University of Jordan
School of Engineering
Electrical Engineering Department

EE 204
Electrical Engineering Lab

EXPERIMENT 9
TRANSISTOR APPLICATIONS

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EXPERIMENT 9
TRANSISTOR APPLICATIONS

OBJECTIVE

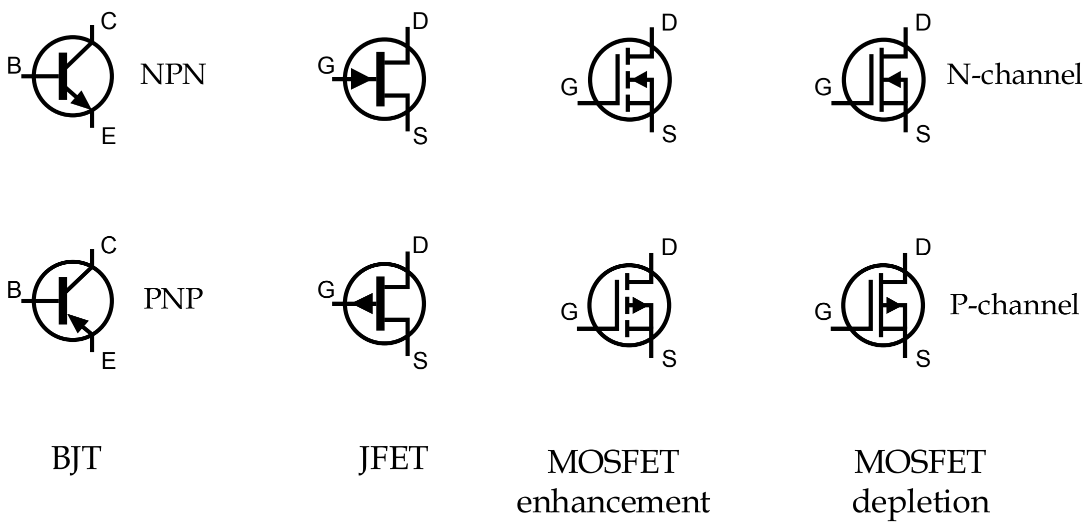
You will examine transistors and some of their applications in this experiment. In particular, you will test the transistor using a digital multimeter, and apply transistors as amplifiers and switches.

DISCUSSION

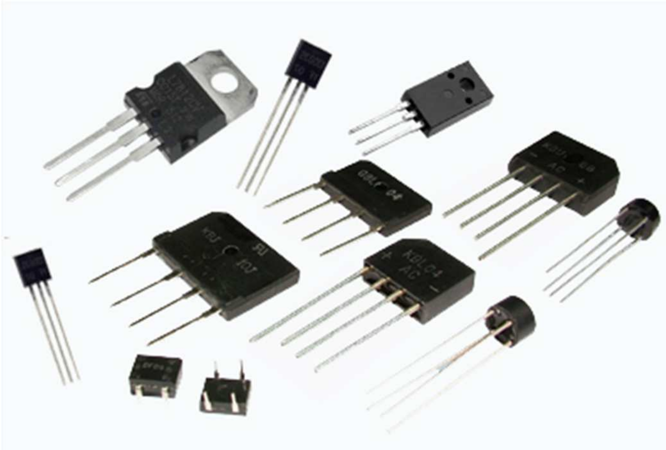
Transistors

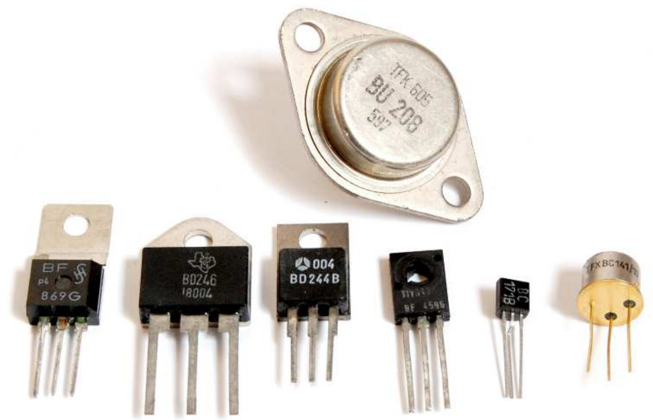
The transistor represents the fundamental building block of modern electronic devices. Transistors exist in your personal computer, cell phone, TV, radio, calculator, power supply, car, fridge, LED light, etc. In this lab, you will use a discrete-component transistor, but typically transistors are built inside small integrated circuits (ICs) that can hold millions of tiny transistors per an area of 1 mm^2.

A transistor is made from a semiconductor material, such as silicon or germanium, with at least three terminals. A transistor can be used to amplify analog signals (voltage or current), or act as a switch has two states (Hi or Low). Several types of transistors exist, such as: Bipolar junction transistor (BJT) (which includes NPN and PNP variants), junction field-effect transistor (JFET) (including p-channel and n-channel variants), metal-oxide-semiconductor field-effect transistor (MOSFET) (including p-channel and n-channel variants, and depletion-mode and enhancement-mode types), etc. Each of these transistor types has its own advantages and disadvantages. The symbols of some of these transistors are shown below.

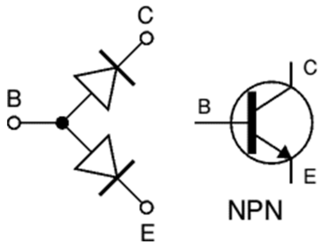


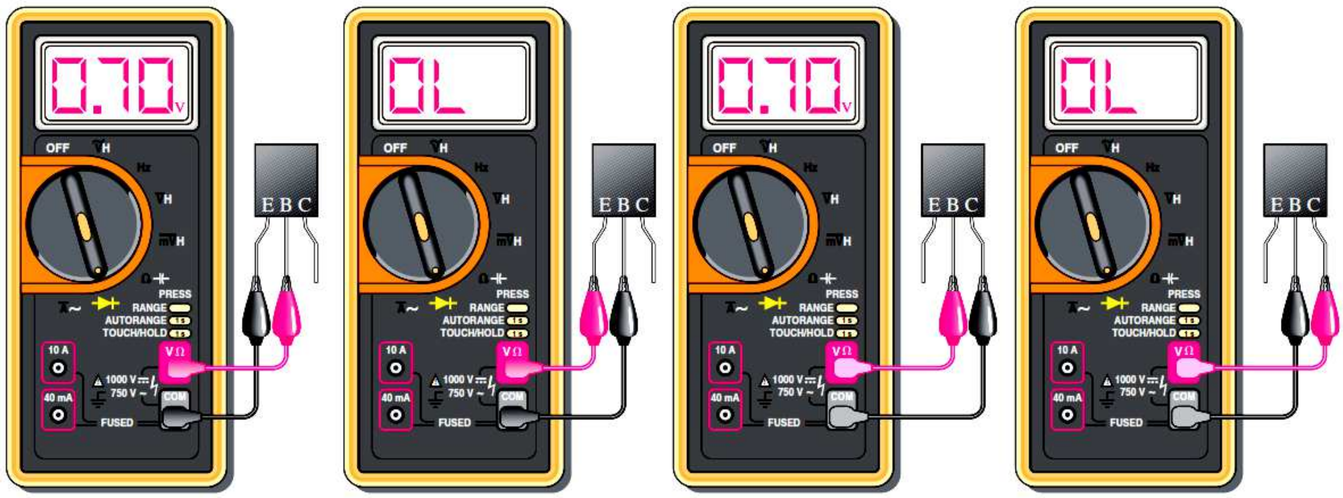
Discrete-component transistors have different package shapes and sizes are shown below. Some can carry more current than others.





The BJT NPN transistor consists of a layer of P-doped semiconductor (known as the base) between two N-doped layers (known as the collector and emitter). You can imagine it like two diodes fused to each other at the anode. Hence, testing the NPN transistor to find the base, collector and emitter pins is as simple as testing for the forward bias threshold voltage V_f of the diodes representing the transistor (see below).





(a) Forward-bias test of the BE junction

(b) Reverse-bias test of the BE junction

(c) Forward-bias test of the BC junction

(d) Reverse-bias test of the BC junction

Fig : Typical DMM test of a properly functioning npn transistor. Leads are reversed for a pnp transistor.

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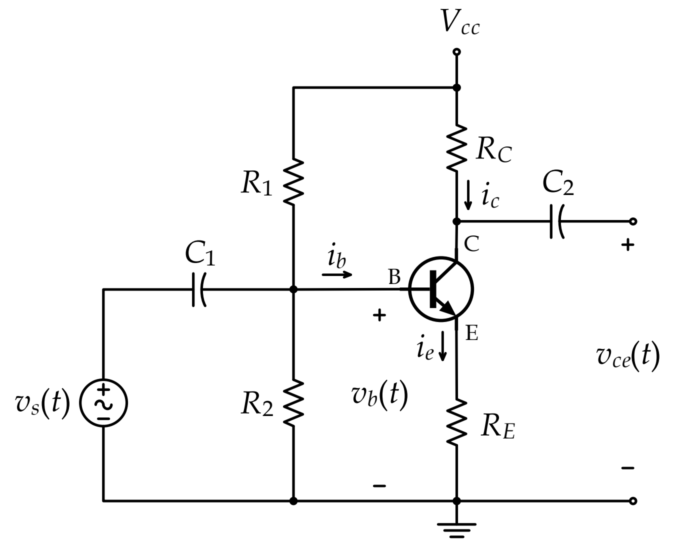
Transistor as an Amplifier

There are several designs for transistor-based analog amplifiers. The most common for the NPN transistor is the common-emitter amplifier design, which is shown below. In this configuration, the input AC signal is applied to the base terminal of the transistor, while the collector provides the output, and the emitter is common to both.

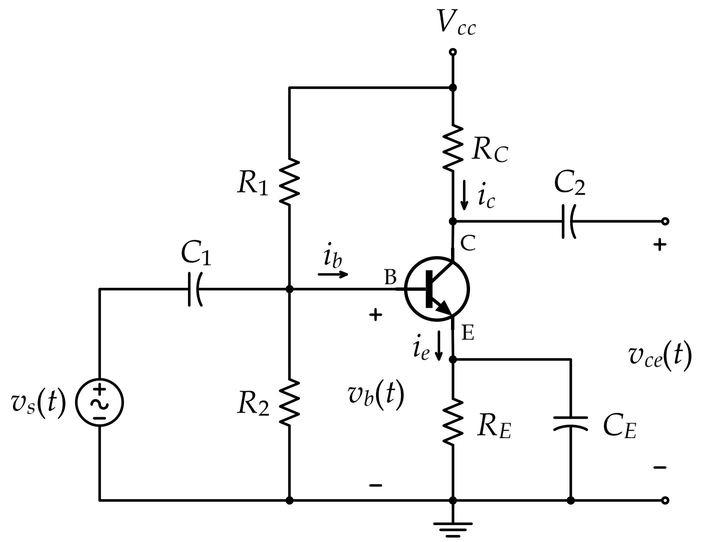


If the transistor is biased properly (using resistors R_1, R_2, R_C and R_E) then the base-to-emitter p-n junction is forward biased, and the quiescent operating point (Q-point) is properly selected, which is the point on the load line representing the values of I_C and V_{ce} that exist in the circuit when no input signal is applied. In such case, the output signal $v_{ce}(t)$ is an *amplified* version of the input signal $v_s(t)$.

The amplifier circuit works like this: During the positive half cycle of the input AC signal, the voltage $v_{be}(t)$ at the base of the transistor increases leading to increasing the input current $i_b(t)$. This results in increasing $i_c(t)$ by $h_{FE} = \beta$ times leading to a decrease in the output voltage, $v_{ce}(t)$. Thus the common-emitter amplifier produces an amplified output with a phase reversal. The voltage gain of this common-emitter amplifier is given by:

$$A_v = \frac{v_{out}}{v_{in}} \approx -\frac{R_C}{R_E}$$

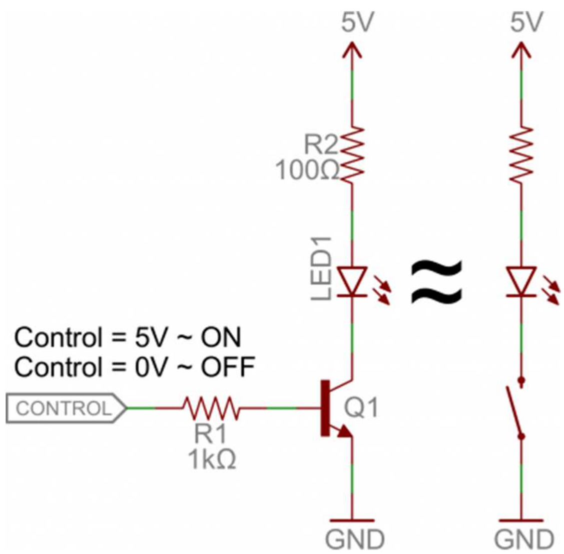
Many times, a bypass capacitor is connected in parallel with the emitter resistance to increase the voltage gain of the common-emitter, as shown below, but you will not test that configuration in this experiment.



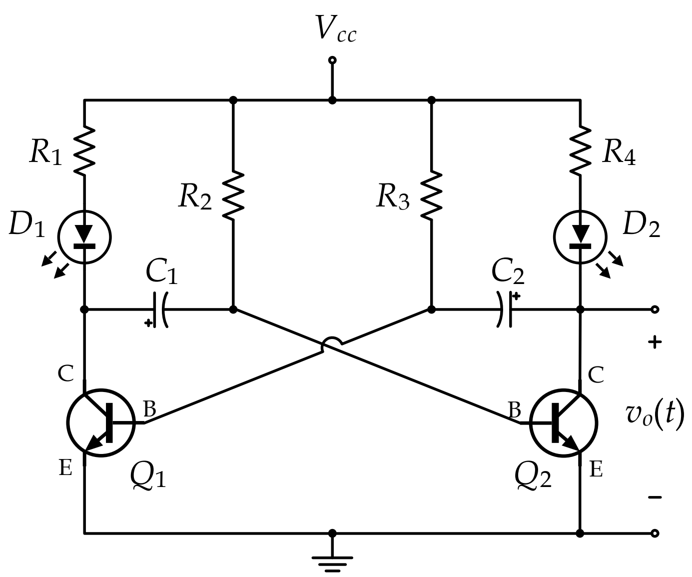
Since the aim of any small signal amplifier is to generate an amplified input signal at the output with minimum distortion possible, the best position for the Q-point is as close to the center position of the load line as reasonably possible, thereby producing a Class A type amplifier operation, i.e. at $V_{ce} = V_{cc}/2$.

Transistor as a Switch

Many modern electronic devices use the transistor as a fast ON/OFF switch, which is controlled by an input signal. When the transistor is sent a control signal to switch OFF (called the *cutoff mode*), the transistor blocks current from passing through it. On the other hand, when the control signal switches the transistor ON (known as the *saturation mode*), the transistor passes current through it. This is illustrated in the figure below.



In this experiment, you will see an example application of the transistor as a switch. The circuit you will test is called an *astable multivibrator* (which is an example of an *oscillator*). An oscillator is a circuit that produces a periodic signal that swings between a high and low voltage. You will use the oscillator to blink an LED as shown below.



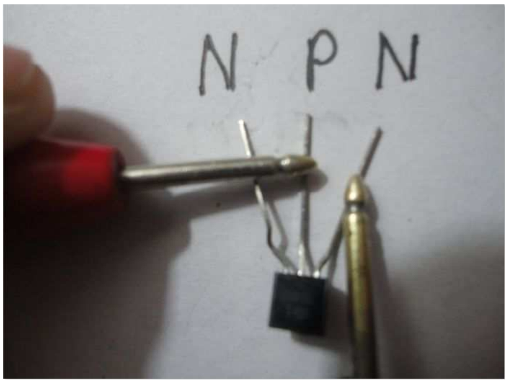
The capacitors in the above circuit alternatively charge (storing a voltage of about V_{cc}) then discharge (reach zero voltage), which causes the two transistors to alternatively turn ON and OFF. If Q_1 is ON, then C_1 positive plate is connected to about 0V. This forces C_1 to discharge through the collector of Q_1. While C_1 is discharging, C_2 charges through the smaller-value resistor R_4. Once C_1 fully discharges, its negative plate will be pulled up to about 0.6V, which will turn on Q_2. This now forces C_2 to discharge through the collector of Q_2, while C_1 can charge through the smaller-value R_1. The cycle keeps repeating to blink the LED's ON and OFF. The frequency of the periodic signal produced by the this multivibrator circuit is:

$$f \approx \frac{1}{\ln(2) \cdot (R_2C_1 + R_3C_2)} \quad (half\ wave)$$

PROCEDURE A – MULTIMETER TRANSISTOR TESTING

1. Turn on the digital multimeter (DMM) and select the *diode test* function. This mode measures the forward voltage of a p-n junction if connected with proper polarity.

2. Place the 2N3904 transistor you are given on a blank piece of paper. Connect the red multimeter lead (+ve) to one terminal of the transistor, and the black multimeter lead (COM) to another terminal of the transistor. If you get a voltage near 0.7 volt, this means that the red multimeter lead is connected to a P junction (anode) and the black multimeter lead is connected to an N junction (cathode). Write this fact on the blank piece of paper.



2. Keep testing every pair of the 2N3904 transistor terminals until you have fully labeled the terminals of the transistor with PNP or NPN.

3. Which of the terminals is the "base" of the transistor?

. . . .

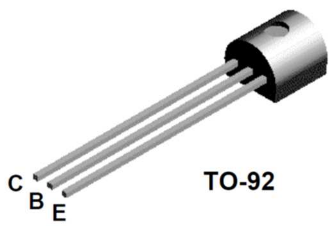
4. Finally, to identify the collector and emitter, we can use the fact that $V_{BE} > V_{BC}$. What are the measured V_{BE} and V_{BC} values?

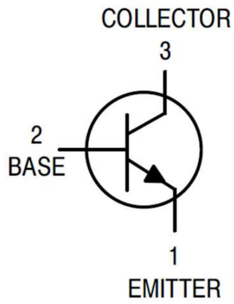
. . . .

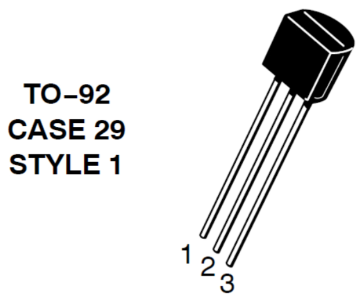
5. Draw below an illustration of the transistor and the pins you identified (similar to the above diagram but with the B, C and E terminals identified).

. . . .

6. Another technique for you to identify the pins of a transistor is to lookup the data sheet of the transistor online. Some of the figures the 2N3904 transistor data sheet has are shown below.

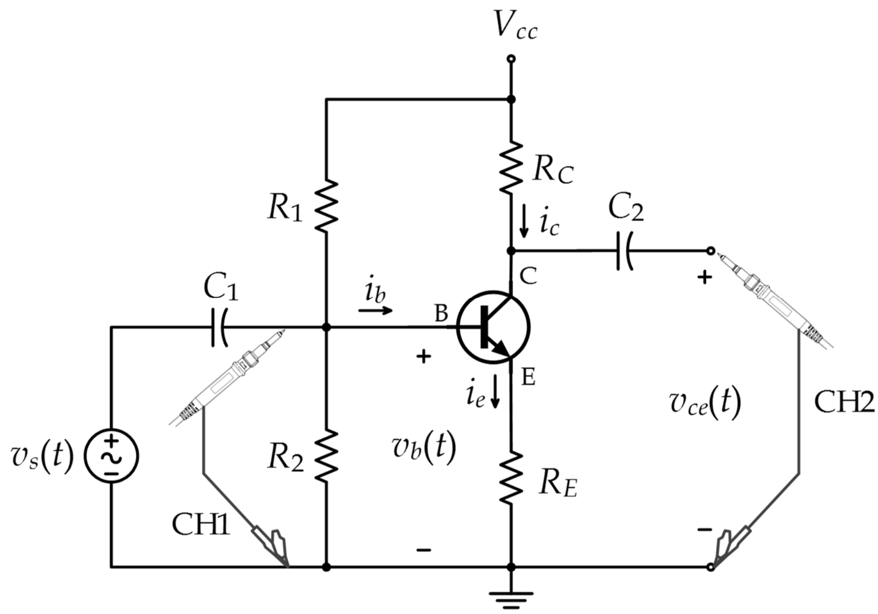






PROCEDURE B – TRANSISTOR AMPLIFIER CIRCUIT

1. Construct the circuit shown below. Use a 2N3904 transistor, R_1 = 47 kΩ, R_2 = 10 kΩ, R_C = 6 kΩ, R_E = 1 kΩ, C_1 = 1 μF, and C_2 = 1 μF. Pay attention to the proper connection of the transistor terminals. Use a DC supply voltage of V_{cc} = 10 V.



2. Set the function generator $v_s(t)$ to produce a sinusoidal waveform (AC) with *frequency* of 1000 Hz and *peak voltage* of V_p = 0.2 V. You can use the attenuation option of the function generator, if necessary, to get small peak voltages.

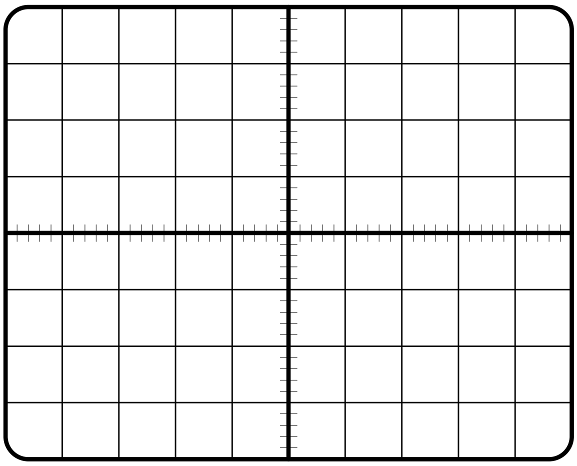
CAUTION: Some older function generators have a defect and produce an AC signal with a slight DC shift. Hence, if you do not see a symmetric sinusoidal signal above and below zero volts, adjust the DC offset knob slightly to force a zero DC offset in the function generator output.

3. Set the oscilloscope Volt/Div and Time/Div so you can see about 2-3 full cycles of the input sinusoidal signal on CH1. Do the same for CH2. Write the settings you chose next to the oscilloscope plots below.

4. What is the difference between the signal you see on CH1 (input v_s) and the signal you see on CH2 (output v_{ce})?

. . . .

5. Draw the input signal v_s (CH1) you see on the oscilloscope screen below.



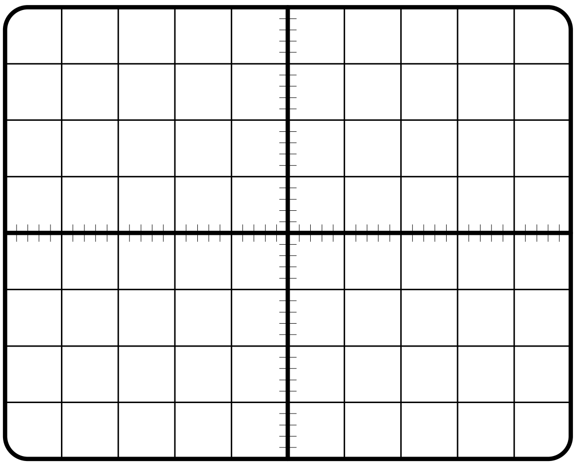
Volt/Div (CH1): ____________________

Time/Div: ____________________

Maximum value: ____________________ V

Minimum value: ____________________ V

6. Draw the output signal v_{ce} (CH2) you see on the oscilloscope screen below.



Volt/Div (CH2): ____________________

Time/Div: ____________________

Maximum value: ____________________ V

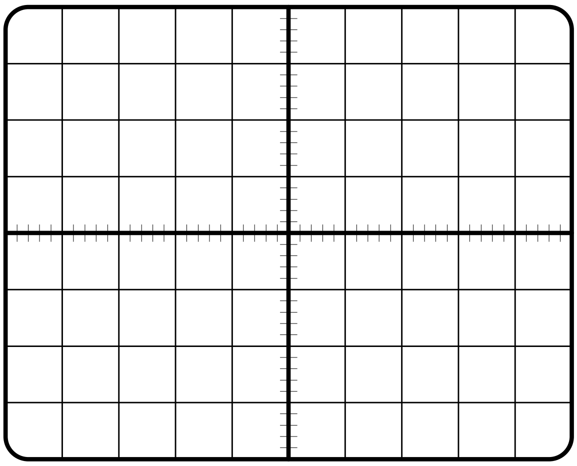
Minimum value: ____________________ V

7. Determine the voltage gain A_v of this amplifier circuit.

. . . .

8. Now change the resistor in the above circuit to R_C = 3 kΩ, while keeping the rest of the circuit unchanged.

9. Draw the output signal v_{ce} (CH2) you see on the oscilloscope screen below.



Volt/Div (CH2): ____________________

Time/Div: __________________________

Maximum value: __________________ V

Minimum value: __________________ V

10. What is the new voltage gain A_v of the amplifier circuit?

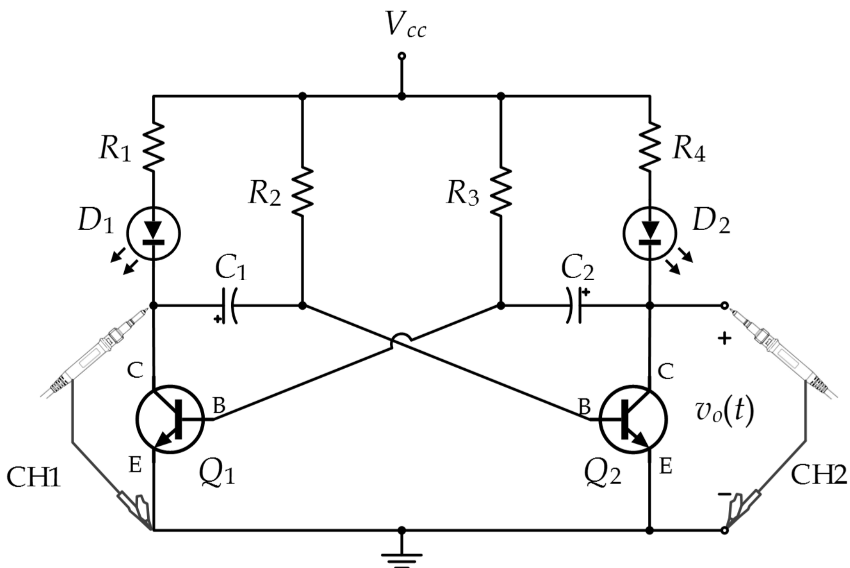
. . . .

11. What is the equation that controls the voltage of this common-emitter amplifier circuit?

. . . .

PROCEDURE C – TRANSISTOR SWITCHING CIRCUIT

1. The circuit shown below will be constructed for you by the lab supervisor. It utilizes 2N3904 transistors for Q1 and Q2, red and green LEDs for D1 and D2, R_1 = 330 Ω, R_2 = 47000 Ω, R_3 = 47000 Ω, R_4 = 330 Ω, C_1 = 10 μF and C_2 = 10 μF. Pay attention to the connection of the transistor terminals and LED terminals.



2. Set the DC supply output voltage controls to minimum then connect it to the circuit. Switch the DC supply ON, and set its voltage Vcc to 5 V. Verify this voltage using a voltmeter.

3. Set the oscilloscope Volt/Div and Time/Div so you can see about 2-3 full cycles of the input sinusoidal signal on CH1. Use the same Volt/Div setting for both CH1 and CH2. Write the settings you chose next to the oscilloscope plots below.

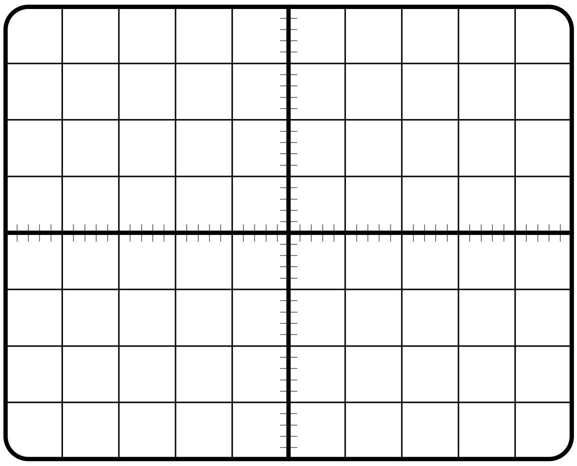
4. What does this circuit do? Describe the pattern you see from the LEDs.

. . . .

5. What is the difference between the signal you see on CH1 (v_{ce} on $Q1$) and the signal on CH2 (v_{ce} on $Q2$)?

. . . .

6. Draw the output signal (v_{ce} on $Q1$) you see on the oscilloscope on CH1 below.



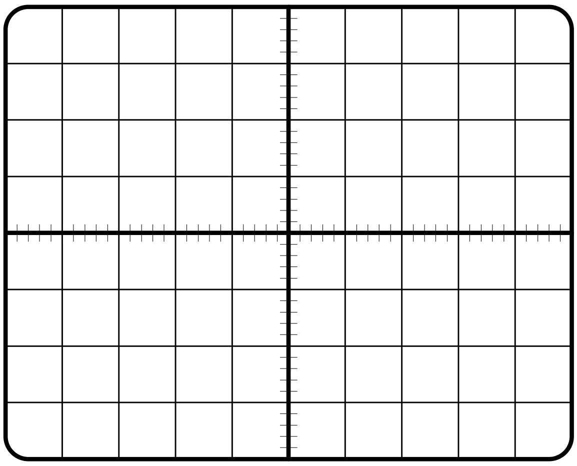
Volt/Div (CH1): ____________________

Time/Div: __________________________

Maximum value: __________________ V

Minimum value: __________________ V

7. Draw the output signal (v_{ce} on $Q2$) you see on the oscilloscope on CH2 below.



Volt/Div (CH2): ____________________

Time/Div: __________________________

Maximum value: __________________ V

Minimum value: __________________ V

8. To turn the LED on and off the transistor is acting like a:

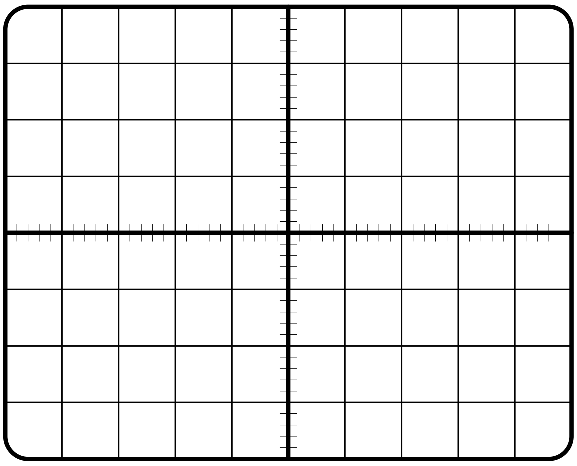
. . . .

9. Now change the resistors in the above circuit to $R_2 = 15000\ \Omega$ and $R_3 = 15000\ \Omega$, while keeping the rest of the circuit unchanged.

10. What has changed about the circuit behavior?

. . . .

11. Draw the new output signal (v_{ce} on $Q2$) you see on the oscilloscope on CH2 below.



Volt/Div (CH2): ____________________

Time/Div: _________________________

Maximum value: __________________ V

Minimum value: __________________ V

**** End ****