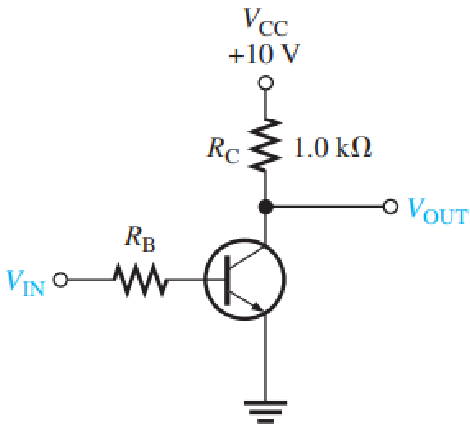
XMUT204 Electronic Design

Tutorial 5: BJT Circuit Analysis and Design

A. BJT Switching Applications

1. For the following BJT transistor circuit as given below, answer the following questions.



   a. What is V_{CE} when V_{IN} = 0 V? [2 marks]

   b. What minimum value of I_B is required to saturate this transistor if β_{DC} is 200? Neglect $V_{CE}(\text{sat})$. [4 marks]

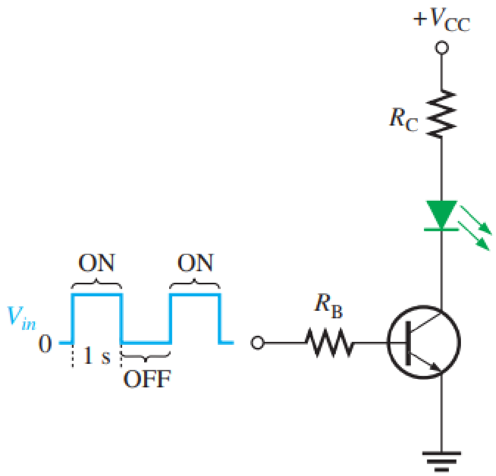
   c. Calculate the maximum value of R_B when V_{IN} = 5 V. [4 marks]

2. The LED in circuit given below requires 30 mA to emit a sufficient level of light. Therefore, the collector current should be approximately 30 mA.

   The values of the components in the circuit are V_{CC} = 9 V, $V_{CE(sat)}$ = 0.3 V, R_C = 220 Ω, R_B = 3.3 kΩ, β_{DC} = 50, and V_{LED} = 1.6 V.

   For the given component values, determine the amplitude of the square wave input voltage necessary to make sure that the transistor saturates. Use a double of the minimum value of base current as a safety margin to ensure saturation.

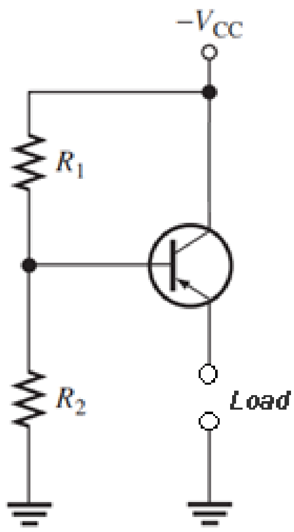
   [8 marks]



3. The most commonly used PNP BJT transistor (e.g. 2N3906) as a switch is as shown in the figure below. If we have a load that requires 100 mA of current and a transistor with a minimum DC gain of 100, answer the following questions:

   a. Calculate the minimum base current required to saturate the transistor in the circuit. [8 marks]

   b. Determine the values of R_1 and R_2 for supply voltage, V_{CC} is -12 V. [8 marks]



4. Transistor switches are used for a wide variety of applications. These transistors are commonly used to turn on transmitter circuits, LED's, cooling fans and even relays. Describe practical implementation of the PNP transistor circuit in the figure given in the previous question for driving a relay coil. [6 marks]

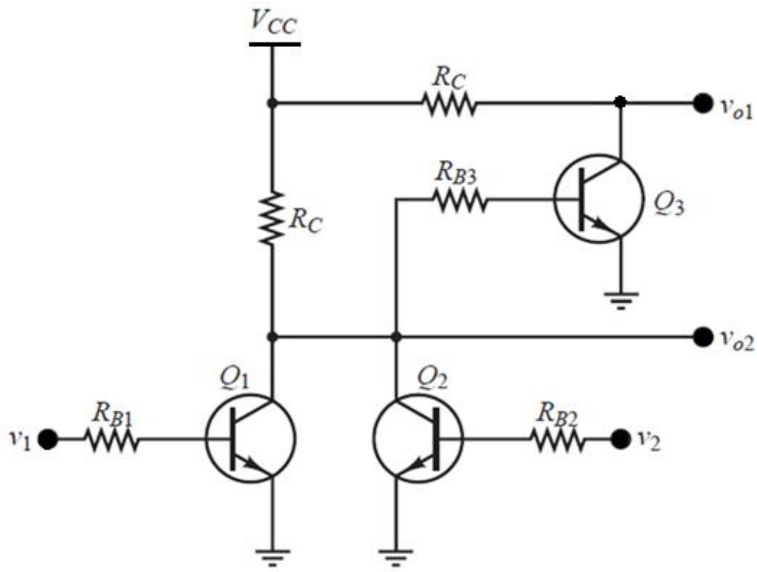
5. Summarise common practical examples of BJT transistor as a switch by comparing the similarities and differences of its use for applications given below:

   a. Switch the LED. [2 marks]

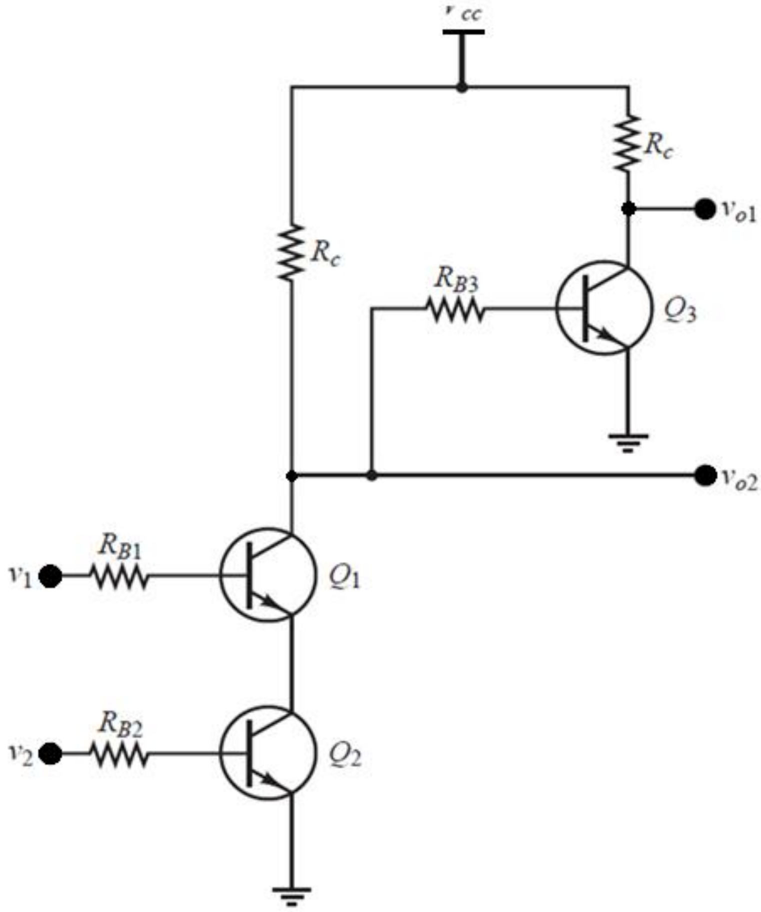
   b. Operate the relay. [2 marks]

   c. Drive the motor. [2 marks]

6. Show that the circuit of the figure below functions as an OR gate if the output is taken at v_{o1}. [8 marks]



7. Show that the circuit of the figure below functions as a NAND gate if the output is taken at v_{o2}.
[8 marks]

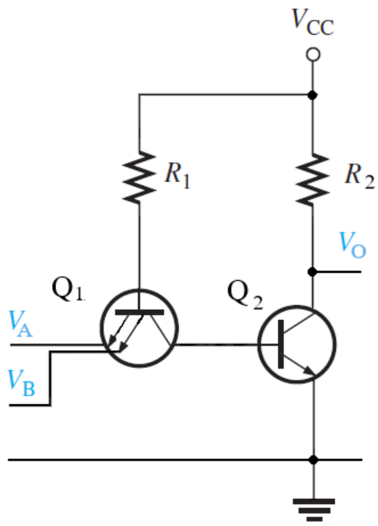


8. There are several BJT logic device families and diode-transistor logic (DTL) and transistor-transistor logic (TTL) are two examples of them.

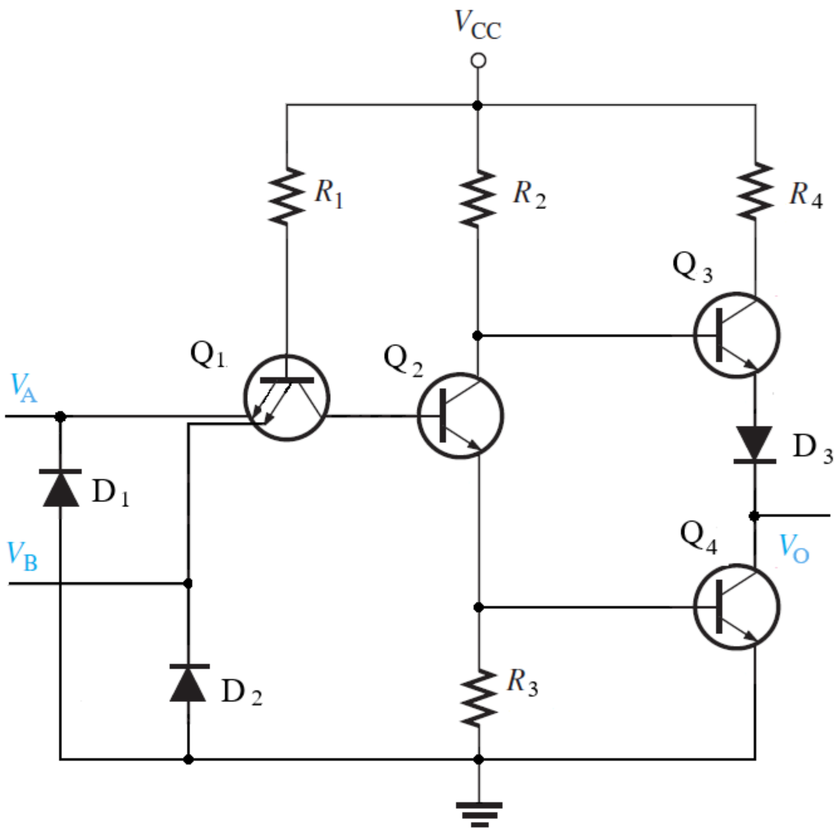
a. What is transistor-transistor logic (TTL)? [3 marks]

b. Explain how the TTL is considered to be an improvement from the DTL. [3 marks]

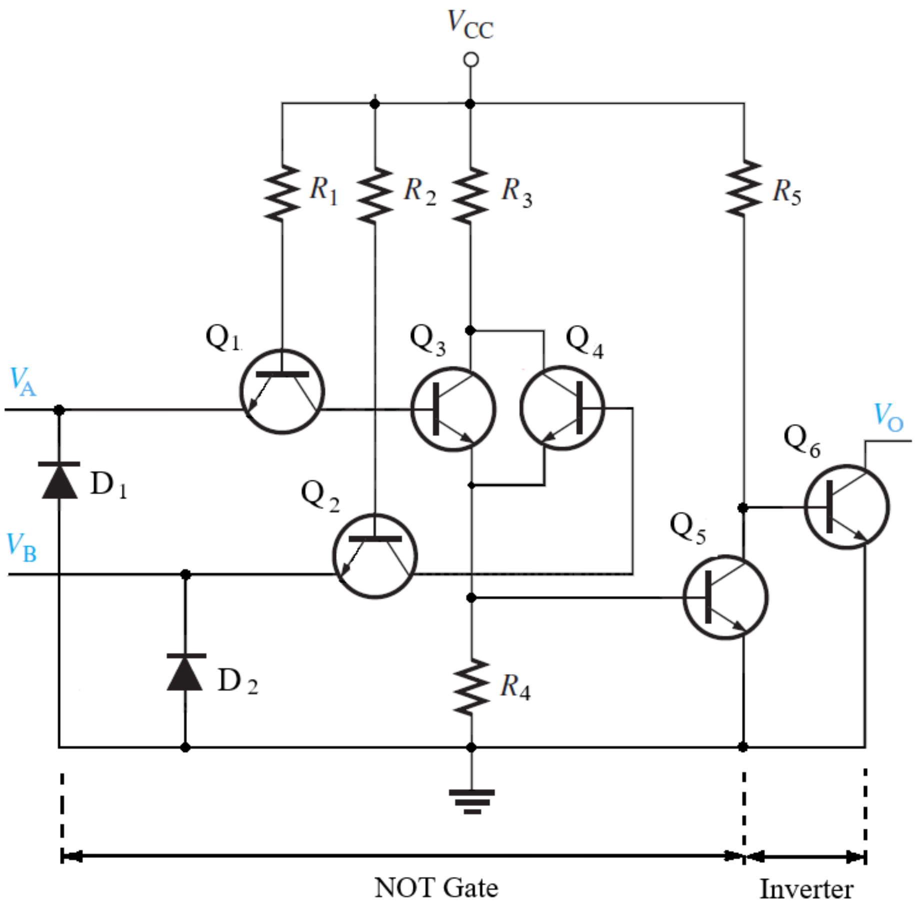
c. Considering a basic transistor-transistor logic circuit diagram as shown in the figure below, describe its basic operations. [8 marks]



9. To understand the working of a transistor-transistor logic (TTL), consider the circuit diagram of the standard TTL logic gate, which executes a positive NAND gate function as shown in the figure below. This standard TTL logic circuit is related to the Diode-Transistor Logic (DTL) circuit in some conditions. Describe how TTL circuit shown below works. [10 marks]



10. The following circuit given in the diagram below shows a transistor-transistor logic (TTL) OR gate with open collector output. Describe the mechanism of its operation. [12 marks]



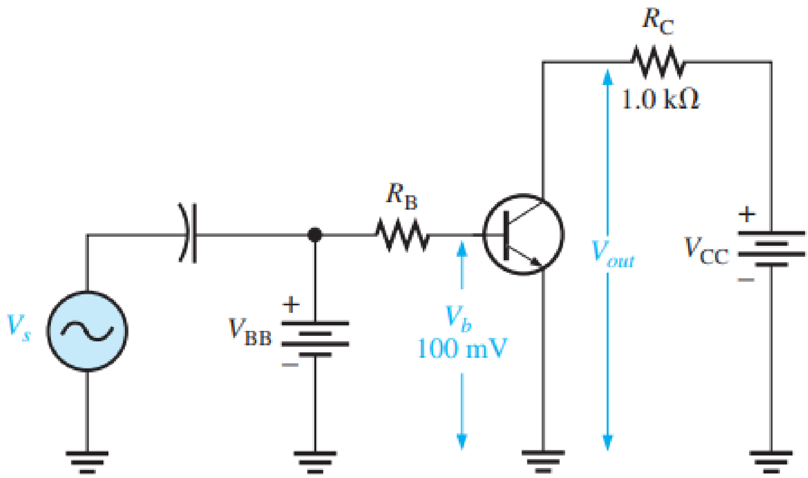
B. BJT Amplifier Applications

1. For amplifier analysis, the AC emitter resistance, r_e' is the most important of the r parameters in BJT amplifier analysis.

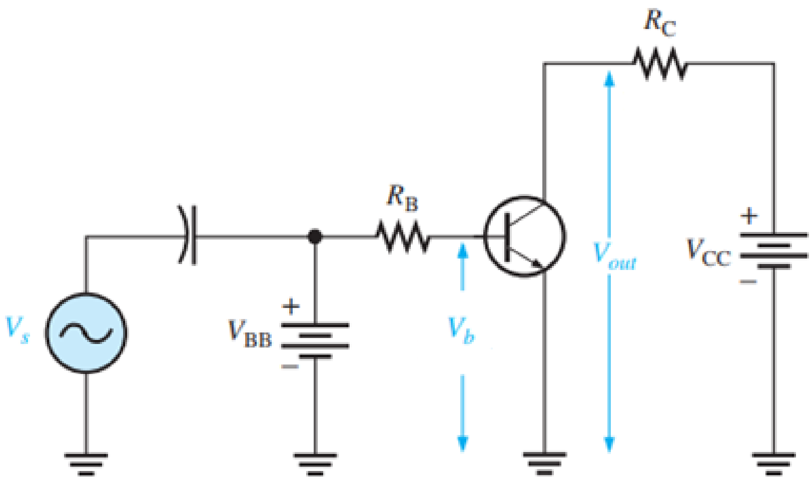
   a. Derive the AC emitter resistance of a transistor. [14 marks]

   b. Determine the r_e' of a transistor that is operating with a DC emitter current of 2 mA. [2 marks]

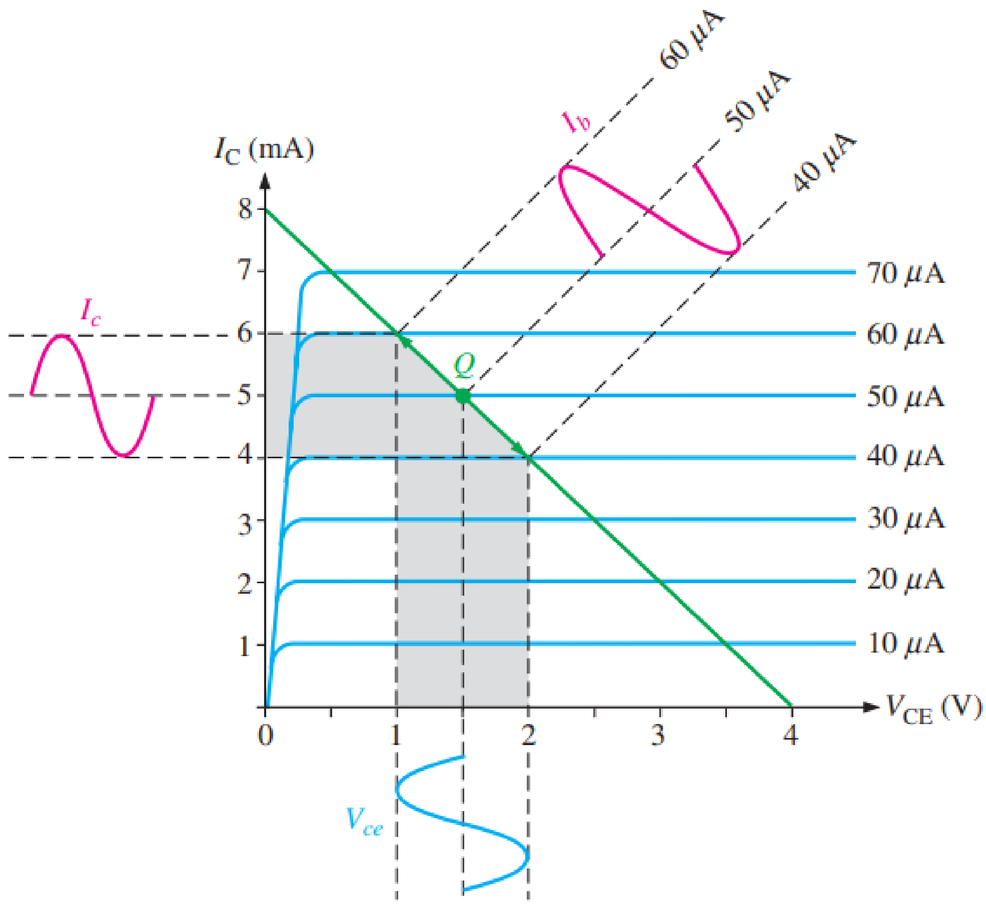
   c. Determine the voltage gain and the AC output voltage in the figure given below if r_e' = 50 Ω. [4 marks]



2. The AC load line of the amplifier is about the operational conditions of the amplifier circuit, and it shows the variation of the base current, collector current, and collector-to-emitter voltage about their DC Q-point values.



The AC load line operation of a certain amplifier extends above and below the Q-point base current value of as shown in the figure given below.



a. Determine the resulting peak-to-peak values of collector current and collector-to-emitter voltage from the graph. [2 marks]

b. Determine the maximum fluctuation of the output voltage. [2 marks]

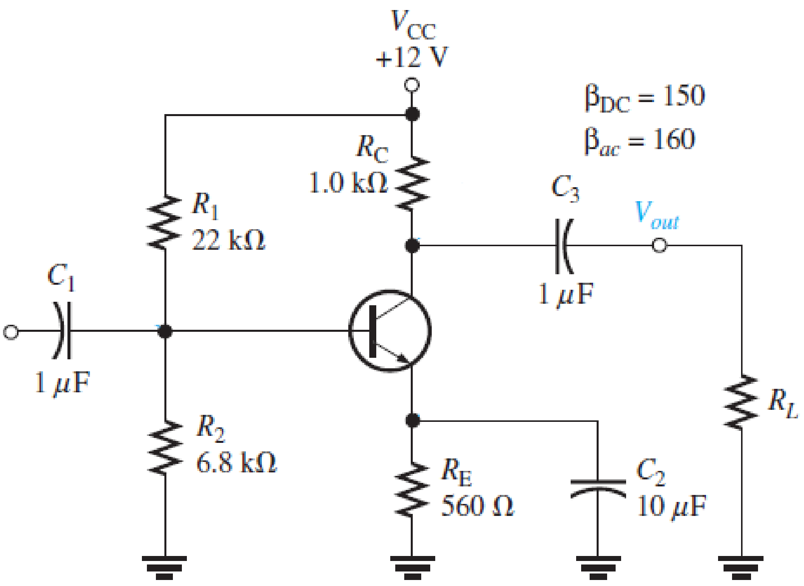
3. The amplifier given in the figure given below is supplied with a 10 mV rms and 300 Ω signal source and the emitter current, I_E was previously found to be 3.80 mA.

 a. Sketch an AC equivalent circuit of the amplifier at the input. [8 marks]

 b. The AC emitter resistance of the amplifier circuit. [4 marks]

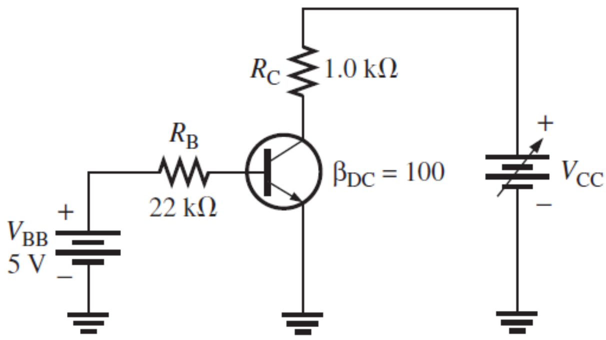
 c. Total input resistance of the amplifier as viewed from the source. [2 marks]

 d. Determine the signal voltage at the base of the transistor. [4 marks]



4. The transistor in this circuit has the following maximum ratings:

- $P_{D(\max)}$ = 800 mW
- $V_{CE(\max)}$ = 15 V
- $I_{C(\max)}$ = 100 mA

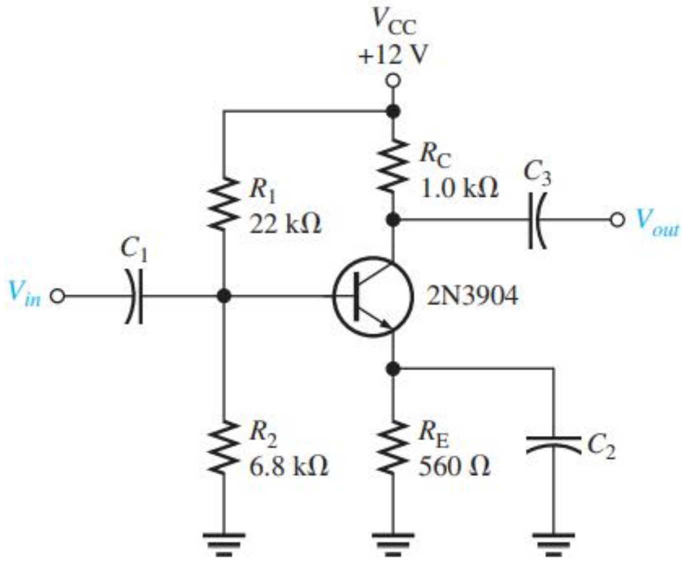


a. Calculate the collector current and comment whether it exceed the maximum rating or not? [6 marks]

b. Calculate the maximum value to which you can adjust V_{CC} without exceeding maximum ratings. [6 marks]

c. What happen when the V_{BB} is reduced to zero? Would the rating of the transistor would be exceeded or not? [4 marks]

5. For the BJT transistor-based amplifier as show below, attempt the following tasks:



a. Select a minimum value for the emitter bypass capacitor, C_2, if the amplifier must operate over a frequency range from 200 Hz to 10 kHz. [4 marks]

b. Calculate the base-to-collector voltage gain of the amplifier both without and with an emitter bypass capacitor if there is no load resistor and r_e' = 6.58 Ω. [4 marks]

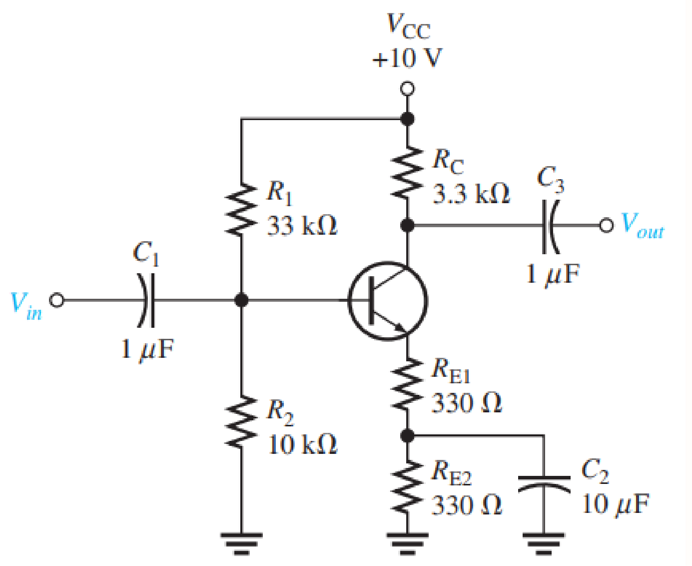
c. Calculate the base-to-collector voltage gain of the amplifier when a load resistance of 5 kΩ is connected to the output. The emitter is effectively bypassed and r_e' = 6.58 Ω. [4 marks]

6. Stability is a measure of how well an amplifier maintains its design values over changes in temperature or for a transistor with a different β.

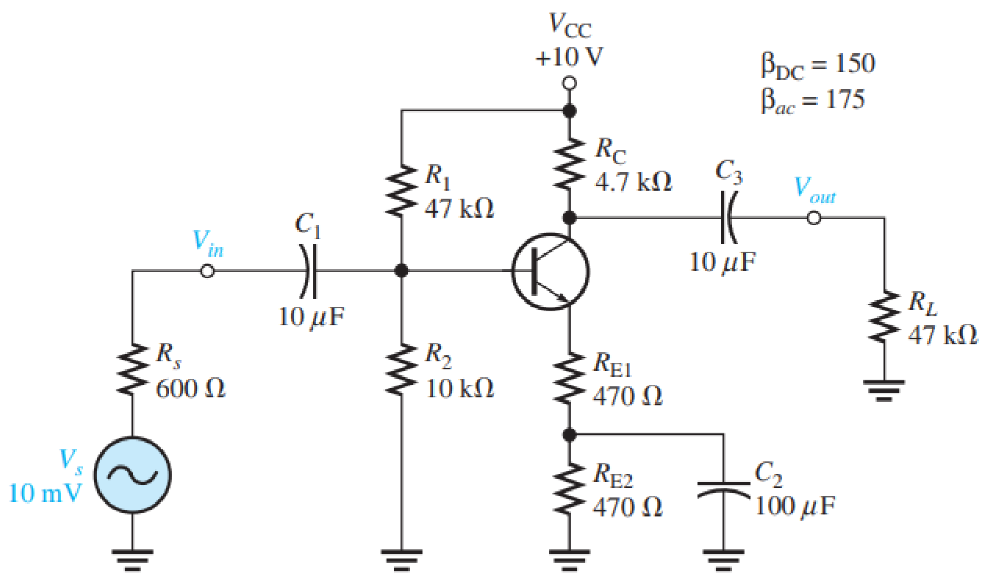
a. Although bypassing R_E does produce the maximum voltage gain, describe why this approach might cause a stability problem to the amplifier. [6 marks]

b. Describe what is swamping to stabilize the voltage gain. [6 marks]

c. Determine the voltage gain of the swamped amplifier in the figure given below. Assume that the bypass capacitor has a negligible reactance for the frequency at which the amplifier is operated. Assume r_e' = 20 Ω. [2 marks]



7. For the amplifier given in the figure below, perform the following tasks.



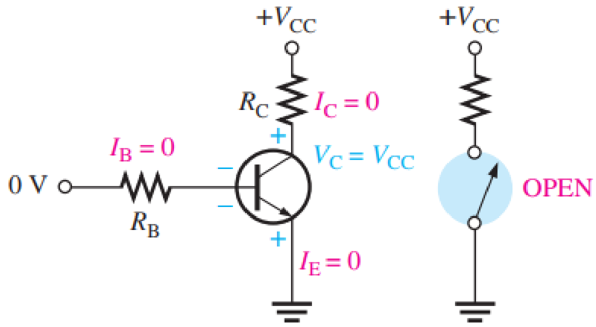
a. Determine the DC collector voltage. [16 marks]

b. Determine the AC collector voltage. [20 marks]

c. Draw the total collector voltage waveform and the total output voltage waveform. [10 marks]

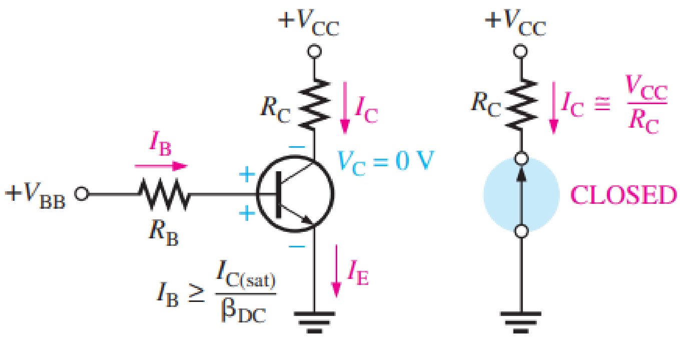
Appendix 1 – Summary of BJT

A1. SWITCHING



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

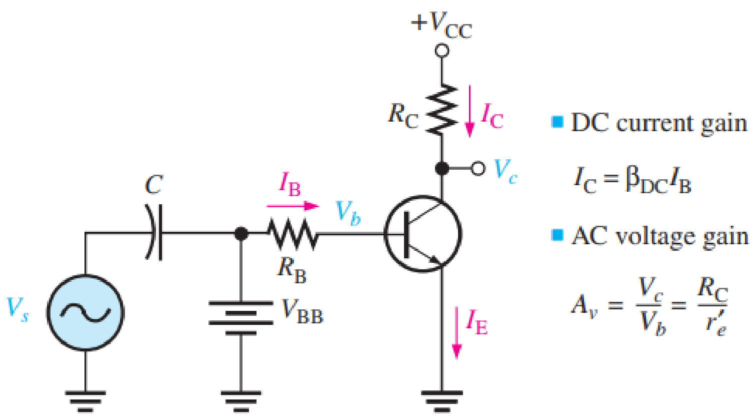
Ideal switch equivalent for cutoff



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

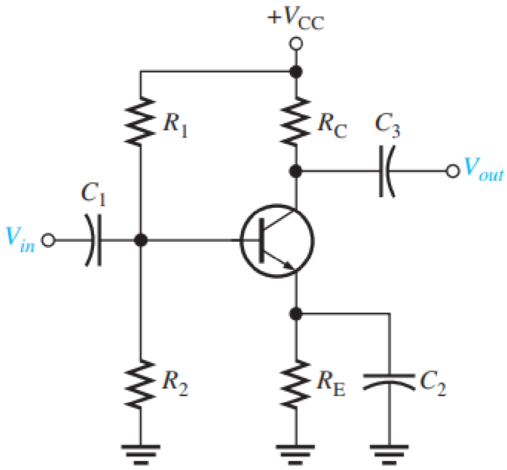
Ideal switch equivalent for saturation

A2. AMPLIFICATION



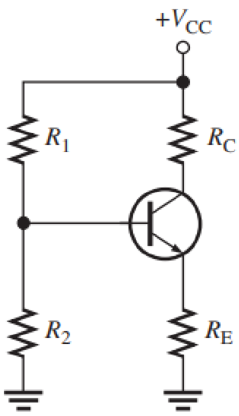
BE junction forward-biased
BC junction reverse-biased

A3. COMMON EMITTER AMPLIFIER

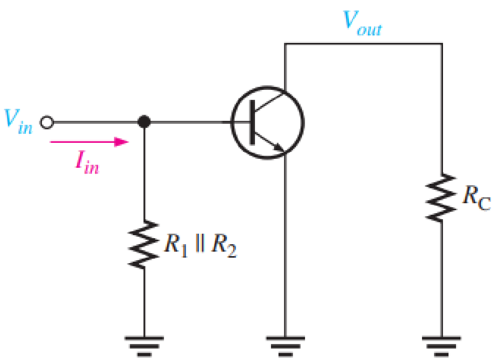


Circuit with voltage-divider bias:

- 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.



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**:

$$r_e' = \frac{25\text{ mV}}{I_E}$$

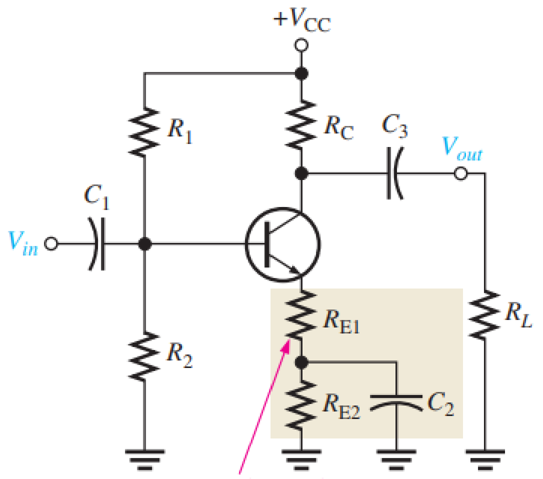
$$R_{in(\text{base})} = \beta_{AC} r_e'$$

$$R_{out} \cong R_C$$

$$A_v = \frac{R_C}{r_e'}$$

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

$$A_p = A_v' A_i$$



Swamped amplifier with resistive load:

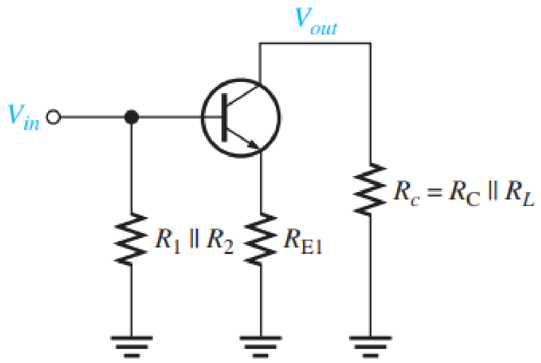
- **AC formulas**:

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

Where: $R_c = R_C \parallel R_L$

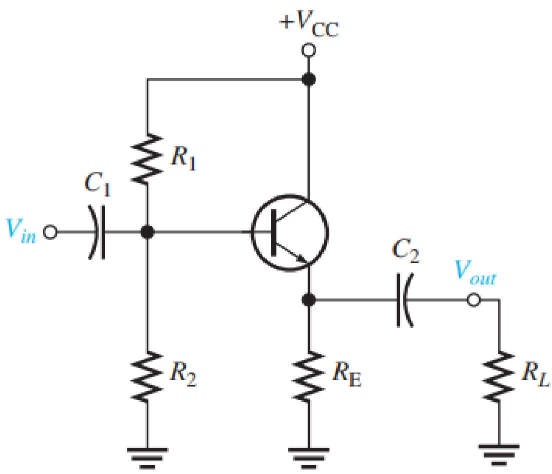
$R_{in(\text{base})} = \beta_{AC}(r_e' + R_{E1})$

- 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.



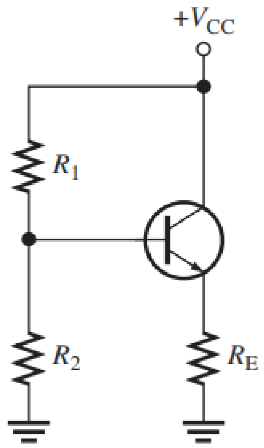
AC equivalent circuit

A4. COMMON COLLECTOR AMPLIFIER

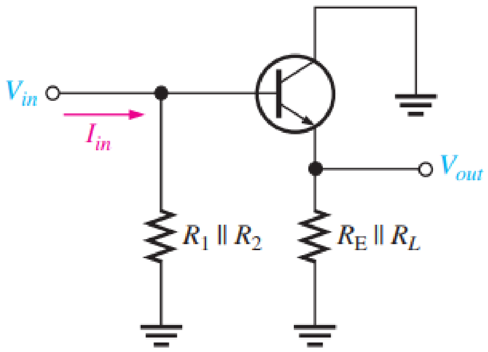


Circuit with voltage-divider bias:

- 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**:

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

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

$$V_E = I_E R_E$$

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

$$V_C = V_{CC}$$

- **AC formulas:**

$$r_e' = \frac{25\text{ mV}}{I_E}$$

$$R_{in(\text{base})} = \beta_{AC}(r_e' + R_e) \cong \beta_{AC} R_e$$

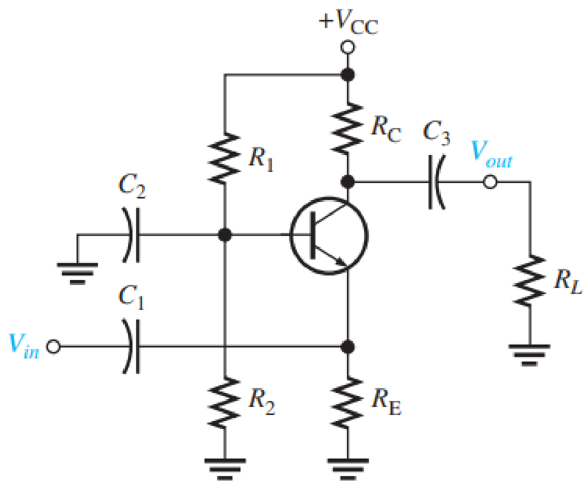
$$R_{out} = \left(\frac{R_s}{\beta_{AC}}\right) \parallel R_E$$

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

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

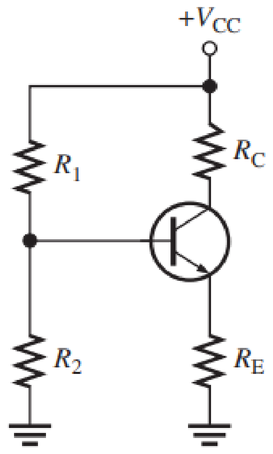
$$A_P \cong A_i$$

A5. COMMON BASE AMPLIFIER

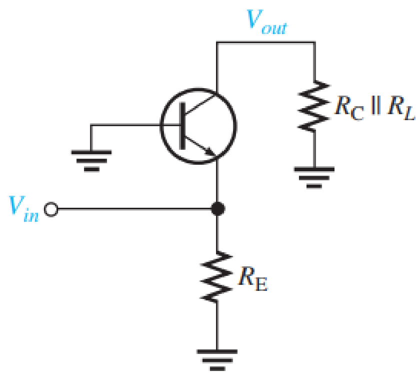


Circuit with voltage-divider bias:

- 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**:

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

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

$$V_E = I_E R_E$$

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

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

- **AC formulas:**

$$r_e' = \frac{25\text{ mV}}{I_E}$$

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

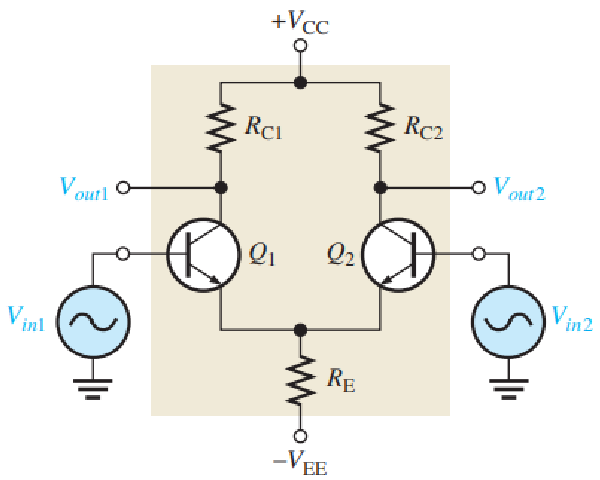
$$R_{out} \cong R_C$$

$$A_v \cong \frac{R_c}{r_e'}$$

$$A_i \cong 1$$

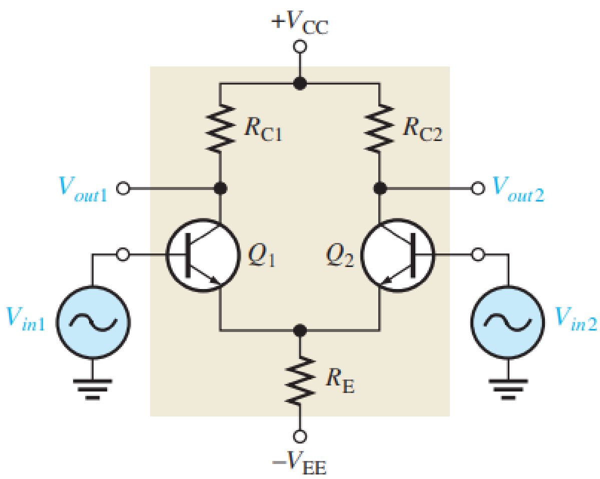
$$A_P \cong A_v$$

A6. 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:

$$\text{CMRR} = \frac{A_{dm}}{A_{cm}}$$

$$\text{CMRR} = 20\log\left(\frac{A_{dm}}{A_{cm}}\right)$$