Solid State Electronics – Unit 9: Transistors

Lab 1 - Transistor

Name ____

OBJECTIVES

- Evaluate the common emitter amplifier.
- Assemble components for NPN and PNP Transistor circuits.
- Understand Transistor ratings   Learn how a transistor operates as a switch.
- Learn how a transistor operates as an amplifier.
- View inputs and outputs of a transistor amplifier.
- Use digital meters to measure voltages at various points of transistor circuits.
- Troubleshooting of transistor circuits.
- Use circuit simulation software to understand semiconductor circuits.

MATERIALS

- PNP Transistor
- NPN Transistor
- Resistors
- Power Supply
- Oscilloscope
- Multimeter
- Breadboard
- Circuit Simulation Software

PROCEDURE

Complete the steps for the transistor switch and for the transistor amplifier.

PART A TRANSISTOR TESTING

1. Examine the specification sheet of the 2N4403 and 2N2222 transistor.

   What is the maximum voltage that can be put across the transistor?

   2N4403 _____________   2N2222 _____________

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What is the maximum current that can flow through the transistor?

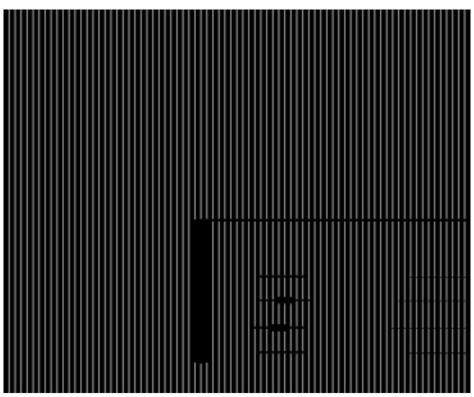
2N4403 _____________ 2N2222 _____________

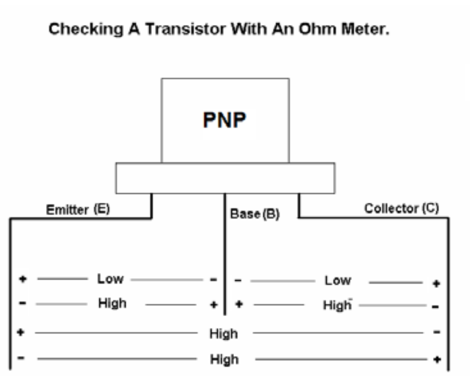
What is the maximum power that can be dissipated by the transistor?

2N4403 _____________ 2N2222 _____________

2. Correctly place your transistor in a breadboard. Also, hook three short (1"-1.5") wires to each leg in the breadboard. Use a multimeter to verify if your transistor is a functioning transistor and also determine if it is an NPN or PNP transistor.

Use the following picture to determine this.





A faulty PN junction will not show a difference in resistance in the forward or reverse connection. A low resistance in both directions shows a junction is shorted. A high resistance in both directions indicates a junction is open.

PART B THE TRANSISTOR AS A SWITCH.

Introduction

A transistor has three regions in which it can operate. The regions are: The Saturation, Cutoff, and Active regions. When a transistor is operating in the saturation and cutoff region only, it is said to be

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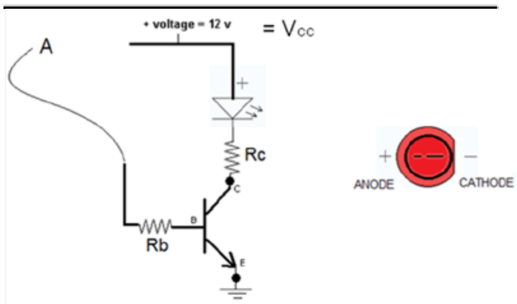
operating as a switch. When the transistor is operating in the saturation region it is operating like a switch that is turned on. When the transistor is operating in the cutoff region, it is operating like a switch that is off.

When the transistor is in the saturation region there is very little voltage across the emitter - collector (VCE). When the transistor is in cutoff there is very little current flow through the transistor (IC). During operation in the cutoff region, VCE is approximately equal to the supply voltage.

3. Connect the NPN type transistor on the breadboard as shown in the following schematic diagram. Fill in the values of voltage and current as you complete the lab. Also, fill in the chart at the end with your data from the NPN transistor only. The PNP operates sin a similar way.



Connect the wire labeled "A" to ground. Leave the wire connected here until instructed to change positions.

4. Measure the voltage across the resistor labeled RC. ______________________

5. Measure the voltage across VCE. _________________

   Measure the collector current. __________________

6. Is the transistor operating in the saturation or cutoff region? __________________

7. Connect the wire labeled "A" to the +12 volt supply voltage.

8. Does the LED light? Yes No

9. Measure the voltage across the resistor labeled RC. ______________________

10. Measure the voltage across VCE. _________________

Measure the collector current. __________________

11. Is the transistor operating in the saturation or cutoff region? __________________

12. Measure the voltage across the base-emitter junction in both cases.

VBE in saturation = _______________

VBE in cutoff = __________________

13. Measure the voltage across the base resistor in both cases.

VRB in saturation = _______________

VRB in cutoff = __________________

14. If a transistor is in cutoff, about what percentage of the supply voltage is across the transistor?

____

15. If a transistor is in saturation, about what percentage of the supply voltage is across the transistor?

____

16. Could other loads be substituted for the LED in the collector lead? Yes No

17. What would be the maximum current that could be switched by the transistor? ________________

18. What could the maximum voltage of the load be? ______________________

19. Connect the PNP type transistor on the breadboard as shown in the following schematic diagram. Notice the transistor is a PNP type and the polarity of the power supply has been switched.

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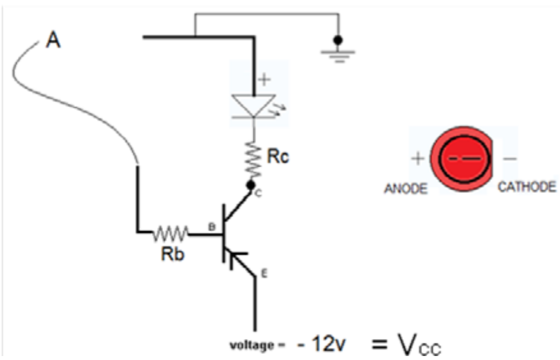

20. Measure the voltage across the resistor labeled RC. ______________________

21. Measure the voltage across VCE. ________________

Measure the collector current. _________________

22. Is the transistor operating in the saturation or cutoff region? ________________

23. Connect the wire labeled "A" to the +12 volt supply voltage.

24. Does the LED light? Yes No

25. Measure the voltage across the resistor labeled RC. ______________________

26. Measure the voltage across VCE. ________________

Measure the collector current. _________________

27. Is the transistor operating in the saturation or cutoff region? _________________

28. Measure the voltage across the base-emitter junction in both cases.

VBE in saturation = ______________

VBE in cutoff = ______________

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29. Measure the voltage across the base resistor in both cases.

VRB in saturation = _______________

VRB in cutoff = _______________

30. If a transistor is in cutoff, about what percentage of the supply voltage is across the transistor?

____

31. If a transistor is in saturation, about what percentage of the supply voltage is across the transistor?

____

32. Could other loads be substituted for the LED in the collector lead? Yes No

33. What would be the maximum current that could be switched by the transistor? ________________

34. What could the maximum voltage of the load be? _______________________

35. Fill in the following chart with your data from above. To calculate, use the formulas given by:

IC = VRC / RC IB = VRB / RB

	Measured Values				Calculated Values		Operating Region
	VCE	VRC	VRB	IC	IC	IB	
circuit 1							
circuit 2							

When the base-emitter junction is reverse biased, the transistor is operating in the cutoff region. This happened when wire "A" was connected to ground. The collector current was also greatly reduced. The source voltage appears across VCE. Since there is no collector current, there will be no voltage across the collector resistor. IC x RC = VRC

When VCE is very small the transistor is in the saturation region. The collector current will be high and there will be a large voltage across RC. The value of IB will also be large.

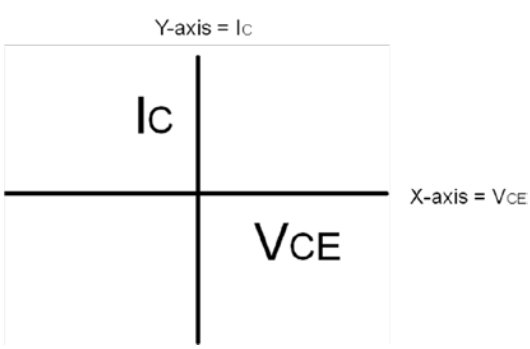
PART C THE TRANSISTOR AS AN AMPLIFIER.

The following was stated in the introduction of the transistor when used as a switch.

A transistor has three regions in which it can operate. The regions are: The Saturation, Cutoff, and Active regions. When a transistor is operating in the saturation and cutoff region only, it is said to be operating as a switch. When the transistor is operating in the saturation region it is operating like a switch that is turned on. When the transistor is operating in the cutoff region, it is operating like a switch that is off.

When the transistor is in the saturation region there is very little voltage across the emitter - collector (VCE). When the transistor is in cutoff there is very little current flow through the transistor (IC). During operation in the cutoff region, VCE is approximately equal to the supply voltage.

A graph can be made of a transistor as a switch. The x-axis will be VCE the voltage from emitter-collector. The y-axis will be the collector current.



The lab showed when the transistor was in cutoff, no collector current flowed and the voltage measured across the emitter to collector (VCE) was equal to the supply voltage (VCC).

We know what the value of "x" is for the transistor when it is in cutoff. In our lab VCC was equal to 12 volts.

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This gives:

"x" = VCE = VCC = 12v.

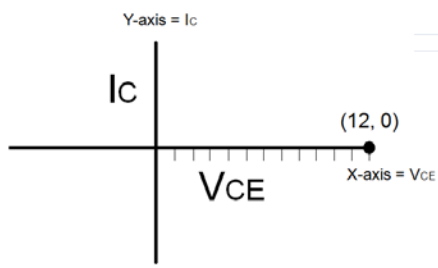
We also know what the value of "y" is for the transistor when it is in cutoff. When the transistor was in cutoff, there was no collector current (IC). This is given as:

"y" = IC = 0 ma.

Every point on a graph can be shown if we have an "x" and a "y" term. We now have one point established on our graph showing how the transistor behaves. This point is given in (x,y) coordinate form is:

(12, 0)

If that point is placed on the graph established it will look like this:



A second point can be established in a similar method. This second point would represent when the transistor is in saturation. In the lab, conditions of saturation, showed zero volts across the emitter-collector (VCE). The "x" value in this condition therefore is:

"x" = VCE = 0 volts

The lab also showed greater current flow through the collector than in the cutoff condition. The amount of current flow through the transistor during the saturation condition is determined by the collector resistor. The exact amount of current can be calculated using Ohm's Law. Look at the picture below:

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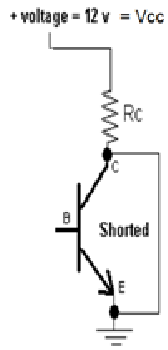


If the transistor was shorted, the current through the collector would be limited by the collector resistor (RC). Using Ohm's Law the current can be calculated.

$IC = VRC / RC$

VRc will be equal to VCC and for simplicity let RC = 1000Ω.

$IC = VRC / RC$

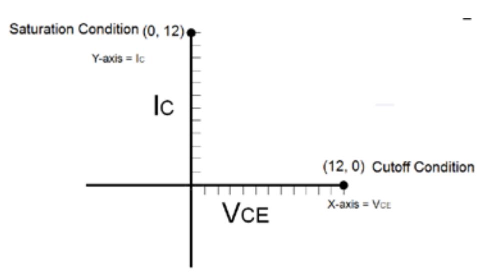
$= 12v / 1000\Omega$

$= 12 \text{ mA}$

This establishes the coordinate pair of the saturated condition or second point.

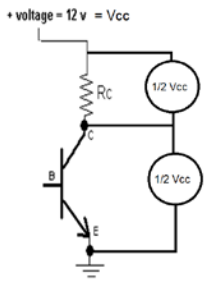
"y" = 12 mA from above "x" = 0 v (0, 12)

The following is the graph with the saturation and cutoff condition established as points on the graph.



The transistor may also operate in the active region. When it is operating in this region it is operating as an amplifier. In this region the transistor can have varying values of collector current (IC) and voltage across the collector-emitter (VCE). These values will depend on how much the transistor is conducting. The amount of conduction is determined by the base current. The base current is determined by the base resistor.

When the values of VCE and VRC are about equal, the transistor is operating in approximately the center of the active area.



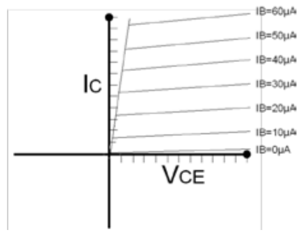
The graph developed above shows the two extreme values, cutoff and saturation. The characteristics of a transistor could be placed on the same graph.

Characteristics of resistance and characteristics of diodes were explained in the STUDY GUIDE. Please refer back to that if necessary.

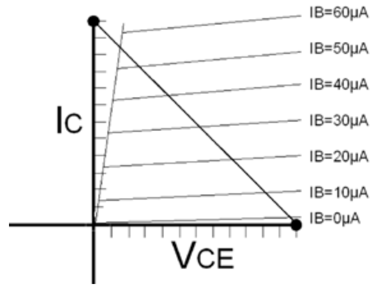
The method used to change the transistor from cutoff to saturation was to move the wire "A" from ground to the supply. This was essentially changing our base current (IB). In the case of cutoff the base current (IB) became zero when "A" was put to ground. When "A" was put to the supply, the base current (IB) became some value greater than zero. It became large enough to turn the transistor on and allow as much current to flow through the collector as possible. The only thing limiting the flow was the collector resistor.

In a like manner the only thing limiting the flow of current through the base of the resistor is the base resistor (RB). If a value of the resistor used for RB was larger than the resistor used in lab was connected, less base current would have flowed. If less base current would have flowed, the transistor would not have been turned on to fully saturate the transistor with current flow. The transistor would have been operating in the active region instead. Also, If a value of the resistor used for RB was increased in increments less base current would have flowed in each corresponding increment. If less base current would have flowed, the transistor would not have been turned on to fully saturate the transistor with current flow. The transistor would have been operating in the active region instead. The incremented smaller base currents produced could be reduced until almost zero base current was flowing through the base of the transistor. The final increment of base current would be zero base current. With zero base current the transistor would be in cutoff.

These varying base currents could be drawn on the graph we used above.

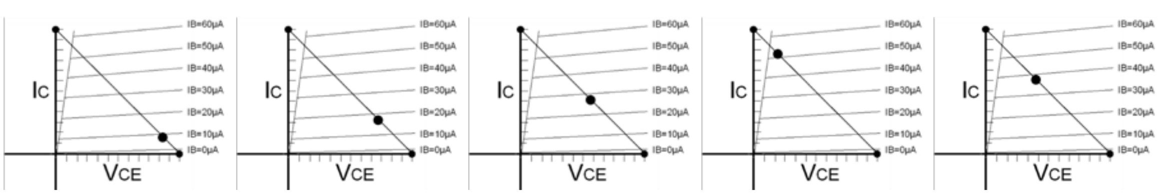


A line drawn on the graph between the cutoff and saturation point is shown.



The transistor must operate on this line. The line is called a load line. In this case, since the value of RC is 1000Ω, this line is called the 1000Ω load line. The transistor can be in cutoff region, through the active region, or in the saturation region.

Examples:



To review:

- The transistor must operate on the load line

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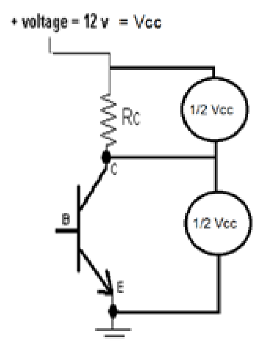
- The load line is determined by the value of RC.
- The operation of the transistor on the load line depends on the value of IB.
- The value of IB is determined by RB.
- A larger RB means a smaller IB. A smaller RB means a larger IB.

The following was stated earlier:

The transistor may also operate in the active region. When it is operating in this region it is operating as an amplifier. In this region the transistor can have varying values of collector current (IC) and voltage across the collector-emitter (VCE). These values will depend on how much the transistor is conducting. The amount of conduction is determined by the base current. The base current is determined by the base resistor.

When the values of VCE and VRC are about equal, the transistor is operating in approximately the center of the active area.



When the transistor is operating in this area it operates at the center of the load line. This can be shown on the graph.

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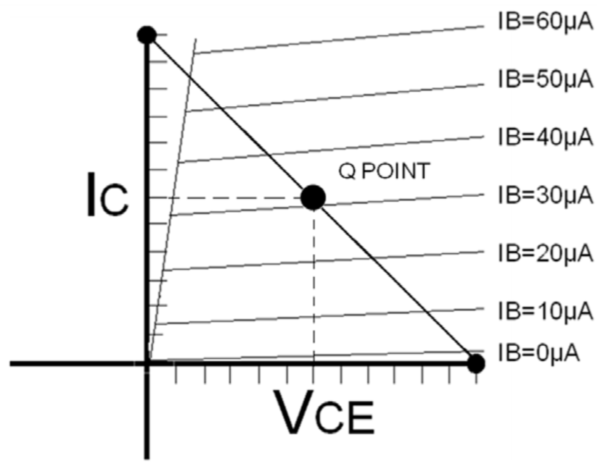
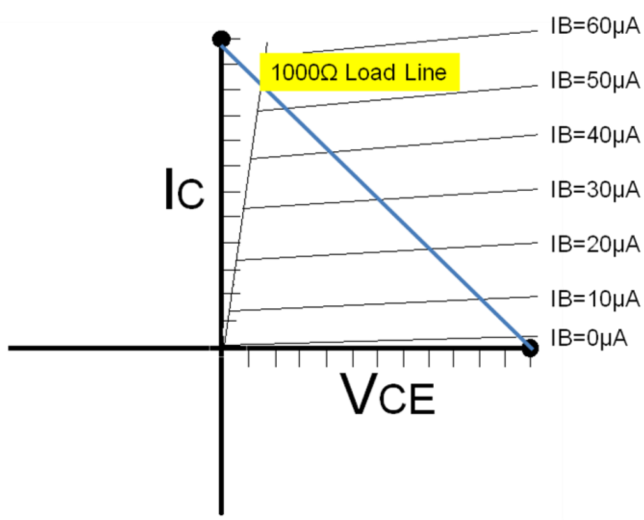


When the transistor operates at the center of the load line it is considered to be operating under optimal conditions. It is said to be operating at the Q Point. The Q Point is short for Quiescent Point. Looking at the graph, at the Q Point, the voltage across the emitter-collector (VCE) for this example is 6 volts. This means there is also 6 volts across the collector resistor (RC). At the Q Point the collector current is 6 mA. This makes sense because according to Ohm's Law...VRC / RC = IC. Then this gives: 6v/1000Ω = 6mA. Also, at the Q Point it can be seen that the base current IB is equal to 30µA.

36. Use the given set of transistor characteristic curves and draw load lines for a transistor circuit with RC values of 1500Ω, 2500Ω and 6000Ω. Put all 3 load lines on the same set of curves.



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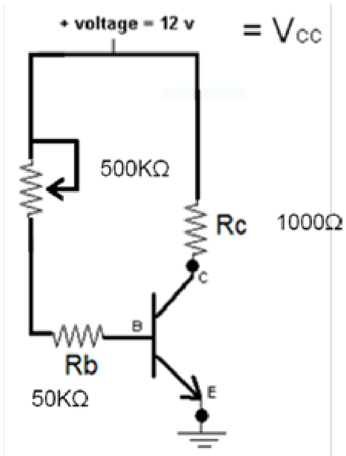
37. What value will IB, IC, and VCE be at the Q Point of each load line?

	1500Ω	2500Ω	6000Ω
IB			
IC			
VCE			

38. Set up the following circuit on the breadboard.



39. Connect a voltmeter across VCE.

40. Turn the potentiometer until you measure 6 volts across VCE.

41. Record your measurement for VCE in the table.

42. Measure IB, IC, VRC, and VRB and record your measurements.

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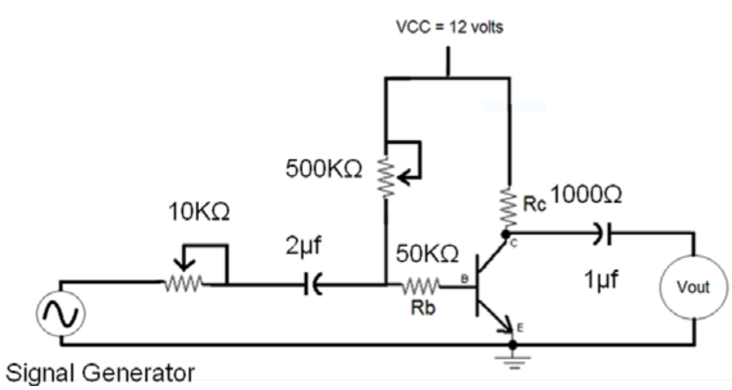
	Measured
VCE	
IB	
IC	
VRC	
VRB	

43. Are the values close to your values you saw in the graph? Yes No

44. Connect a signal generator to your circuit as shown below. Be sure to observe polarities of the capacitors.



45. Connect channel 2 of an oscilloscope where the diagram shows Vout.

46. Adjust the signal generator until you have a 2 volt peak-to-peak signal at the output. Do this at a frequency of 1000 Hz.

47. Once your output is established, measure the input signal with channel 1 of the oscilloscope.

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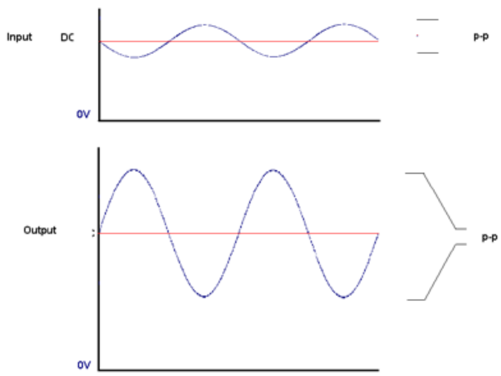
48. Show both the input and the output of the amplifier at the same time on the oscilloscope.

49. Notice the output is out of phase with the input by 180o.

50. Fill in your information in the provided waveforms.



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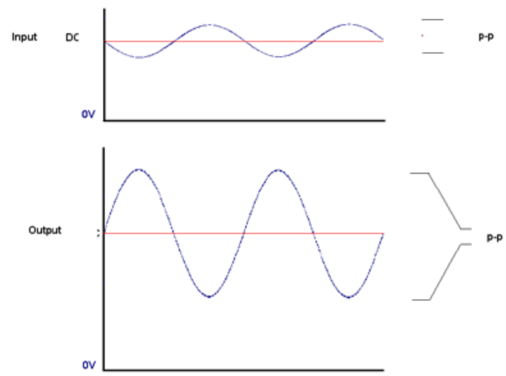

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51. An amplifier takes a small input signal and multiplies it to make a larger output signal. This is called gain. There is current gain, voltage gain, and power gain.

52. Find the voltage gain of your amplifier circuit. To do this divide the output voltage by the input voltage. Voltage gain is given the variable name AV.

AV = Vout / Vin

Your AV = ___________________

Slowly increase the amplitude of the signal generator while monitoring the output voltage. Increase the input signal until the output just begins to distort. Fill in your information in the provided waveforms.

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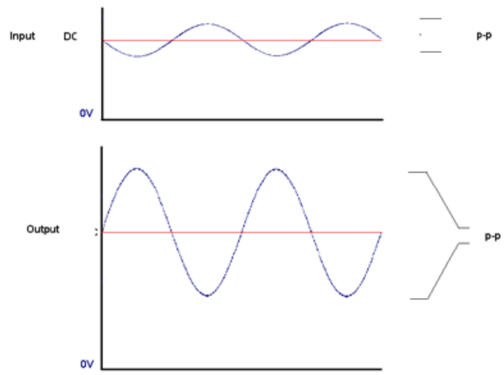

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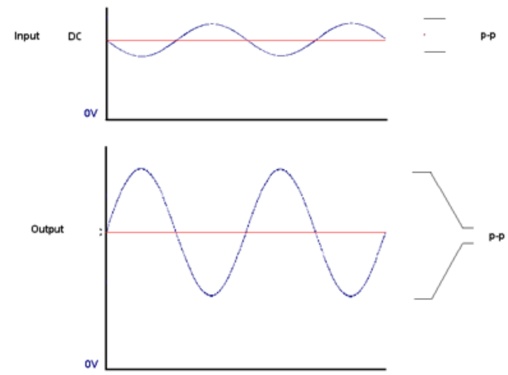

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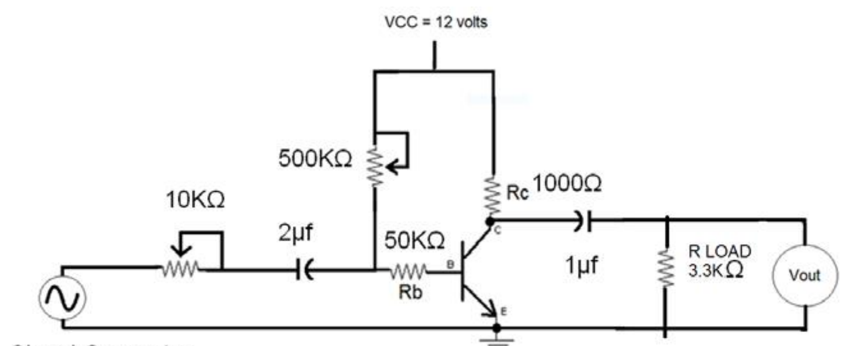
53. Connect a load resistor to the amplifier circuit.



54. Connect channel 2 of an oscilloscope where the diagram shows Vout.

55. Adjust the signal generator until you have a 2 volt peak-to-peak signal at the output. Do this at a frequency of 1000 Hz.

56. Once your output is established, measure the input signal with channel 1 of the oscilloscope.

57. Show both the input and the output of the amplifier at the same time on the oscilloscope.

58. Notice the output is out of phase with the input by 180o.

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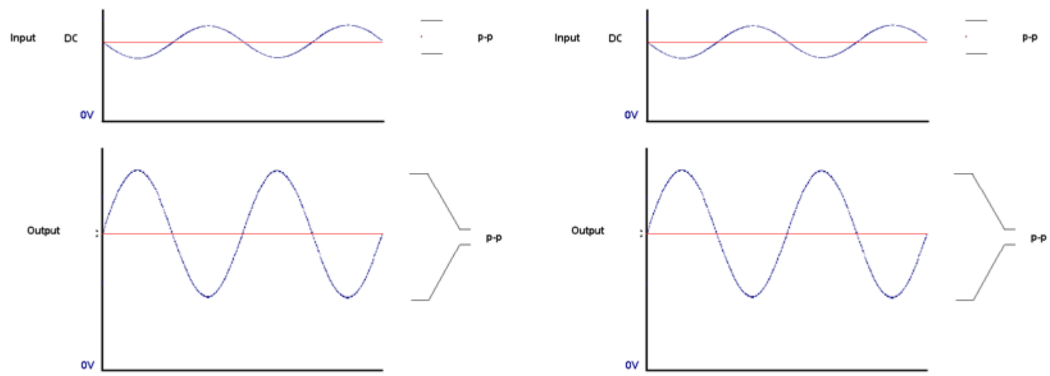
59. Fill in your information in the provided waveforms. LEFT SIDE OF CAP RIGHT SIDE OF CAP



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60. An amplifier takes a small input signal and multiplies it to make a larger output signal. This is called gain. There is current gain, voltage gain, and power gain.

61. Find the voltage gain of your amplifier circuit with the load. To do this divide the output voltage by the input voltage. Voltage gain is given the variable name AV.

AV = Vout / Vin

Your AV = ___________________

Slowly increase the amplitude of the signal generator while monitoring the output voltage. Increase the input signal until the output just begins to distort. Fill in your information in the provided waveforms.

The circuit used up to this point is not the only circuit used to build an amplifier. In order to acquire a greater circuit stability the following circuit is more common.

62. Connect the following circuit.

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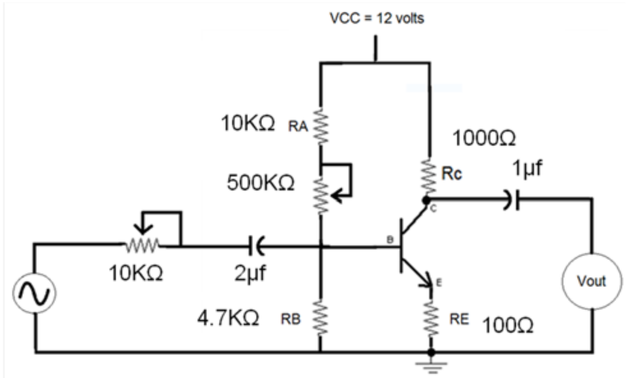

63. Disconnect the signal generator from the circuit. Simply shutting off the signal generator is not the same as disconnecting.

64. Connect a voltmeter across RB.

65. Adjust the 500KΩ pot until you measure 1 volt across RB.

66. Re-connect the signal generator.

67. Connect channel 2 of an oscilloscope where the diagram shows Vout.

68. Adjust the signal generator until you have a 2 volt peak-to-peak signal at the output. Do this at a frequency of 1000 Hz.

69. Once your output is established, measure the input signal with channel 1 of the oscilloscope.

70. Show both the input and the output of the amplifier at the same time on the oscilloscope.

71. Notice the output is out of phase with the input by 180o.

72. Fill in your information in the provided waveforms.

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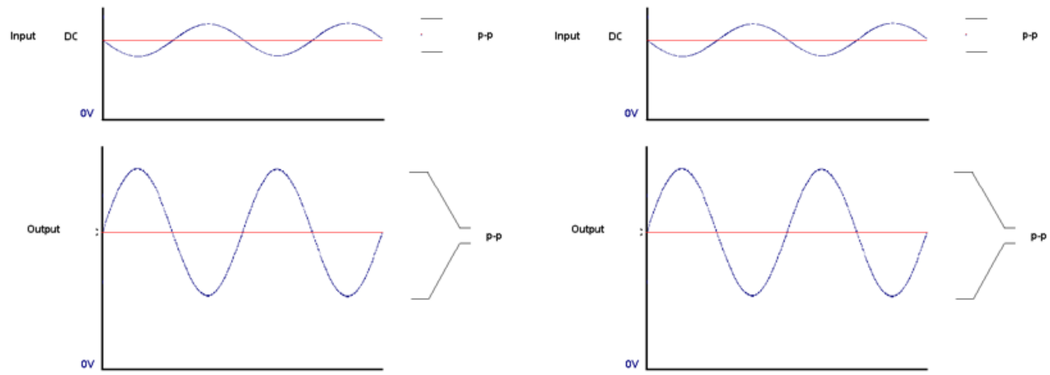

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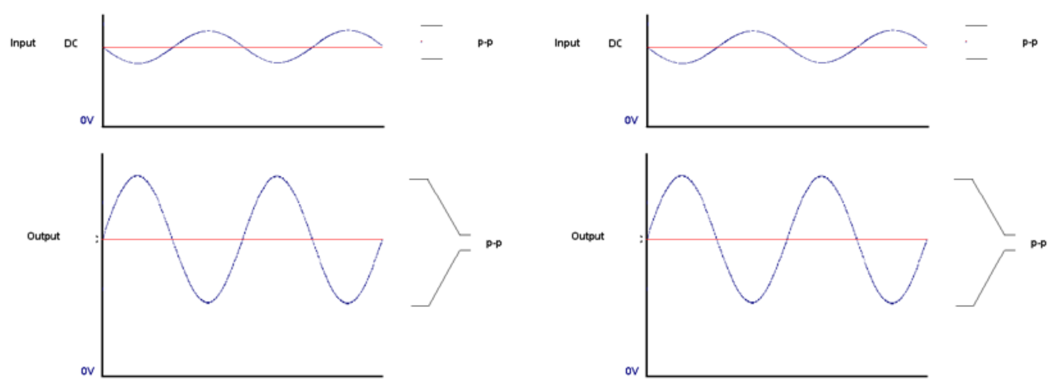
73. An amplifier takes a small input signal and multiplies it to make a larger output signal. This is called gain. There is current gain, voltage gain, and power gain.

74. Find the voltage gain of your amplifier circuit. To do this divide the output voltage by the input voltage. Voltage gain is given the variable name AV.

    AV = Vout / Vin

    Your AV = ___________________

    Slowly increase the amplitude of the signal generator while monitoring the output voltage. Increase the input signal until the output just begins to distort. Fill in your information in the provided waveforms.



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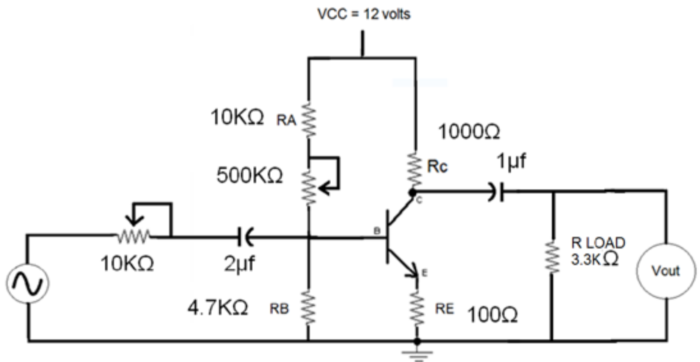
75. Connect a load resistor to the amplifier circuit.



76. Connect channel 2 of an oscilloscope where the diagram shows Vout.

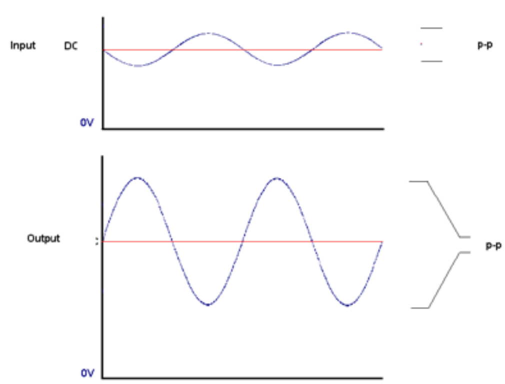
77. Adjust the signal generator until you have a 2 volt peak-to-peak signal at the output. Do this at a frequency of 1000 Hz.

78. Once your output is established, measure the input signal with channel 1 of the oscilloscope.

79. Show both the input and the output of the amplifier at the same time on the oscilloscope.

80. Notice the output is out of phase with the input by 180o.

81. Fill in your information in the provided waveforms.



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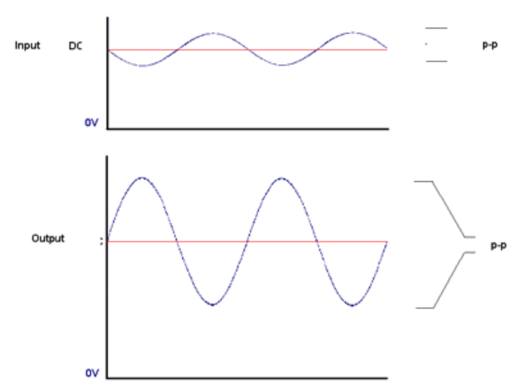

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82. An amplifier takes a small input signal and multiplies it to make a larger output signal. This is called gain. There is current gain, voltage gain, and power gain.

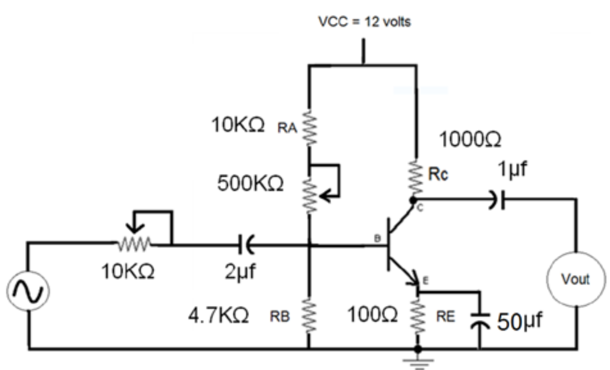
83. Find the voltage gain of your amplifier circuit with the load. To do this divide the output voltage by the input voltage. Voltage gain is given the variable name AV.

    AV = Vout / Vin

    Your AV = ___________________

    Slowly increase the amplitude of the signal generator while monitoring the output voltage. Increase the input signal until the output just begins to distort. Fill in your information in the provided waveforms.

84. Connect the capacitor across RE.



85. Set the input signal to achieve a maximum undistorted output signal.

86. Find the voltage gain of your amplifier circuit with the load. To do this divide the output voltage by the input voltage. Voltage gain is given the variable name AV.

    AV = Vout / Vin

    Your AV = ___________________

    The capacitor increases the gain.

87. Disconnect the signal generator.

88. Measure VRA = ___________________

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89. Measure VRB = ___________________

90. Measure VRC = ___________________

91. Measure VRE = __________________

92. Measure VCE = __________________

93. Calculate the emitter current = IE = VRE / RE _________________

94. Calculate the collector current = IC = VRC / RC _________________

95. Calculate the base current = IB = IE - IC ________________

96. The Beta (β) of a transistor is the current gain of the transistor. On the spec sheet of a transistor it is usually called Hfe. It is calculated by dividing IC by IB. Calculate your Beta.

    β = IC / IB = _______________

97. Construct the following circuit in the electronic simulation software.

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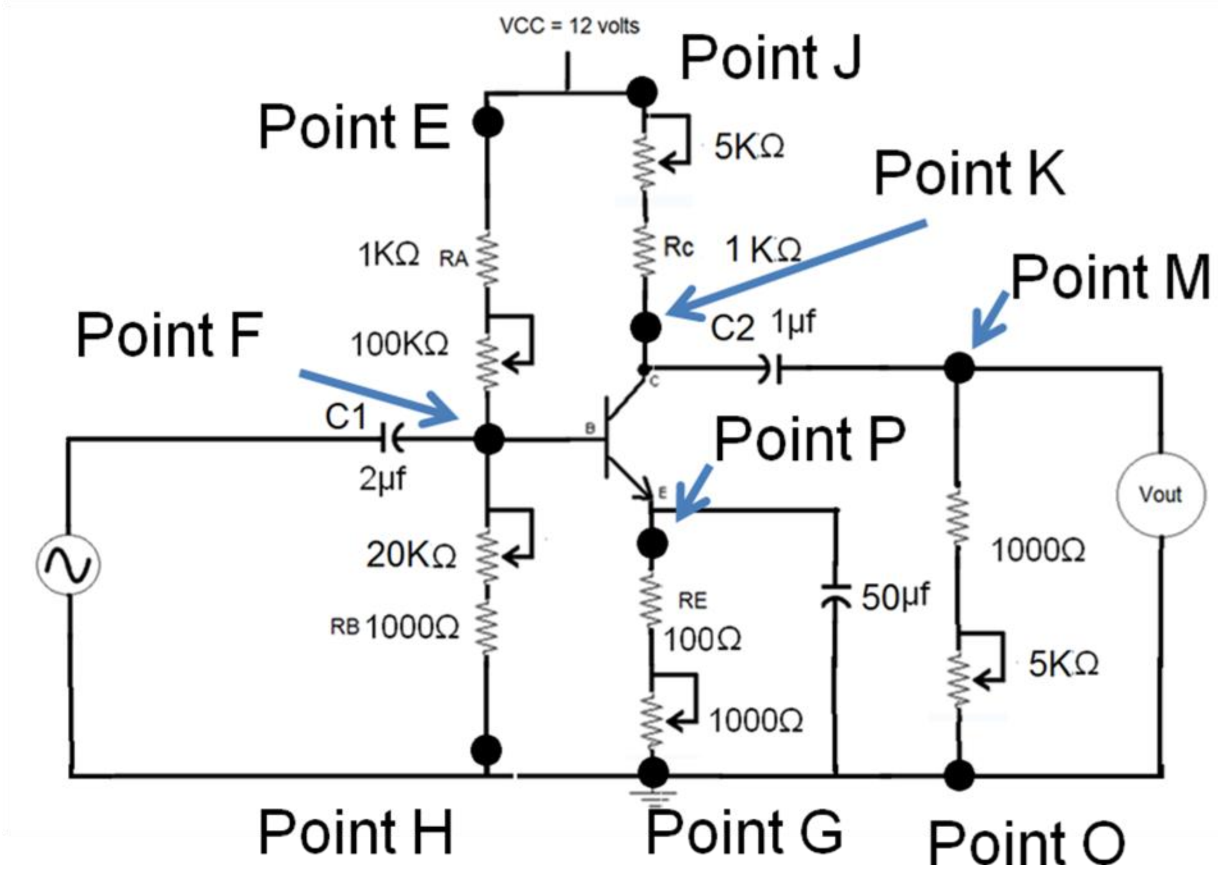

Notice VRL is the voltage across the load. The load in this case is the resistance between points M and O.

VRE is the voltage across RE and the 5000Ω Pot. This is the resistance between points P and G.

VRC is the voltage across RC and the 1000Ω Pot. This is the resistance between points J and K.

VRA is the voltage across RA and the 100KΩ Pot. This is the resistance between points E and F.

VRB is the voltage across RB and the 20KΩ Pot. This is the resistance between points F and H.

These values should be adjusted individually so their reason for being in the circuit can be defined.

98. Develop a detailed data table and graph for the following:

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1. What happens to VRL as the input frequency is adjusted between 20-20,000 Hz?

2. What happens to VRL as the C1 is varied between .1µfd - 20µfd?

3. What happens to VRL as the C2 is varied between .1µfd - 20µfd?

4. What happens to VRL as the VRA is varied between min and max?

5. What happens to VRL as the VRB is varied between. min and max?

6. What happens to VRL as the VRC is varied between. min and max?

7. What happens to VRL as the VRE is varied between. min and max?

8. What happens to VRL as the VRB is varied between. min and max?

9. What happens to VRL as the VRL is varied between. min and max?

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