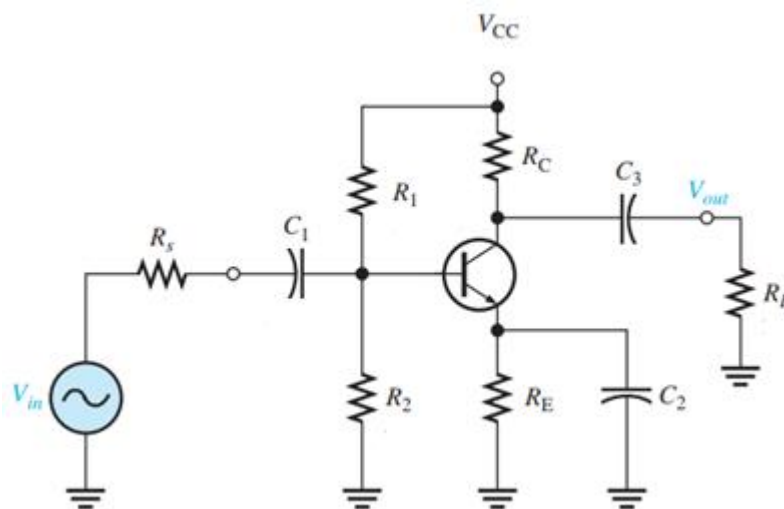


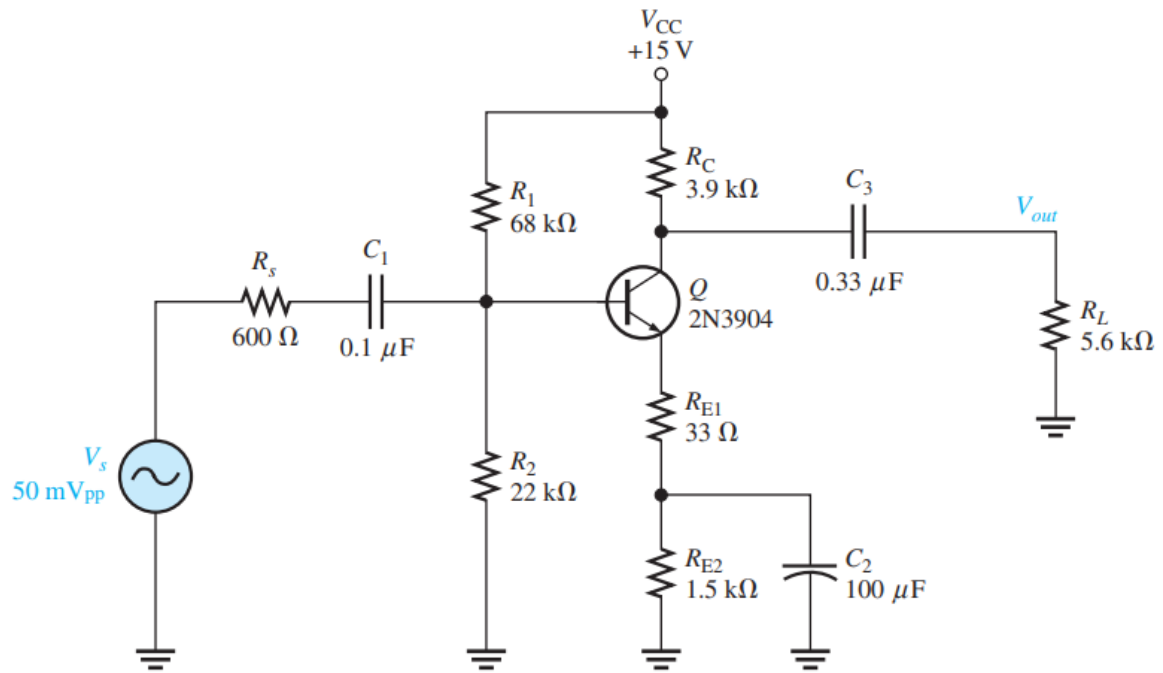
A. Frequency Response of BJT Amplifiers

1. Bode plot is very handy for helping you to design the frequency response characteristics of the amplifier.
 - a. Draw a composite Bode plot of a BJT amplifier response for three low-frequency RC circuits with different critical frequencies (e.g. $f_{cl(\text{bypass})} < f_{cl(\text{input})} < f_{cl(\text{output})}$). [4 marks]
 - b. Draw a composite Bode plot of an amplifier response where all RC circuits have the same critical frequencies (f_{cl}). [4 marks]
 - c. The midrange voltage gain of a certain amplifier is 100. The input RC circuit has a lower critical frequency of 1 kHz. Determine the actual voltage gain at $f = 1 \text{ kHz}$, $f = 100 \text{ Hz}$, and $f = 10 \text{ Hz}$. [6 marks]

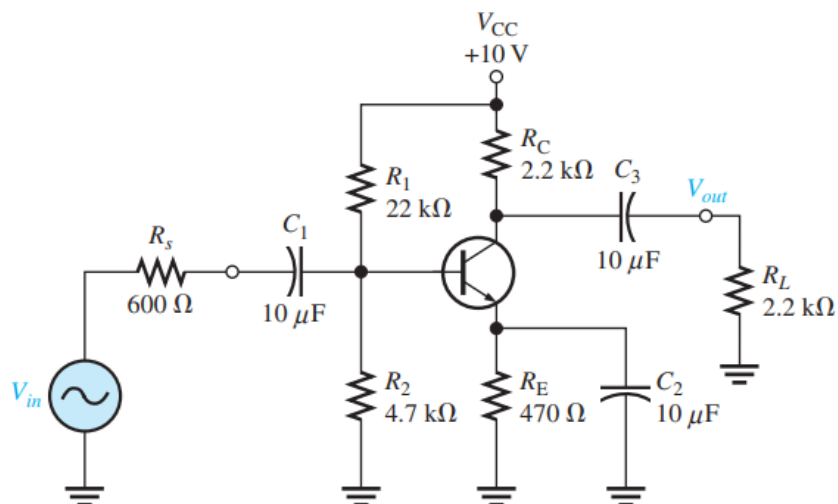
As a reference for this question, an example of the BJT amplifier circuit is given in the following figure.



2. For the common emitter BJT circuit in the figure given below, assuming $r_e' = 9.6 \Omega$ and $\beta = 200$, notice that a swamping resistor, R_{E1} and R_{E1} , are used.
 - a. Calculate the lower critical frequency due to the input RC circuit. [4 marks]
 - b. Calculate the lower critical frequency due to the output RC circuit. [4 marks]
 - c. Calculate the lower critical frequency due to the bypass RC circuit. [4 marks]
 - d. Determine the mid-band gain in decibels and draw the Bode plot, showing each of the lower critical frequencies. [8 marks]



3. For the following BJT amplifier:

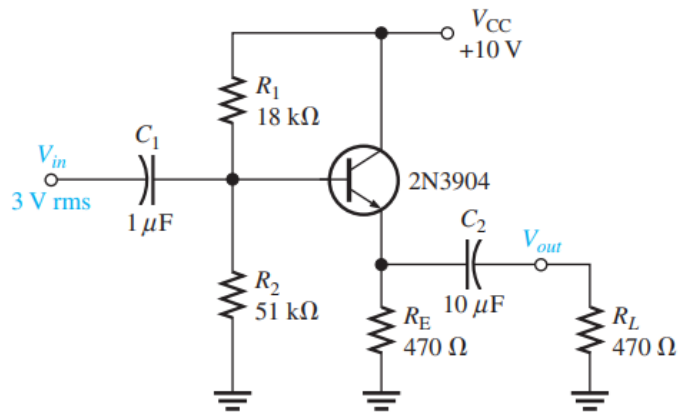


- Derive the equivalent high-frequency input RC circuit for the BJT. Use this to determine the upper critical frequency due to the input circuit. The transistor's datasheet provides the following: $\beta_{ac} = 125$, $C_{be} = 20 \text{ pF}$, and $C_{bc} = 2.4 \text{ pF}$. [20 marks]
- Determine the upper-critical frequency of the amplifier due to its output RC circuit. [8 marks]

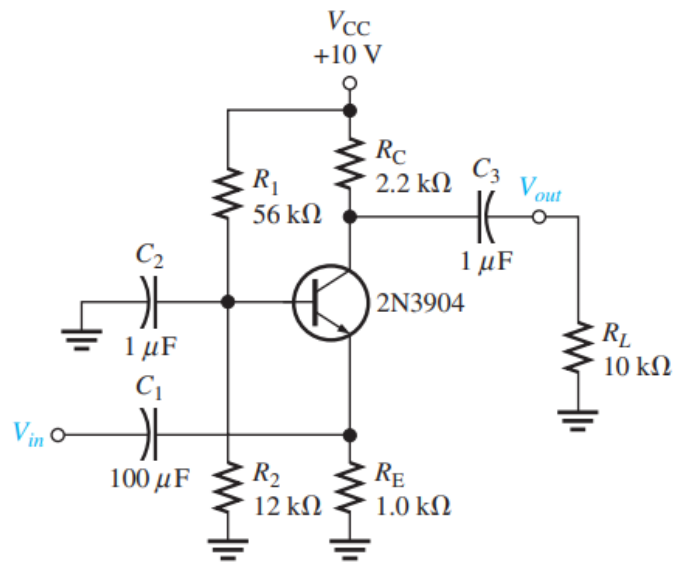
B. BJT Circuit Configurations

- For the common collector (emitter-follower) in the figure given below, assume $\beta_{AC} = 175$ and that the capacitive reactance are negligible at the frequency of operation.

- a. Determine the total input resistance of the circuit. [6 marks]
- b. Also find the voltage gain, current gain, and power gain in terms of power delivered to the load, R_L . [24 marks]

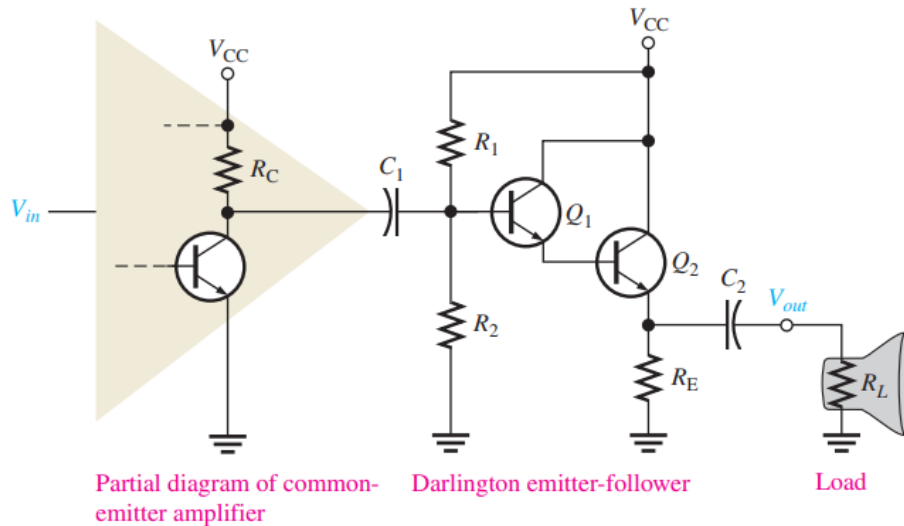


2. Find the input resistance, voltage gain, current gain, and power gain for the common-base amplifier as shown in the figure below. Consider that $\beta_{DC} = 250$. [18 marks]



C. Multistage BJT Amplifiers

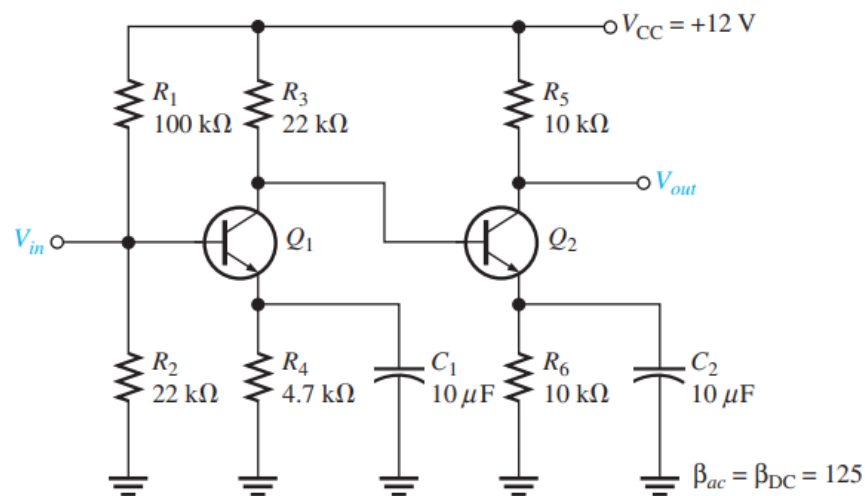
1. In the figure below for the common-emitter amplifier, $V_{CC} = 12\text{ V}$, $R_C = 1\text{ k}\Omega$ and $r_e' = 5\ \Omega$. For the Darlington emitter-follower, $R_1 = 10\text{ k}\Omega$, $R_2 = 22\text{ k}\Omega$, $R_E = 22\ \Omega$, $R_L = 8\ \Omega$, $V_{CC} = 12\text{ V}$, and $\beta_{dc} = \beta_{ac} = 100$ for each transistor. Neglect $R_{in(\text{base})}$ of the Darlington.



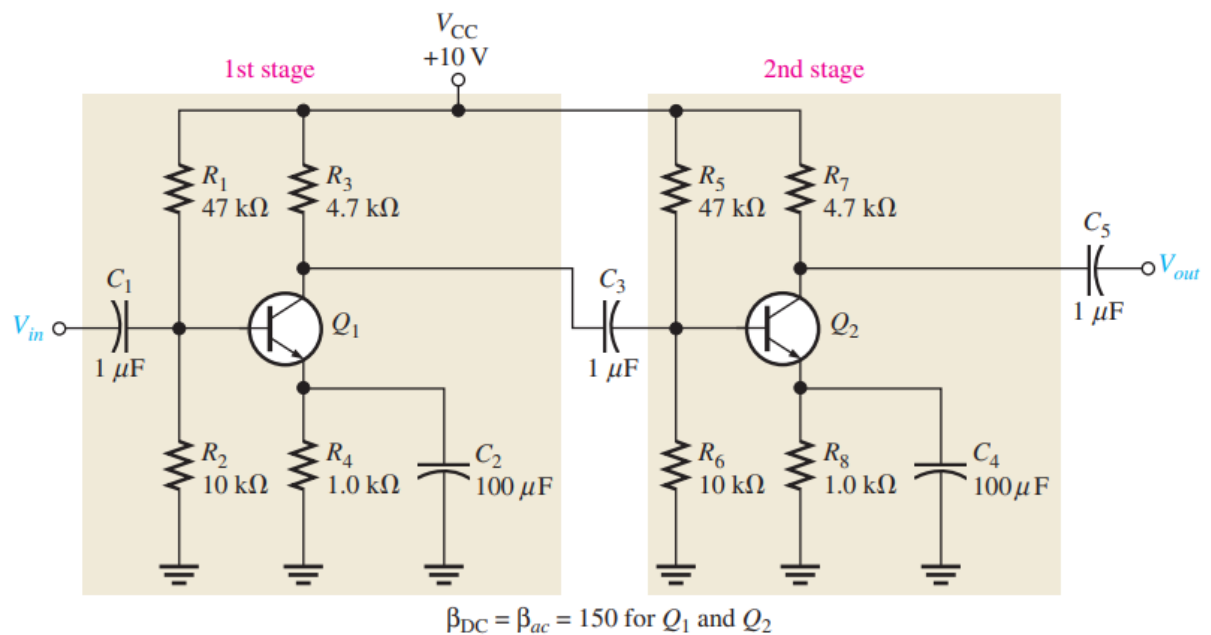
- a. Determine the voltage gain of the common-emitter amplifier. [18 marks]
- b. Determine the voltage gain of the Darlington emitter-follower. [2 marks]
- c. Determine the overall voltage gain and compare to the gain of the common-emitter amplifier driving the speaker directly without the Darlington emitter-follower. [2 marks]

2. Figure below shows a direct-coupled (i.e. no coupling capacitors between stages) two-stage amplifier. The DC bias of the first stage sets the DC bias of the second. Determine:

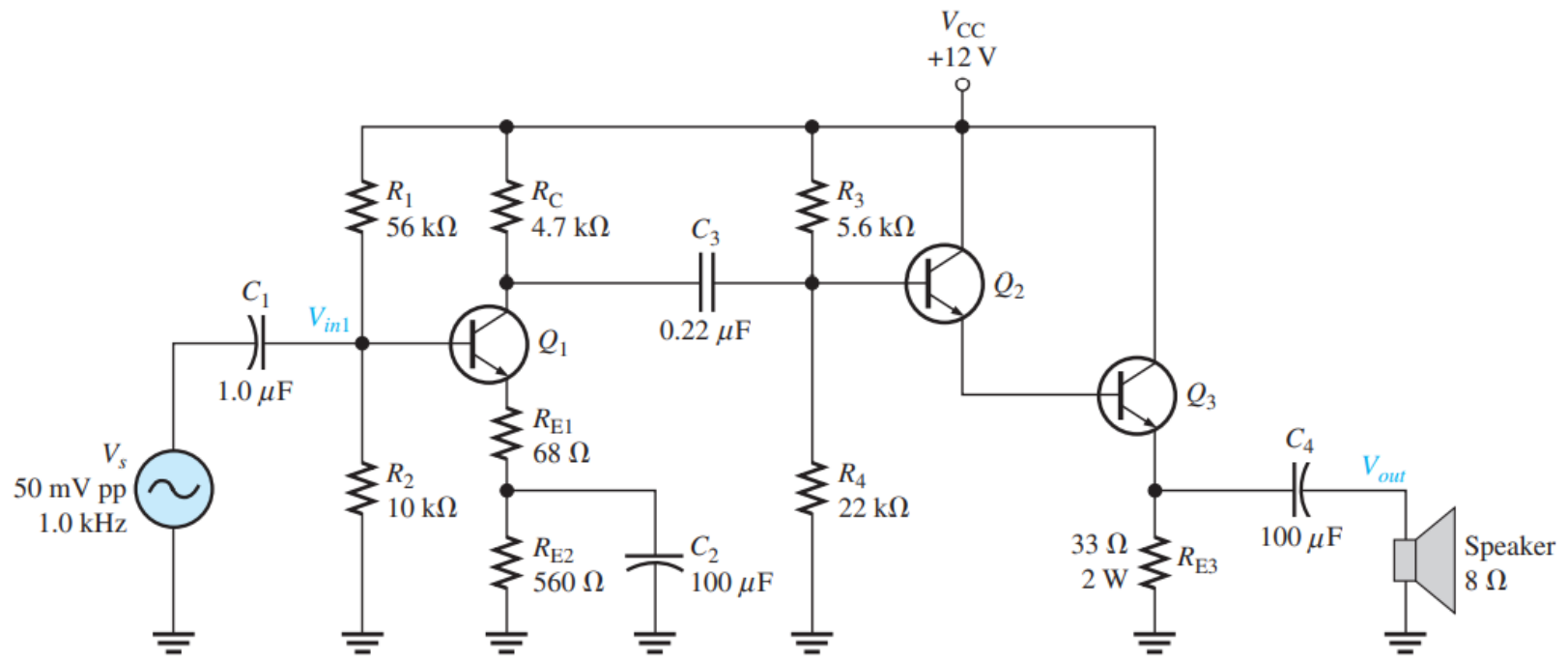
- a. All DC voltages for the first stage. [8 marks]
- b. All DC voltages for the second stage. [8 marks]
- c. The AC voltage gain of the first stage. [4 marks]
- d. The AC voltage gain of the second stage. [6 marks]
- e. The overall AC voltage gain. [2 marks]



3. For the following capacitively-coupled multistage NPN BJT transistor amplifier, answer the following questions.
- Describe the loading effect of the second stage of the amplifier. [5 marks]
 - Determine the voltage gain of the first stage. [6 marks]
 - Determine the voltage gain of the second stage. [2 marks]
 - Determine the overall voltage gain of the amplifier. [6 marks]
 - Determine the DC Voltages in the amplifier. [10 marks]

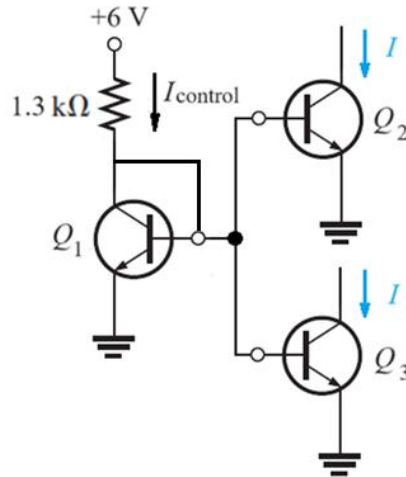


4. Determine the voltage gain and the power gain of the Class A power amplifier in the figure below. Assume $\beta_{ac} = 200$ for all transistors. [16 marks]

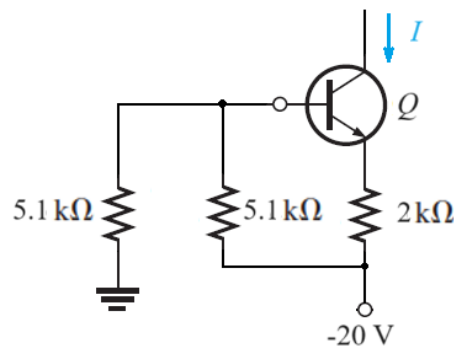


D. BJT Other Circuits

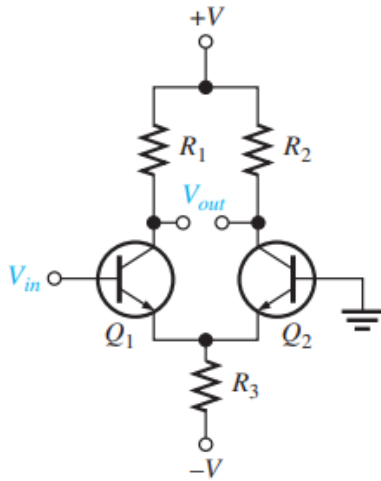
1. Calculate the current I through each of the transistor Q_2 and Q_3 in the current mirror circuit given below. Assume the V_{BE} of the BJT is 0.7 V. [10 marks]



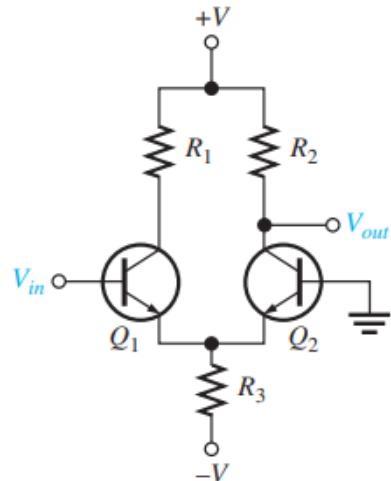
2. Calculate the constant current I in the constant-current source circuit as shown in the figure below. Assume the V_{BE} of the BJT is 0.7 V. [7.5 marks]



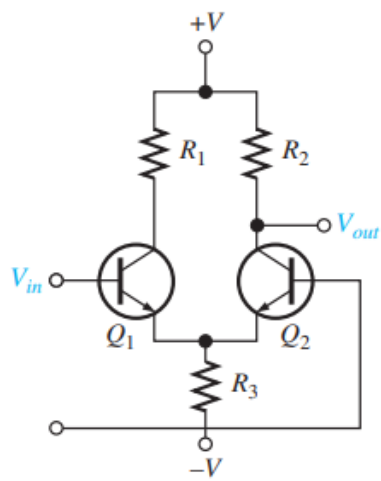
3. Differential amplifier is an amplifier that produces outputs that are a function of the difference between two input voltages. The differential amplifier has two basic modes of operation: differential (in which the two inputs are different) and common mode (in which the two inputs are the same).
 - a. Identify the type of input and output configuration for each basic differential amplifier given below. [2 marks]



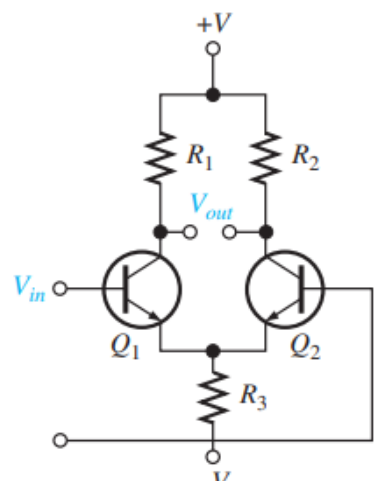
Differential amplifier (i)



Differential amplifier (ii)

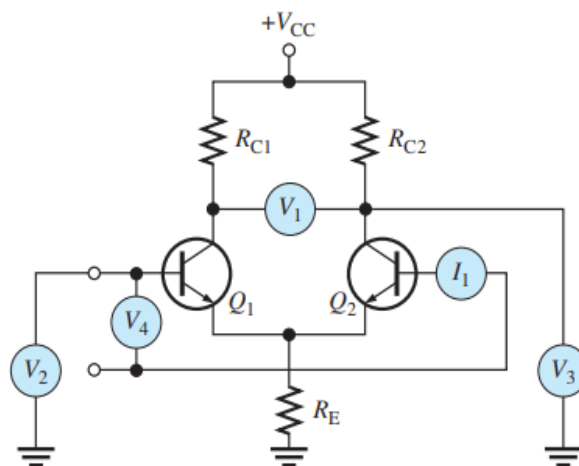


Differential amplifier (iii)

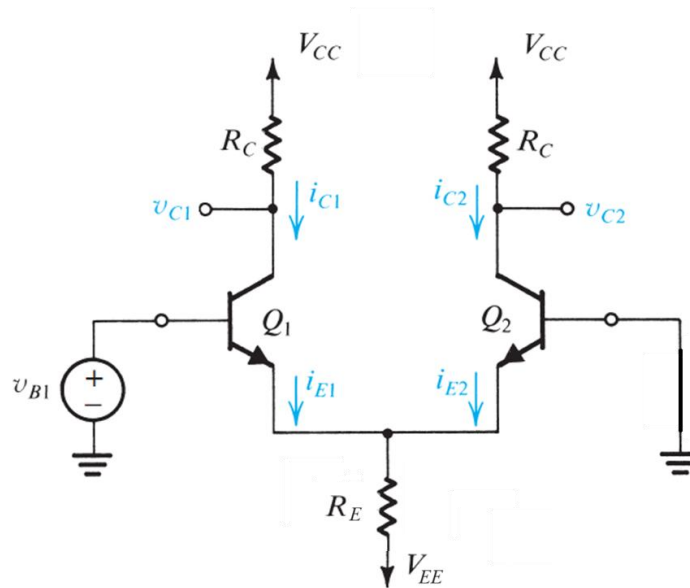


Differential amplifier (iv)

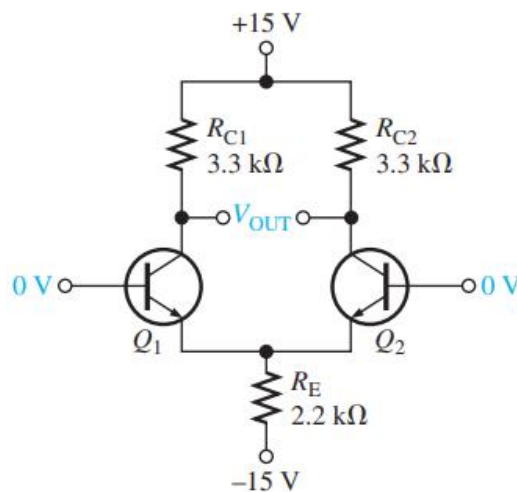
- b. Identify the quantity measured by each meter in the differential amplifier given in the figure below. [2.5 marks]



4. For the differential amplifier circuit given below, $V_{CC} = +15\text{ V}$, $R_C = 5\text{ k}\Omega$, $V_{B1} = 1\text{ mV}$, $R_E = 7.5\text{ k}\Omega$, and $V_{EE} = -15\text{ V}$.

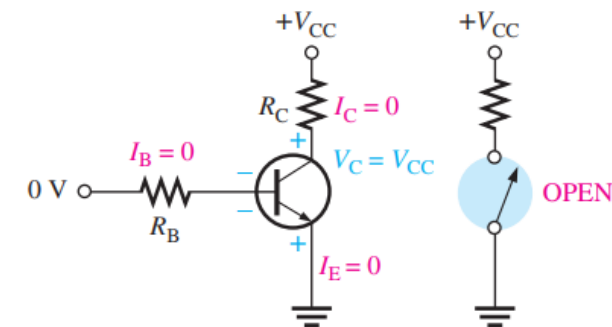


- What are the tail currents (I_E) and collector voltage (V_C)? [6 marks]
 - What is the AC output voltage? If $\beta = 300$, what is the input impedance of the difference amplifier. [8 marks]
5. The DC base voltages in the differential amplifier in the figure below are zero. Using your knowledge of transistor analysis, determine the DC differential output voltage as a function of emitter current. Assume that Q_1 has an $\alpha = 0.980$ and Q_2 has an $\alpha = 0.975$. [18 marks]



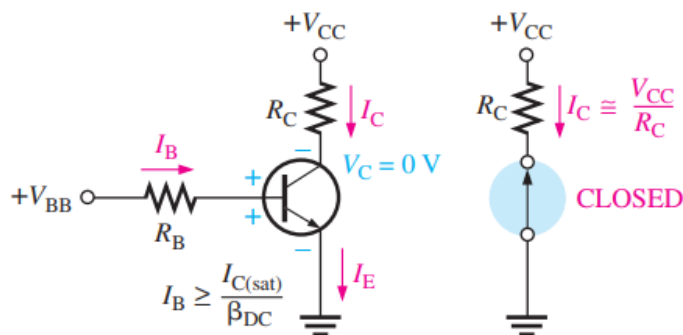
Appendix 1 – Summary of BJT

Switching Applications



Cutoff: BE junction reverse-biased
BC junction reverse-biased

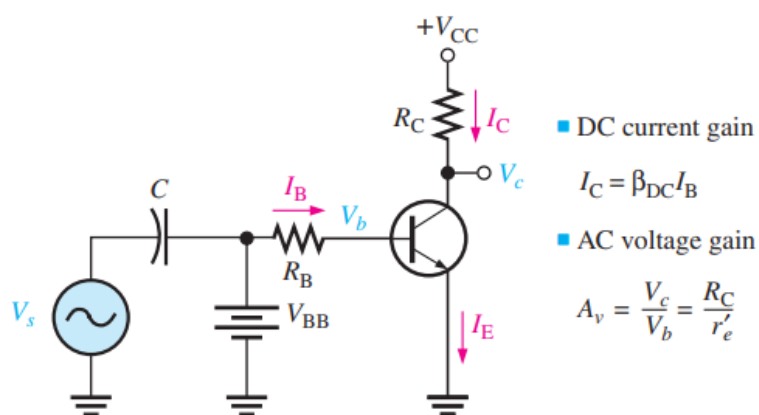
Ideal switch
equivalent for
cutoff



Saturation: BE junction forward-biased
BC junction forward-biased

Ideal switch
equivalent for
saturation

Amplifier Applications



■ DC current gain

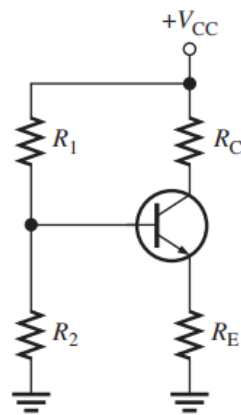
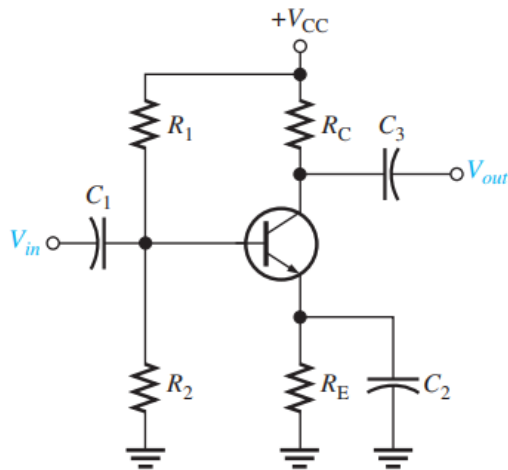
$$I_C = \beta_{DC} I_B$$

■ AC voltage gain

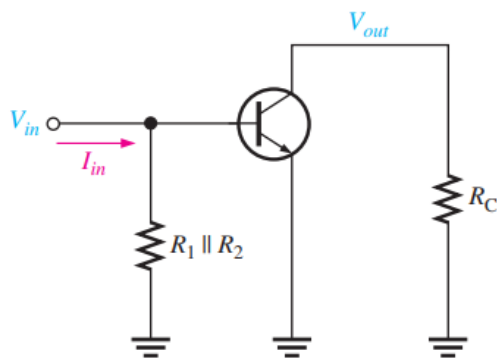
$$A_v = \frac{V_c}{V_b} = \frac{R_C}{r'_e}$$

BE junction forward-biased
BC junction reverse-biased

Common Emitter Amplifier



DC equivalent circuit



AC equivalent circuit

CIRCUIT WITH VOLTAGE-DIVIDER BIAS

- Input is at the base. Output is at the collector.
- There is a phase inversion from input to output.
- C_1 and C_3 are coupling capacitors for the input and output signals.
- C_2 is the emitter-bypass capacitor.
- All capacitors must have a negligible reactance at the frequency of operation, so they appear as shorts.
- Emitter is at ac ground due to the bypass capacitor.

EQUIVALENT CIRCUITS AND FORMULAS

- DC formulas:

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2}$$

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2} \right) V_{CC}$$

$$I_E = \frac{V_{TH} - V_{BE}}{R_E + R_{TH}/\beta_{DC}}$$

$$V_E = I_E R_E$$

$$V_B = V_E + V_{BE}$$

$$V_C = V_{CC} - I_C R_C$$

- AC formulas:

$$r'_e = \frac{25 \text{ mV}}{I_E}$$

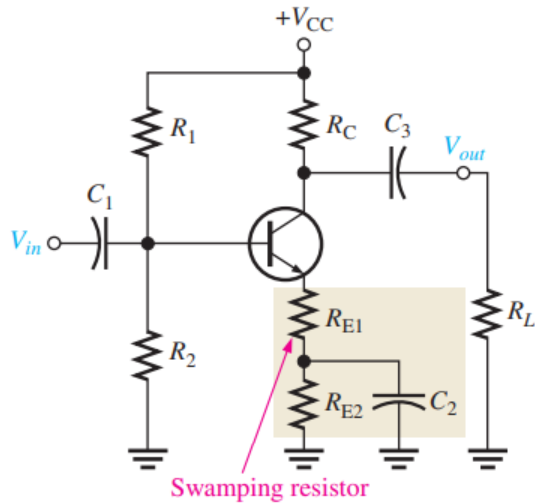
$$R_{in(base)} = \beta_{ac} r'_e$$

$$R_{out} \cong R_C$$

$$A_v = \frac{R_C}{r'_e}$$

$$A_i = \frac{I_C}{I_{in}}$$

$$A_p = A'_v A_i$$



SWAMPED AMPLIFIER WITH RESISTIVE LOAD

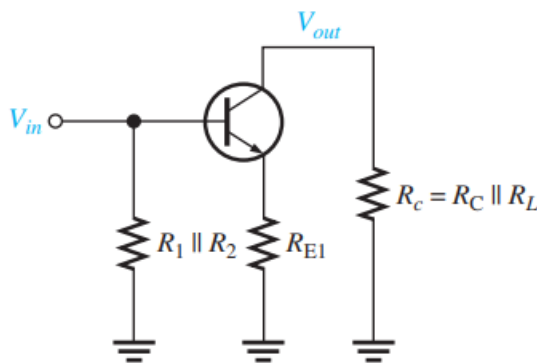
- AC formulas:

$$A_v \cong \frac{R_c}{R_{E1}}$$

where $R_c = R_C \parallel R_L$

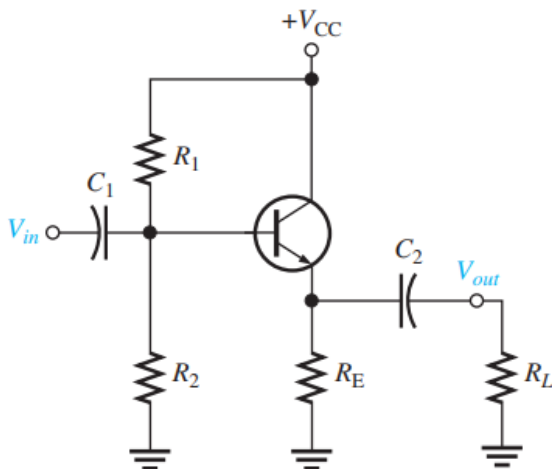
$$R_{in(base)} = \beta_{ac}(r'_e + R_{E1})$$

- Swamping stabilizes gain by minimizing the effect of r'_e .
- Swamping reduces the voltage gain from its unswamped value.
- Swamping increases input resistance.
- The load resistance reduces the voltage gain. The smaller the load resistance, the less the gain.



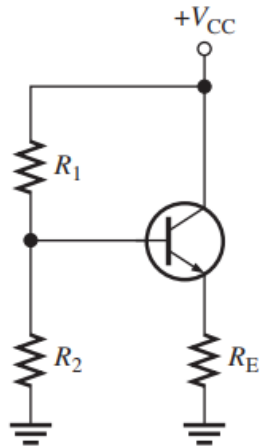
AC equivalent circuit

Common Collector Amplifier

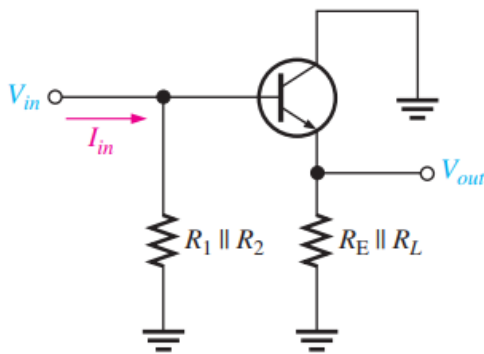


CIRCUIT WITH VOLTAGE-DIVIDER BIAS

- Input is at the base. Output is at the emitter.
- There is no phase inversion from input to output.
- Input resistance is high. Output resistance is low.
- Maximum voltage gain is 1.
- Collector is at ac ground.
- Coupling capacitors must have a negligible reactance at the frequency of operation.



DC equivalent circuit



AC equivalent circuit

EQUIVALENT CIRCUITS AND FORMULAS

- DC formulas:

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2}$$

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2} \right) V_{CC}$$

$$I_E = \frac{V_{TH} - V_{BE}}{R_E + R_{TH}/\beta_{DC}}$$

$$V_E = I_E R_E$$

$$V_B = V_E + V_{BE}$$

$$V_C = V_{CC}$$

- AC formulas:

$$r'_e = \frac{25 \text{ mV}}{I_E}$$

$$R_{in(base)} = \beta_{ac}(r'_e + R_e) \cong \beta_{ac}R_e$$

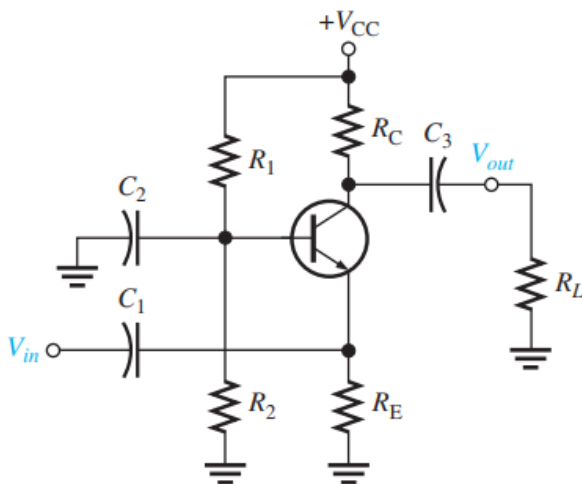
$$R_{out} = \left(\frac{R_s}{\beta_{ac}} \right) \parallel R_E$$

$$A_v = \frac{R_e}{r'_e + R_e} \cong 1$$

$$A_i = \frac{I_e}{I_{in}}$$

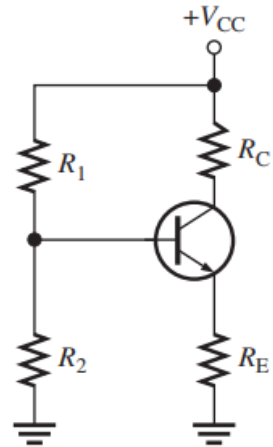
$$A_p \cong A_i$$

Common Base Amplifier

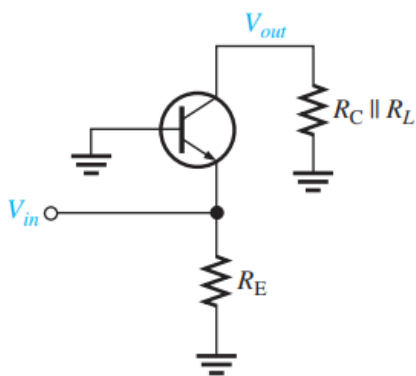


CIRCUIT WITH VOLTAGE-DIVIDER BIAS

- Input is at the emitter. Output is at the collector.
- There is no phase inversion from input to output.
- Input resistance is low. Output resistance is high.
- Maximum current gain is 1.
- Base is at ac ground.



DC equivalent circuit



AC equivalent circuit

EQUIVALENT CIRCUITS AND FORMULAS

- DC formulas:

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2}$$

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2} \right) V_{CC}$$

$$I_E = \frac{V_{TH} - V_{BE}}{R_E + R_{TH} / \beta_{DC}}$$

$$V_E = I_E R_E$$

$$V_B = V_E + V_{BE}$$

$$V_C = V_{CC} - I_C R_C$$

- AC formulas:

$$r'_e = \frac{25 \text{ mV}}{I_E}$$

$$R_{in(\text{emitter})} \cong r'_e$$

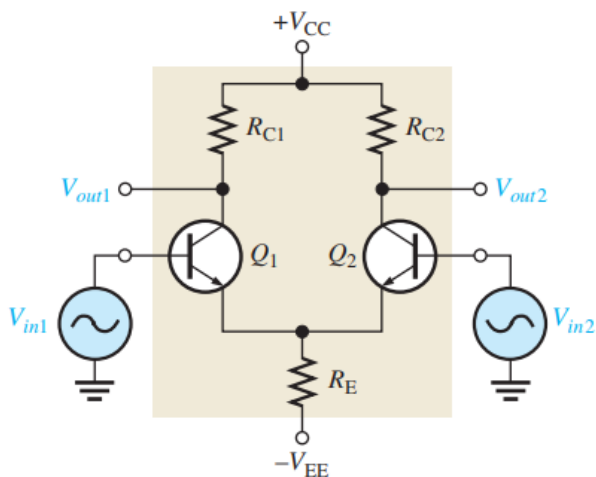
$$R_{out} \cong R_C$$

$$A_v \cong \frac{R_C}{r'_e}$$

$$A_i \cong 1$$

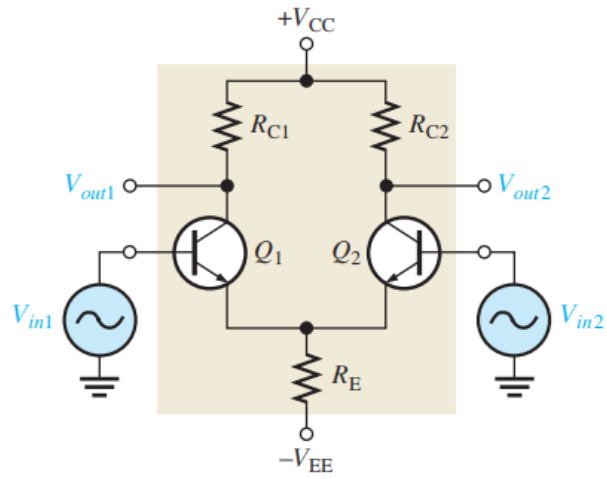
$$A_p \cong A_v$$

Differential Amplifier



CIRCUIT WITH DIFFERENTIAL INPUTS

- Double-ended differential inputs (shown) signal on both inputs Input signals are out of phase
- Single-ended differential inputs (not shown) signal on one input only One input connected to ground



CIRCUIT WITH COMMON-MODE INPUTS

- Both input signals are the same phase, frequency, and amplitude.
- Common-mode rejection ratio:

$$CMRR = \frac{A_{v(d)}}{A_{cm}}$$

$$CMRR = 20 \log \left(\frac{A_{v(d)}}{A_{cm}} \right)$$