and r_π is 2.5 kΩ. Draw the complete amplifier model using the hybrid-π BJT equivalent circuit. Calculate the overall voltage gain (v_c/v_s). What is the value of BJT β implied by the values of the model parameters? To what value must β be increased to double the overall voltage gain?

5.115 For the circuit shown in Fig. P5.115, draw a complete small-signal equivalent circuit utilizing an appropriate T model for the BJT (use $\alpha = 0.99$). Your circuit should show the values of all components, including the model parameters. What is the input resistance R_{in}? Calculate the overall voltage gain (v_o/v_{sig}).

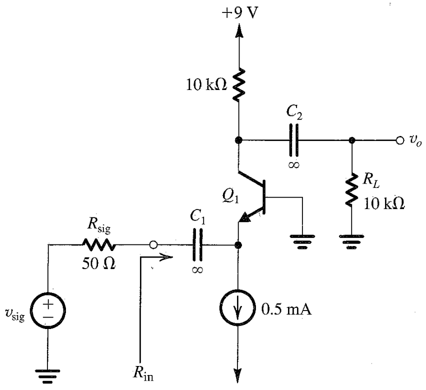

FIGURE P5.115

5.116 In the circuit shown in Fig. P5.116, the transistor has a β of 200. What is the dc voltage at the collector? Find the input resistances R_{ib} and R_{in} and the overall voltage gain (v_o/v_{sig}). For an output signal of ±0.4 V, what values of v_{sig} and v_b are required?

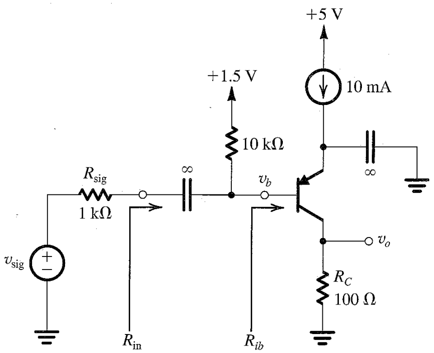

FIGURE P5.116

5.117 Consider the augmented hybrid-π model shown in Fig. 5.58(a). Disregarding how biasing is to be done, what is the largest possible voltage gain available for a signal source connected directly to the base and a very-high-resistance load? Calculate the value of the maximum possible gain for $V_A = 25$ V and $V_A = 250$ V.

5.118 Reconsider the amplifier shown in Fig. 5.53 and analyzed in Example 5.14 under the condition that β is not well controlled. For what value of β does the circuit begin to saturate? We can conclude that large β is dangerous in this circuit. Now, consider the effect of reduced β, say, to $\beta = 25$. What values of r_e, g_m, and r_π result? What is the overall voltage gain? (*Note:* You can see that this circuit, using base-current control of bias, is very β-sensitive and usually *not recommended.*)

5.119 Reconsider the circuit shown in Fig. 5.55(a) under the condition that the signal source has an internal resistance of 100 Ω. What does the overall voltage gain become? What is the largest input signal voltage that can be used without output-signal clipping?

D5.120 Redesign the circuit of Fig. 5.55 by raising the resistor values by a factor n to increase the resistance seen by the input v_i to 75 Ω. What value of voltage gain results? Grounded-base circuits of this kind are used in systems such as cable TV, in which, for highest-quality signaling, load resistances need to be "matched" to the equivalent resistances of the interconnecting cables.

5.121 Using the BJT equivalent circuit model of Fig. 5.52(a), sketch the equivalent circuit of a transistor amplifier for which a resistance R_e is connected between the emitter and ground, the collector is grounded, and an input signal source v_b is connected between the base and ground. (It is assumed that the transistor is properly biased to operate in the active region.) Show that:

(a) the voltage gain between base and emitter, that is, v_e/v_b, is given by

$$\frac{v_e}{v_b} = \frac{R_e}{R_e + r_e}$$

(b) the input resistance,

$$R_{in} \equiv \frac{v_b}{i_b} = (\beta + 1)(R_e + r_e)$$

Find the numerical values for (v_e/v_b) and R_{in} for the case $R_e = 1$ kΩ, $\beta = 100$, and the emitter bias current $I_E = 1$ mA.

5.122 When the collector of a transistor is connected to its base, the transistor still operates (internally) in the active region because the collector–base junction is still in effect reverse biased. Use the simplified hybrid-π model to find the incremental (small-signal) resistance of the resulting two-terminal device (known as a diode-connected transistor.)

****D5.123** Design an amplifier using the configuration of Fig. 5.55(a). The power supplies available are ±10 V. The input signal source has a resistance of 100 Ω, and it is required that the amplifier input resistance match this value. (Note that $R_{in} = r_e \,//\, R_E \simeq r_e$.) The amplifier is to have the greatest possible voltage gain and the largest possible output signal but retain small-signal linear operation (i.e., the signal component across the base–emitter junction should be limited to no more than 10 mV). Find appropriate values for R_E and R_C. What is the value of voltage gain realized?

***5.124** The transistor in the circuit shown in Fig. P5.124 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. 5.52(b) (remember to replace the dc power supply with a short circuit). Analyze the resulting amplifier equivalent circuit to show that

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

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

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?

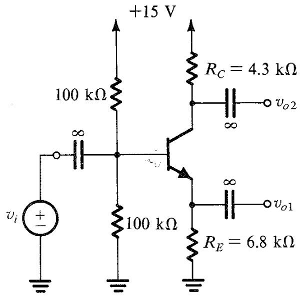

FIGURE P5.124

SECTION 5.7: SINGLE-STAGE BJT AMPLIFIERS

5.125 An amplifier is measured to have $R_i = 10$ kΩ, $A_{vo} = 100$ V/V, and $R_o = 100$ Ω. Also, when a load resistance R_L of 1 kΩ is connected between the output terminals, the input resistance is found to decrease to 8 kΩ. If the amplifier is fed with a signal source having an internal resistance of 2 kΩ, find G_m, A_v, G_{vo}, G_v, R_{out}, and A_i.

5.126 Figure P5.126 shows an alternative equivalent circuit for representing *any* linear two-port network including voltage amplifiers. This non-unilateral equivalent circuit is based on the g-parameter two-port representation (see Appendix B).

(a) Using the values of R_i, A_{vo}, and R_o found in Example 5.17 together with the measured value of R_{in} of 400 kΩ obtained when a load R_L of 10 kΩ is connected to the output, determine the value of the feedback factor f.

(b) Now, use the equivalent circuit of Fig. P5.126 to determine the value of R_{out} obtained when the amplifier is fed with a signal generator having $R_{sig} = 100$ kΩ. Check your result against that found in Example 5.17.

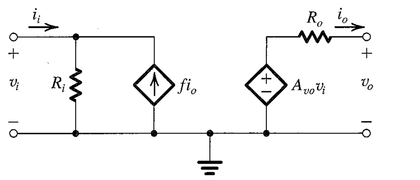

FIGURE P5.126

5.127 Refer to Table 5.5. By equating the expression for G_v obtained from Equivalent Circuit A to that obtained from Equivalent Circuit C with $G_{vo} = [R_i/(R_i + R_{sig})]A_{vo}$, show that

$$\frac{R_{in}}{R_i}\frac{R_{sig} + R_i}{R_{sig} + R_{in}} = \frac{R_L + R_o}{R_L + R_{out}}$$

Now, use this expression to:

(a) Show that for $R_L = \infty$, $R_{in} = R_i$.
(b) Show that for $R_{sig} = 0$, $R_{out} = R_o$.
(c) Find R_{out} when $R_{sig} = \infty$ (i.e., the amplifier input is open-circuited), and evaluate its value for the amplifier specified in Example 5.17.

5.128 A common-emitter amplifier of the type shown in Fig. 5.60(a) is biased to operate at $I_C = 0.2$ mA and has a collector resistance $R_C = 24$ kΩ. The transistor has $\beta = 100$ and a large V_A. The signal source is directly coupled to the base, and C_{C1} and R_B are eliminated. Find R_{in}, the voltage gain A_{vo}, and R_o. Use these results to determine the overall voltage gain when a 10-kΩ load resistor is connected to the collector and the source resistance $R_{sig} = 10$ kΩ.

5.129 Repeat Problem 5.128 with a 125-Ω resistance included in the signal path in the emitter. Furthermore, contrast the maximum amplitude of the input sine wave that can be applied with and without R_e assuming that to limit distortion the signal between base and emitter is not to exceed 5 mV.

5.130 For the common-emitter amplifier shown in Fig. P5.130, let $V_{CC} = 9$ V, $R_1 = 27$ kΩ, $R_2 = 15$ kΩ, $R_E = 1.2$ kΩ, and $R_C = 2.2$ kΩ. The transistor has $\beta = 100$ and $V_A = 100$ V.

Calculate the dc bias current I_E. If the amplifier operates between a source for which R_{sig} = 10 kΩ and a load of 2 kΩ, replace the transistor with its hybrid-π model, and find the values of R_{in}, the voltage gain v_o/v_{sig}, and the current gain i_o/i_i.

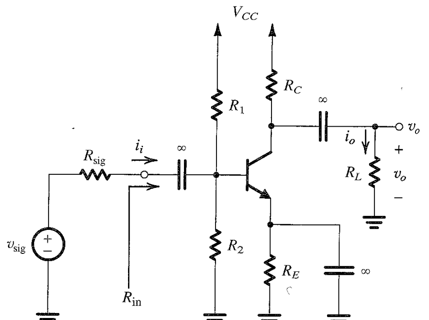

FIGURE P5.130

D5.131 Using the topology of Fig. P5.130, design an amplifier to operate between a 10-kΩ source and a 2-kΩ load with a gain v_o/v_{sig} of −8 V/V. The power supply available is 9 V. Use an emitter current of approximately 2 mA and a current of about one-tenth of that in the voltage divider that feeds the base, with the dc voltage at the base about one-third of the supply. The transistor available has β = 100 and V_A = 100 V. Use standard 5% resistor (see Appendix G).

5.132 A designer, having examined the situation described in Problem 5.130 and estimating the available gain to be approximately −8 V/V, wishes to explore the possibility of improvement by reducing the loading of the source by the amplifier input. As an experiment, the designer varies the resistance levels by a factor of approximately 3: R_1 to 82 kΩ, R_2 to 47 kΩ, R_E to 3.6 kΩ, and R_C to 6.8 kΩ (standard values of 5%-tolerance resistors). With V_{CC} = 9 V, R_{sig} = 10 kΩ, R_L = 2 kΩ, β = 100, and V_A = 100 V, what does the gain become? Comment.

D5.133 Consider the CE amplifier circuit of Fig. 5.60(a). It is required to design the circuit (i.e., find values for I, R_B, and R_C) to meet the following specifications:

(a) $R_{in} \cong$ 5 kΩ.

(b) the dc voltage drop across R_B is approximately 0.5 V.

(c) the open-circuit voltage gain from base to collector is the maximum possible, consistent with the requirement that the collector voltage never falls by more than approximately 0.5 V below the base voltage with the signal between base and emitter being as high as 5 mV.

Assume that v_{sig} is a sinusoidal source, the available supply V_{CC} = 5 V, and the transistor has β = 100 and a very large Early voltage. Use standard 5%-resistance values, and specify the value of I to one significant digit. What base-to-collector open-circuit voltage gain does your design provide? If R_{sig} = R_L = 10 kΩ, what is the overall voltage gain?

D5.134 In the circuit of Fig. P5.134, v_{sig} is a small sine-wave signal with zero average. The transistor β is 100.

(a) Find the value of R_E to establish a dc emitter current of about 0.5 mA.

(b) Find R_C to establish a dc collector voltage of about +5 V.

(c) For R_L = 10 kΩ and the transistor r_o = 200 kΩ, draw the small-signal equivalent circuit of the amplifier and determine its overall voltage gain.

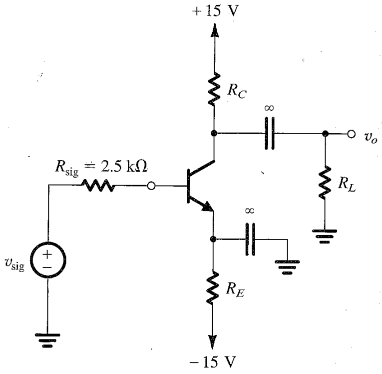

FIGURE P5.134

***5.135** The amplifier of Fig. P5.135 consists of two identical common-emitter amplifiers connected in cascade. Observe that the input resistance of the second stage, R_{in2}, constitutes the load resistance of the first stage.

(a) For V_{CC} = 15 V, R_1 = 100 kΩ, R_2 = 47 kΩ, R_E = 3.9 kΩ, R_C = 6.8 kΩ, and β = 100, determine the dc collector current and dc collector voltage of each transistor.

(b) Draw the small-signal equivalent circuit of the entire amplifier and give the values of all its components. Neglect r_{o1} and r_{o2}.

(c) Find R_{in1} and v_{b1}/v_{sig} for R_{sig} = 5 kΩ.

(d) Find R_{in2} and v_{b2}/v_{b1}.

(e) For R_L = 2 kΩ, find v_o/v_{b2}.

(f) Find the overall voltage gain v_o/v_{sig}.

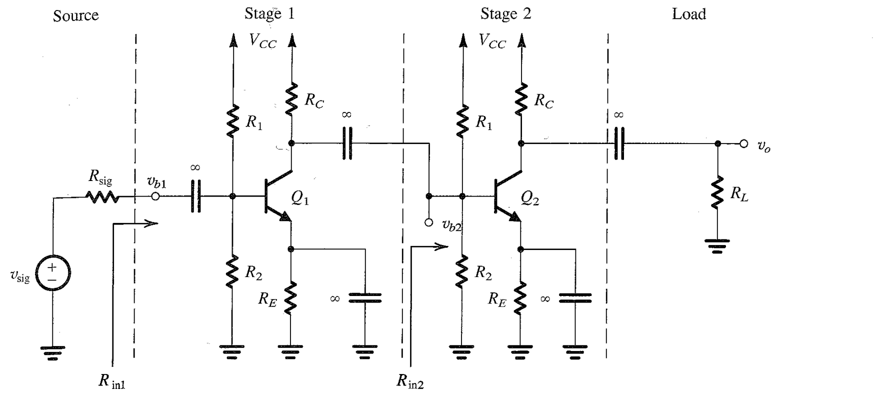

FIGURE P5.135

5.136 In the circuit of Fig. P5.136, v_{sig} is a small sine-wave signal. Find R_{in} and the gain v_o/v_{sig}. Assume β = 100. If the amplitude of the signal v_{be} is to be limited to 5 mV, what is the largest signal at the input? What is the corresponding signal at the output?

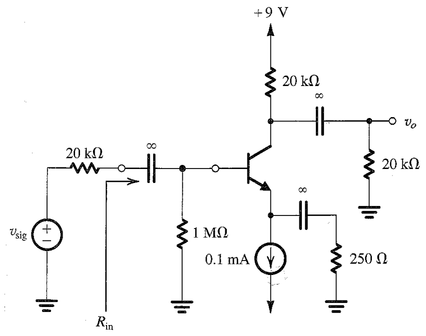

FIGURE P5.136

***5.137** The BJT in the circuit of Fig. P5.137 has β = 100.

(a) Find the dc collector current and the dc voltage at the collector.

(b) Replacing the transistor by its T model, draw the small-signal equivalent circuit of the amplifier. Analyze the resulting circuit to determine the voltage gain v_o/v_i.

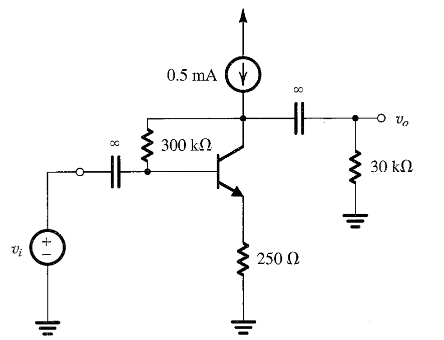

FIGURE P5.137

***5.138** Refer to the voltage-gain expression (in terms of transistor β) given in Eq. (5.135) for the CE amplifier with a resistance R_e in the emitter. Let the BJT be biased at an emitter current of 0.5 mA. The source resistance R_{sig} is 10 kΩ. The BJT β is specified to lie in the range of 50 to 150 with a nominal value of 100.

(a) What is the ratio of maximum to minimum voltage gain obtained without R_e?

(b) What value of R_e should be used to limit the ratio of maximum to minimum gain to 1.2?

(c) If the R_e found in (b) is used, by what factor is the gain reduced (compared to the case without R_e) for a BJT with a nominal β?