.60 Specify the parameters R_{in}, A_{vo}, and R_o of an amplifier that is to be connected between a 100-kΩ source and a 2-kΩ load and is required to meet the following specifications:

(a) No more than 5% of the signal strength is lost in the connection to the amplifier input;
(b) If the load resistance changes from the nominal value of 2 kΩ to a low value of 1 kΩ, the change in output voltage is limited to 5% of nominal value; and
(c) The nominal overall voltage gain is 10 V/V.

7.61 Figure P7.61 shows an alternative equivalent-circuit representation of an amplifier. If this circuit is to be equivalent to that in Fig. 7.34(b) show that $G_m = A_{vo}/R_o$. Also convince yourself that the transconductance G_m is defined as

$$G_m = \left.\frac{i_o}{v_i}\right|_{R_L=0}$$

and hence is known as the short-circuit transconductance. Now, if the amplifier is fed with a signal source (v_{sig}, R_{sig}) and is connected to a load resistance R_L show that the gain of the amplifier proper A_v is given by $A_v = G_m(R_o \| R_L)$ and the overall voltage gain G_v is given by

$$G_v = \frac{R_{in}}{R_{in} + R_{sig}} G_m (R_o \| R_L)$$

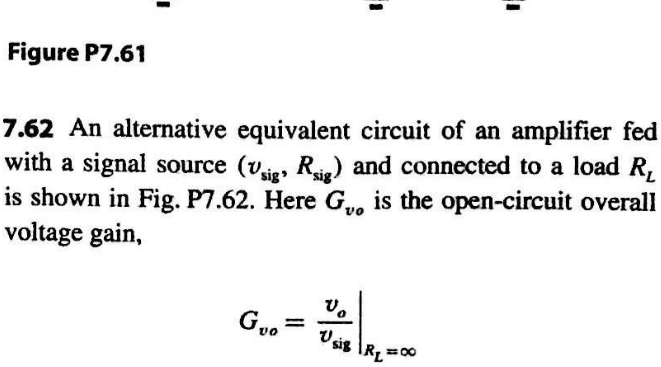

Figure P7.61

7.62 An alternative equivalent circuit of an amplifier fed with a signal source (v_{sig}, R_{sig}) and connected to a load R_L is shown in Fig. P7.62. Here G_{vo} is the open-circuit overall voltage gain,

$$G_{vo} = \left.\frac{v_o}{v_{sig}}\right|_{R_L=\infty}$$

(b) Show that including R_e reduces the magnitude of A_M by a certain factor. What is this factor?

(c) Show that including R_e reduces f_L by the same factor as in (b) and thus one can use R_e to trade off gain for bandwidth.

(d) For $I = 0.25$ mA, $R_C = 10$ kΩ, and $C_E = 10$ μF, find $|A_M|$ and f_L with $R_e = 0$. Now find the value of R_e that lowers f_L by a factor of 10. What will the gain become? Sketch on the same diagram a Bode plot for the gain magnitude for both cases.

Section 10.2: Internal Capacitive Effects and the High-Frequency Model of the MOSFET and the BJT

10.13 Refer to the MOSFET high-frequency model in Fig. 10.12(a). Evaluate the model parameters for an NMOS transistor operating at $I_D = 200$ μA, $V_{SB} = 1$ V, and $V_{DS} = 1.5$ V. The MOSFET has $W = 20$ μm, $L = 1$ μm, $t_{ox} = 8$ nm, $\mu_n = 450$ cm^2/V·s, $\gamma = 0.5$ V$^{1/2}$, $2\phi_f = 0.65$ V, $\lambda = 0.05$ V^{-1}, $V_0 = 0.7$ V, $C_{sb0} = C_{db0} = 20$ fF, and $L_{ov} = 0.05$ μm. [Recall that $g_{mb} = \chi g_m$, where $\chi = \gamma/(2\sqrt{2\phi_f + V_{SB}})$, and that $\epsilon_{ox} = 3.45 \times 10^{-11}$ F/m.]

10.14 Find f_T for a MOSFET operating at $I_D = 200$ μA and $V_{OV} = 0.3$ V. The MOSFET has $C_{gs} = 25$ fF and $C_{gd} = 5$ fF.

10.15 Starting from the expression of f_T for a MOSFET,

$$f_T = \frac{g_m}{2\pi(C_{gs} + C_{gd})}$$

and making the approximation that $C_{gs} \gg C_{gd}$ and that the overlap component of C_{gs} is negligibly small, show that

$$f_T \simeq \frac{1.5}{\pi L}\sqrt{\frac{\mu_n I_D}{2C_{ox}WL}}$$

Thus note that to obtain a high f_T from a given device, it must be operated at a high current. Also note that faster operation is obtained from smaller devices.

10.16 Starting from the expression for the MOSFET unity-gain frequency,

$$f_T = \frac{g_m}{2\pi(C_{gs} + C_{gd})}$$

and making the approximation that $C_{gs} \gg C_{gd}$ and that the overlap component of C_{gs} is negligibly small, show that for an n-channel device

$$f_T \simeq \frac{3\mu_n V_{OV}}{4\pi L^2}$$

Observe that for a given channel length, f_T can be increased by operating the MOSFET at a higher overdrive voltage. Evaluate f_T for devices with $L = 0.5$ μm operated at overdrive voltages of 0.2 V and 0.4 V. Use $\mu_n = 450$ cm^2/V·s.

10.17 It is required to calculate the intrinsic gain A_0 and the unity-gain frequency f_T of an n-channel transistor fabricated in a 0.13-μm CMOS process for which $L_{ov} = 0.1\,L$, $\mu_n = 400$ cm^2/V·s, and $V_A' = 5$ V/μm. The device is operated at $V_{OV} = 0.2$ V. Find A_0 and f_T for devices with $L = L_{min}$, $2L_{min}$, $3L_{min}$, $4L_{min}$, and $5L_{min}$. Present your results in a table. (*Hint:* For f_T, use the approximate expression $f_T \simeq \frac{3\mu_n V_{OV}}{4\pi L^2}$.)

10.18 A particular BJT operating at $I_C = 0.5$ mA has $C_\mu = 1$ pF, $C_\pi = 8$ pF, and $\beta = 100$. What are f_T and f_β for this situation?

10.19 For the transistor described in Problem 10.18, C_π includes a relatively constant depletion-layer capacitance

Transistor	I_E(mA)	r_e(Ω)	g_m(mA/V)	r_x (kΩ)	β_0	f_T(MHz)	C_μ(pF)	C_π(pF)	f_β(MHz)
(a)	2				100	500	2		
(b)		25					2	10.7	4
(c)				2.5	100	500		10.7	
(d)	10				100	500	2		
(e)	0.1				100	150	2		
(f)	1				10	500	2		
(g)						800	1	9	80

of 2 pF. If the device is operated at $I_C = 0.25$ mA, what does its f_T become?

10.20 An *npn* transistor is operated at $I_C = 1$ mA and $V_{CB} = 2$ V. It has $\beta_0 = 100$, $V_A = 50$ V, $\tau_F = 30$ ps, $C_{je0} = 20$ fF, $C_{\mu 0} = 30$ fF, $V_{0c} = 0.75$ V, $m_{CBJ} = 0.5$, and $r_x = 100\ \Omega$. Sketch the complete hybrid-π model, and specify the values of all its components. Also, find f_T.

10.21 Measurement of h_{fe} of an *npn* transistor at 50 MHz shows that $|h_{fe}| = 10$ at $I_C = 0.2$ mA and 12 at $I_C = 1.0$ mA. Furthermore, C_μ was measured and found to be 0.1 pF. Find f_T at each of the two collector currents used. What must τ_F and C_{je} be?

10.22 A particular small-geometry BJT has f_T of 10 GHz and $C_\mu = 0.1$ pF when operated at $I_C = 1.0$ mA. What is C_π in this situation? Also, find g_m. For $\beta = 120$, find r_π and f_β.

10.23 For a BJT whose unity-gain bandwidth is 2 GHz and $\beta_0 = 200$, at what frequency does the magnitude of h_{fe} become 40? What is f_β?

***10.24** For a sufficiently high frequency, measurement of the complex input impedance of a BJT having (ac) grounded emitter and collector yields a real part approximating r_x. For what frequency, defined in terms of ω_β, is such an estimate of r_x good to within 10% under the condition that $r_x \le r_\pi/10$?

***10.25** Complete the table entries on the previous page for transistors (a) through (g), under the conditions indicated. Neglect r_x.

Section 10.3: High-Frequency Response of the CS and CE Amplifiers

10.26 In a particular common-source amplifier for which the midband voltage gain between gate and drain (i.e., $-g_m R_L'$) is −39 V/V, the NMOS transistor has $C_{gs} = 1.0$ pF and $C_{gd} = 0.1$ pF. What input capacitance would you expect? For what range of signal-source resistances can you expect the 3-dB frequency to exceed 1 MHz? Neglect the effect of R_G.

D 10.27 In the circuit of Fig. P10.27, the voltage amplifier is ideal (i.e., it has an infinite input resistance and a zero output resistance).

(a) Use the Miller approach to find an expression for the input capacitance C_{in} in terms of A and C.

(b) Use the expression for C_{in} to obtain the transfer function $V_o(s)/V_{sig}(s)$.

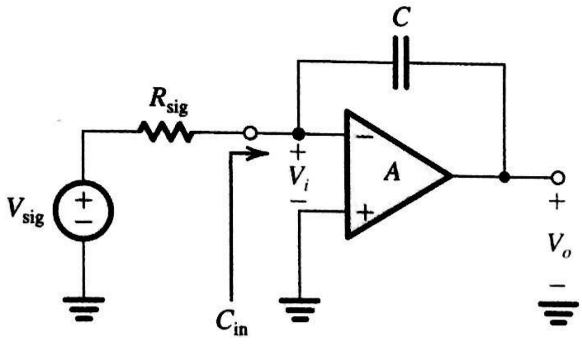

Figure P10.27

(c) If $R_{sig} = 1$ kΩ, and the gain V_o/V_{sig} is to have a dc value of 40 dB and a 3-dB frequency of 100 kHz, find the values required for A and C.

(d) Sketch a Bode plot for the gain and use it to determine the frequency at which its magnitude reduces to unity.

10.28 An ideal voltage amplifier having a voltage gain of −1000 V/V has a 0.2-pF capacitance connected between its output and input terminals. What is the input capacitance of the amplifier? If the amplifier is fed from a voltage source V_{sig} having a resistance $R_{sig} = 1$ kΩ, find the transfer function V_o/V_{sig} as a function of the complex-frequency variable s and hence the 3-dB frequency f_H and the unity-gain frequency f_t.

D 10.29 A design is required for a CS amplifier for which the MOSFET is operated at $g_m = 5$ mA/V and has $C_{gs} = 5$ pF and $C_{gd} = 1$ pF. The amplifier is fed with a signal source having $R_{sig} = 1$ kΩ, and R_G is very large. What is the largest value of R_L' for which the upper 3-dB frequency is at least 6 MHz? What is the corresponding value of midband gain and gain–bandwidth product? If the specification on the upper 3-dB frequency can be relaxed by a factor of 3, that is, to 2 MHz, what can A_M and GB become?

10.30 Reconsider Example 10.3 for the situation in which the transistor is replaced by one whose width W is half that of the original transistor while the bias current remains unchanged. Find modified values for all the device parameters along with A_M, f_H, and the gain–bandwidth product, GB. Contrast this with the original design by calculating the ratios of new value to old for W, V_{OV}, g_m, C_{gs}, C_{gd}, C_{in}, A_M, f_H, and GB.

D *10.31 In a CS amplifier, such as that in Fig. 10.3(a), the resistance of the source $R_{sig} = 100$ kΩ, amplifier

SIM = Multisim/PSpice; * = difficult problem; ** = more difficult; *** = very challenging; D = design problem