EEE3307 ELECTRONICS I

LABORATORY MANUAL

DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING

University of Central Florida
Stands For Opportunity

Prepared by: Dr. Jiann S. Yuan

Revised Summer 2011

Preface

This laboratory book in Electronics I has been revised in order to be up to date with curriculum changes, laboratory equipment upgrading, and the latest circuit simulation software.

Every effort has been made to correct all the known errors. If you find any additional errors or anything else that you think is an error, please contact Dr. Yuan at the following email address:

yuanj@mail.ucf.edu

Dr. Jiann S. Yuan
Summer 2011

Table of Contents

Safety Rules and Operating Procedures

1. Note the location of the Emergency Disconnect (red button near the door) to shut off power in an emergency. Note the location of the nearest telephone (map on bulletin board).
2. Students are allowed in the laboratory only when the lab instructor is present.
3. Open drinks and food are not allowed near the lab benches.
4. Report any broken equipment or defective parts to the lab instructor. Do not open, remove the cover, or attempt to repair any equipment.
5. When the lab exercise is over, all instruments, except computers, must be turned off. Return substitution boxes to the designated location. Your lab grade will be affected if your laboratory station is not tidy when you leave.
6. University property must not be taken from the laboratory.
7. Do not move instruments from one lab station to another lab station.
8. Do not tamper with or remove security straps, locks, or other security devices. Do not disable or attempt to defeat the security camera.
9. Anyone violating any rules or regulations may be denies access to these facilities.

I have read and understand these rules and procedures. I agree to abide by these rules and procedures at all times while using these facilities. I understand that failure to follow these rules and procedures will result in my immediate dismissal from the laboratory and additional disciplinary action may be taken.

Signature Date Lab #

Laboratory Safety Information

The danger of injury or death from electrical shock, fire, or explosion is present while conducting experiments in this laboratory. To work safely, it is important that you understand the prudent practices necessary to minimize the risks and what to do if there is an accident.

Electrical Shock:

Avoid contact with conductors in energized electrical circuits. Electrocution has been reported at de voltages as low as 42 volts. Just 100 mA of current passing through the chest is usually fatal. Muscle contractions can prevent the person from moving away while being electrocuted.

Do not touch someone who is being shocked while still in contact with the electrical conductor or you may also be electrocuted. Instead, press the Emergency Disconnect (red button located near the door to the laboratory). This shuts off all power, except the lights.

Make sure your hands are dry. The resistance of dry, unbroken skin is relatively high and thus reduces the risk of shock. Skin that is broken, wet or damp with sweat has a low resistance.

When working with an energized circuit, work with only your right hand, keeping your left hand away from all conductive material. This reduces the likelihood of an accident that results in current passing through your heart.

Be cautious of rings, watches, and necklaces. Skin beneath a ring or watch is damp, lowering the skin resistance. Shoes covering the feet are much safer than sandals.

If the victim isn't breathing, find someone certified in CPR. Be quick! Some of the staff in the Department Office are certified in CPR. If the victim is unconscious or needs an ambulance, contact the Department Office for help or call 911. If able, the victim should go to the Student Health Services for examination and treatment.

Fire:

Transistors and other components can become extremely hot and cause severe burns if touched. If resistors or other components on your proto-board catch fire, turn off the power supply and notify the instructor. If electronic instruments catch fire, press the Emergency Disconnect (red button). These small electrical fires extinguish quickly after the power is shut off. Avoid using fire extinguishers on electronic instruments.

Explosion:

When using electrolytic capacitors, be careful to observe proper polarity and do not exceed the voltage rating. Electrolytic capacitors can explode and cause injury. A first aid kit is located on the wall near the door. Proceed to Student Health Services, if needed.

Guidelines for Laboratory Notebook

The laboratory notebook is a record of all work pertaining to the experiment. This record should be sufficiently complete so that you or anyone else of similar technical background can duplicate the experiment and data by simply following your laboratory notebook. Record everything directly into the notebook during the experiment. Do not use scratch paper for recording data. Do not trust your memory to fill in the details at a later time.
Organization in your notebook is important. Descriptive headings should be used to separate and identify the various parts of the experiment. Record data in chronological order. A neat, organized and complete record of an experiment is just as important as the experimental work.

1. Heading: The experiment identification (number) should be at the top of each page. Your name and date should be at the top of the first page of each day's experimental work.

2. Object: A brief but complete statement of what you intend to find out or verify in the experiment should be at the beginning of each experiment

3. Diagram: A circuit diagram should be drawn and labeled so that the actual experiment circuitry could be easily duplicated at any time in the future. Be especially careful to record all circuit changes made during the experiment.

4. Equipment List: List those items of equipment which have a direct effect on the accuracy of the data. It may be necessary later to locate specific items of equipment for rechecks if discrepancies develop in the results.

5. Procedure: In general, lengthy explanations of procedures are unnecessary. Be brief. Short commentaries along side the corresponding data may be used. Keep in mind the fact that the experiment must be reproducible from the information given in your notebook.

6. Data: Think carefully about what data is required and prepare suitable data tables. Record instrument readings directly. Do not use calculated results in place of direct data; however, calculated results may be recorded in the same table with the direct data. Data tables should be clearly identified and each data column labeled and headed by the proper units of measure.

7. Calculations: Not always necessary but equations and sample calculations are often given to illustrate the treatment of the experimental data in obtaining the results.

8. Graphs: Graphs are used to present large amounts of data in a concise visual form. Data to be presented in graphical form should be plotted in the laboratory so that any questionable data points can be checked while the experiment is still set up. The grid lines in the notebook can be used for most graphs. If special graph paper is required, affix the graph permanently into the notebook. Give all graphs a short descriptive title. Label and scale the axes. Use units of measure. Label each curve if more than one on a graph.

9. Results: The results should be presented in a form which makes the interpretation easy. Large amounts of numerical results are generally presented in graphical form. Tables are generally used for small amounts of results. Theoretical and experimental results should be on the same graph or arrange in the same table in a way for easy correlation of these results.

10. Conclusion: This is your interpretation of the results of the experiment as an engineer. Be brief and specific. Give reasons for important discrepancies.

Trouble Shooting Hints

1. Be sure that the power is turned on.

2. Be sure the ground connections are common.

3. Be sure the circuit you built is identical to that in the diagram. (Do a node-by-node check)

4. Be sure that the supply voltages are correct.

5. Be sure you plug in cable to the right terminal in the multimeter to measure the voltage/resistance (upper terminal) or the current (lower terminal).

6. Be sure that the equipment is set up correctly and you are measuring the correct parameter.

7. Be sure the BJT's collector and emitter terminals are in correct orientation.

8. If steps 1 through 5 are correct, then you probably have used a component with the wrong value or one that doesn't work. It is also possible that the equipment does not work (although this is not probable) or the protoboard you are using may have some unwanted paths between nodes. To find your problem you must trace through the voltages in your circuit node by node and compare the signal you have to the signal you expect to have. Then if they are different use your engineering judgment to decide what is causing the different or ask your lab assistant.

Eeperiment Evaluation Form

COURSE: EEE3307
SEMESTER:
COURSE INSTRUCTOR:
LAB INSTRUCTOR:
EXPERIMENT:

Please write comments on the following issues:

PART A (experiment):

1) Was the experiment successful?

2) Did the experimental results match the theory?

3) Was the material covered in the lecture?

4) Was the experiment instructive?

5) Was the lab manual clearly written?

PART B (facility):

1) Did all the instruments work properly?

2) Were all the needed parts available?

3) Any other problems?

PART C (Lab Instructor):

1) Was the lab instructor helpful?

2) Did the lab instructor know the experiment?

3) Was there any brief lecture in the lab?

4) Did the lab instructor know how to operate the instruments?

5) Any comments that may help the lab instructor improve?

Your name (optional): Please return to your course instructor

Experiment # 1

SPICE Circuit Simulation and Equipment Usage

Goals:

To familiarize with Multisim circuit simulation for pre-lab prepartion and the use of measurement equipment at the Electronics lab

References:

The following two links are to the Tektronix website for the user manuals for the 4034B Mixed Signal oscilloscope and for the AFG3022 Function generator:

Oscilloscope:
http://www2.tek.com/cmswpt/madetails.lotr?ct=MA&cs=mur&ci=16272&lc=EN

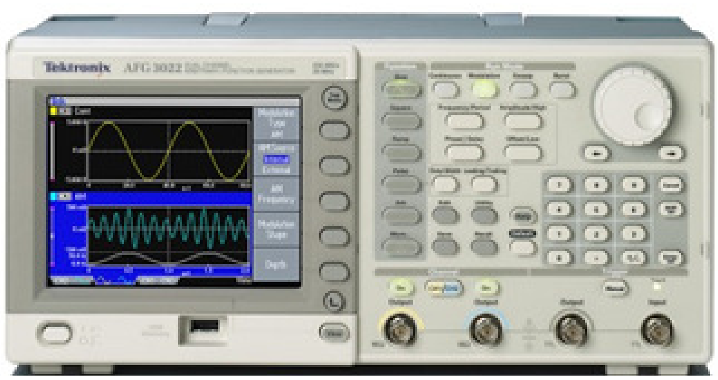
Function Generator:
http://www2.tek.com/cmswpt/madetails.lotr?ct=MA&cs=mur&ci=11920&lc=EN

Please note, to download the user manual, Tektronix requires that you fill out the user information form before downloading can begin.

Equipment:

Oscilloscope: Tektronix DPO 4034 Digital Oscilloscope
Function Generator: Tektronix AFG3022 Dual Channel Function Generator
Power Supply: Agilent E3630A
IN4148 Diode
Breadboard
Resistors available in the laboratory

Tektronix MSO 4034 Oscilloscope



Tektronix AFG3022 Function Generator

Computer Simulation

Connect the circuit in Fig. 1 using the schematic drawing in your computer simulation software. Let the input be a sinusoid of -2 V to 2 V amplitude at 5 kHz. R = 1 kΩ. Plot the output waveform versus time.

Experimental Procedure:

Connect the circuit in Fig. 1. Let the input be a sinusoid of 4 V peak to peak (i.e., - 2V to 2 V) with 0 V DC offset voltage at 5 kHz. Measure the output waveform versus time at your oscilloscope.

Connnect the circuit in Fig. 2. At the input DC votlage V_B of 1 V, measure the DC current flowing through the resistance (R = 1 kΩ). Change V_B to 2 volts, measure the DC current flowing through R again. Compare these two results.

(Note that the diode has a turn-on voltage of about 0.6 V.)

Report:

In your lab report, present experimental data and compare them with your expected results. Discuss any discrepancies, make comments, and write conclusions.

Your report will include the following information:

1. Laboratory partner.
2. Date and time data were taken.
3. The pre-laboratory results.
4. The experimental procedures.
5. All calculations or simulation results for each step.
6. All plots or waveforms for each step.
7. Short summary discussing what was observed for each of the steps given in experiment.
8. What you learned.

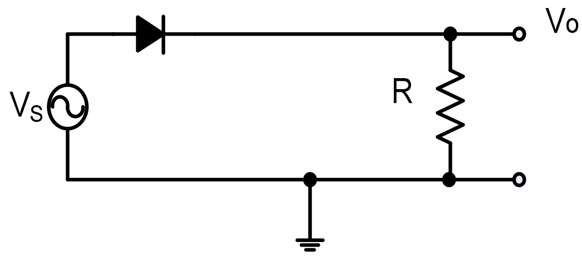


Fig. 1

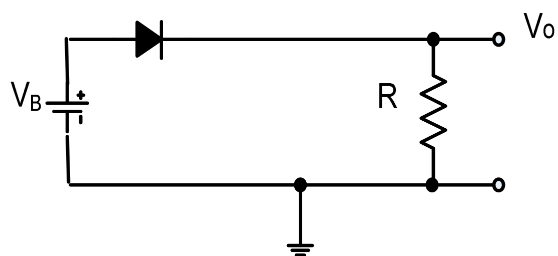


Fig. 2

Experiment # 2

Diode and Applications

(This experiment should be for two weeks so that the lab will be synchronizied with the lecture)

Goals:

To study the characteristics and the applications of PN junction diodes

References:

Microelectronics-Circuit Analysis and Design, D. A. Neamen, McGraw-Hill, 4th Edition, 2007, ISBN: 978-0-07-252362-1

Equipment:

Oscilloscope: Tektronix DPO 4034 Digital Oscilloscope
Function Generator: Tektronix AFG3022 Dual Channel Function Generator
Power Supply: Agilent E3630A
IN4148 Diodes (4)
IN5234 Zener Diodes (2)
Breadboard
Capacitors available in the laboratory
Resistors available in the laboratory

Background Information:

Diodes find numerous applications in practices, including rectifiers, clipping, clamping, and other signal processing circuits. They are also used in temperature compensated biasing and in digital circuits.

A) Rectifiers:

The basic half-wave rectifier is shown in Fig. 1. Because filtering is not perfect, there will be a residual voltage fluctuation known as ripple, on the output voltage. The amount of ripple can be reduced by a factor of two by using the full-wave rectifier shown in Fig. 2.

B) Clipping Circuits

Clipping circuits are used I applications where an input voltage should not be allowed to exceed a maximum value, and also in wave shaping of signal (function generation). A typical one is show in Fig. 3. The same result can be obtained with the circuit of Fig. 4 using two back to back Zener diodes.

C) Clamping Circuit:

The clamping circuit is a DC level restorer and changes the DC level of an arbitrary waveform, to a predetermined one. A simple clamping circuit is shown in Fig. 5.

Pre-laboratory:

Read this laboratory experiment carefully to become familiar with the background procedural steps in this experiment.

Using the circuit simulation software to simulate the following circuits:

(If you do not have access to Multisim, LTSpice IV is a free to use spice program available from Linear Technology Inc. and can be downloaded from the following site: http://www.linear.com/designtools/software/#LTspice)

A) For the circuits of Fig. 1 and Fig. 2, choose available values of R_L and C so that $R_LC = 0.2$ second approximately. Draw the output waveforms when the input is sinusoidal of frequency 100 Hz and 10 V peak to peak, under the following cases:

1) Capacitor only is removed. Plot the transfer (V_{out} versus V_{in}) characteristics.
2) Resistor only is removed.
3) Capacitor and resistor are both in place. Calculate the peak-to-peak ripple voltage.

B) Determine the transfer characteristics of the circuits in Fig. 3 and Fig. 4. Draw the output waveforms assuming that the input is a sinusoid with sufficiently larger amplitude (larger than both reference voltages or the Zener voltages) amplitude.

C) For the circuit shown in Fig. 5, draw the output waveform if the input is a sinusoid. Do not neglect the diode turn on voltage (≈ 0.65 V). Select available values of R and C so that RC time constant is equal to 0.2 seconds approximately (e.g., for a capacitor of 10 µF, the resistor value should be 20 kΩ).

Experimental Procedure:

Rectifiers:

Perform all the steps of preparation part A by experiments to study the diode characteristics and the operation of the various application circuits experimentally.

For each part test, what happens if the input is changed to a triangular or square input?

Important: Because the ground lead of the oscilloscope is internally connected to the ground of the function generator in Fig. 2, you cannot connect the ground lead of the oscilloscope to the (-) point of the output voltage. Instead, you should use two scope channels and use the scope in the differential mode. Consult with your lab instructor on how to do that.

Clipping Circuits:

a) Connect the circuit in Fig. 3. Let the input be a sinusoid of frequency 1 kHz. Display the input and output waveforms on the oscilloscope. Vary the amplitude of the input and observe the result. Display the V_{out} vs. V_{in} transfer characteristics of the circuit on the oscilloscope. Change the input waveform to a triangular or square waveform and see what happens.

b) Repeat the same steps for the circuit in Fig. 4. Note that the Zener breakdown voltage of 1N5234 is about -6.2 V and Zener diode's forward turn-on voltage is about 0.65 V. Your input voltage may change to 20 V peak to peak to provide sufficiently larger amplitude.

Clamping Circuit:

a) Connect the circuit in Fig. 5. Let the input be a sinusoid of any amplitude at 1 kHz.
While observing the output waveform (set the oscilloscope scope to be DC coupled), vary the amplitude of the input and observe the result. Next, leave the amplitude the same and add a DC offset in the input (There should be an "offset" control on the generator) and again observe the output. Make comments.

b) Repeat the same steps for a square-wave input.

Report:

In your lab report, present experimental data and compare them with your expected results. Discuss any discrepancies, make comments, and write conclusions.

Your report will include the following information:
1. Laboratory partner.
2. Date and time data were taken.
3. The pre-laboratory results.
4. The experimental procedures.

5. All calculations or simulation results for each step.
6. All plots or waveforms for each step.
7. Short summary discussing what was observed for each of the steps given in experiment.
8. What you learned.

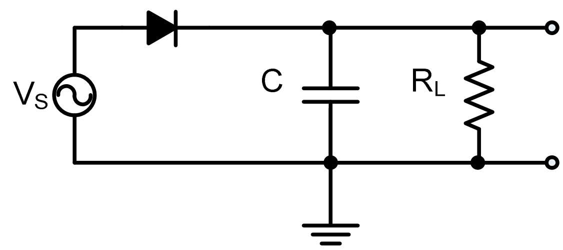


Fig. 1

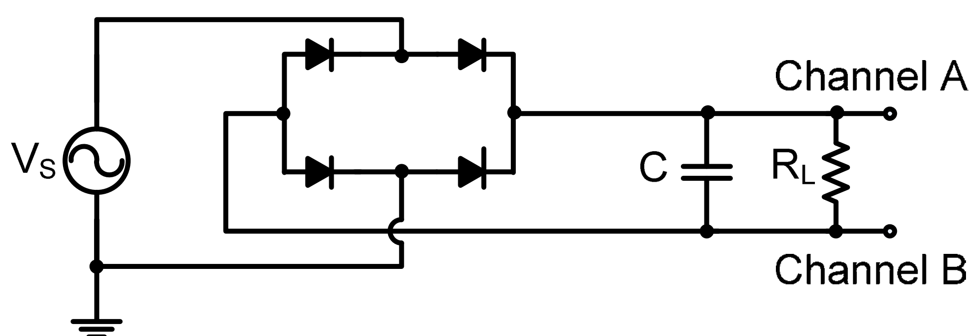


Fig. 2

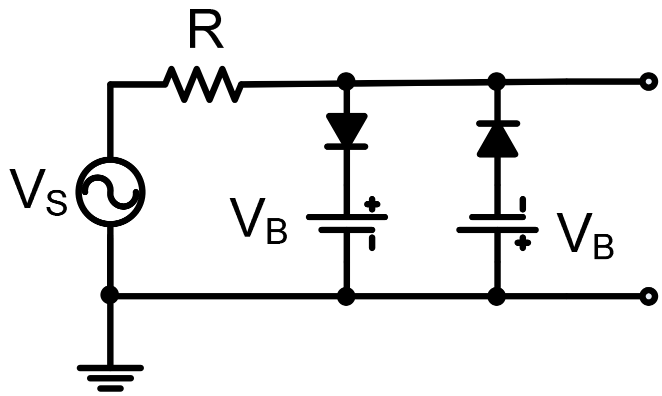


Fig. 3

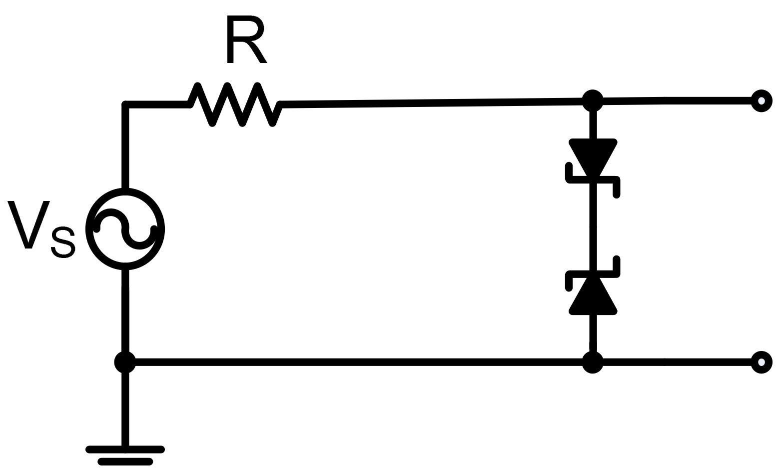


Fig. 4

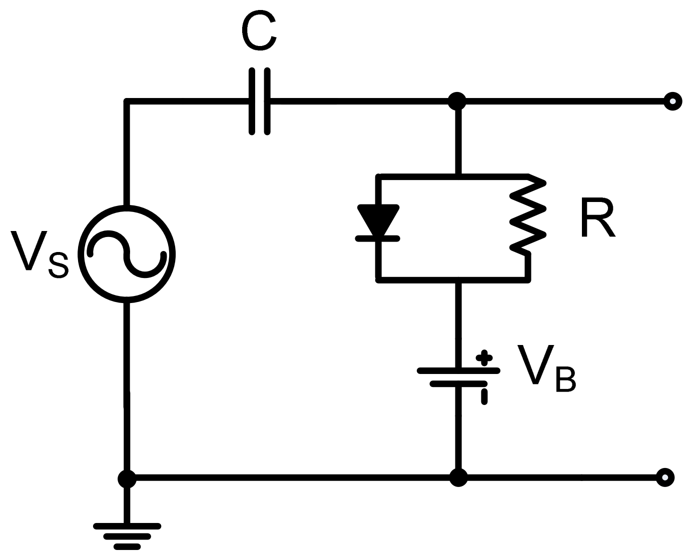


Fig. 5

Experiment # 3

Transistor Biasing

Goals:

To study the transistor biasing and bias stability

References:

Microelectronics-Circuit Analysis and Design, D. A. Neamen, McGraw-Hill, 4^{th} Edition, 2007, ISBN: 978-0-07-252362-1

Equipment:

Oscilloscope: Tektronix DPO 4034 Digital Oscilloscope
Function Generator: Tektronix AFG3022 Dual Channel Function Generator
Power Supply: Agilent E3630A
2N2222 Bipolar Transistors
Breadboard
Capacitors available in the laboratory
Resistors available in the laboratory

Background Information:

A typical transistor amplifier circuit is shown Fig. 1.a. Figure 1.b is a simplified equivalent. Figure 2 shows a typical DC load line and a Q-point. The input AC signal disturbs the base current that in turn makes the Q-point move on the load line producing a proportionally larger disturbance in the collector current, thus producing amplification. Fig. 3 is the same as Fig. 1 with an AC input signal added.

Pre-laboratory:

Assume V_{CC} = 12 V.

A) Consider the circuit in Fig. 1.b with R_C = 1.8 kΩ, R_B = 5.6 kΩ, and R_E = 0 Ω.

B) Calculate V_{BB} so that I_C = 2 mA. Assume β = 220 and V_{BE} = 0.7 V. Find the Q-point.
C) If β changes to 150, what is the new I_C from your circuit simulation? (Consult with your lab instructor how to change the current gain β in the 2N222 model parameter in MultiSim.)

D) Repeat (B) above if R_E is changed to 1.8 kΩ.

E) Consider the circuit in Fig. 3 with $R_C = R_E = 1.8$ kΩ. Calculate the values for R_1, R_2 so that $I_{CQ} = 2$ mA. Use a sinusoidal input (small-signal peak to peak voltage of 20 mV) and current gain of 150 in your circuit simulation. Plot v_i, v_C, v_E, and v_{CE} versus time.

Computer Simulation:

Using a circuit simulation program to simulate the preparation parts.

Experimental Procedure:

The purpose of this experiment is to verify the theoretical and simulation results.

a) Connect the circuit of Fig. 1.b with values calculated in the pre-lab preparation. Measure the Q-point and compare with expected value. Measure I_C and I_B and compute the current gain β.

b) If needed, adjust V_{BB} so that I_{CQ} is about 2 mA. Replace the transistor with another one and check if the I_{CQ} remains the same. Repeat with a third transistor. Does the collector current remain the same? Why or Why not?

c) Modify the circuit by inserting R_E as in the preparationand repeat parts a) above.

d) Connect the circuit in Fig. 3 using the values you have calculated in the preparation. Measure the Q-point and compare with expected value.

e) Connect and set the generator to a sinusoidal of 3 kHz. Use 10 µF for the capacitor C. Make sure the capacitor is connected with the correct polarity. Adjust the input amplitude so that none of the waveforms is clipped. Observe and include in your report the following waveforms:

Input voltage v_i, collector voltage v_C, emitter voltage v_E, and collector-emitter voltage v_{CE}.
Plot all those waveforms on a common time scale using 2 to 3 sinusoidal cycles.

Report:

In your lab report, include theoretical, simulated, and experimental results and make comment about discrepancies, as well as any other observations that you have.

Your report will also include the following information:
1. Laboratory partner.
2. Date and time data were taken.
3. The pre-laboratory results.
4. The experimental procedures.

5. All calculations or simulation results for each step.
6. All plots or waveforms for each step.
7. Short summary discussing what was observed for each of the steps given in experiment.
8. What you learned.

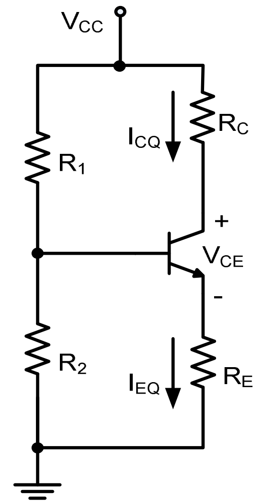


Fig. 1a

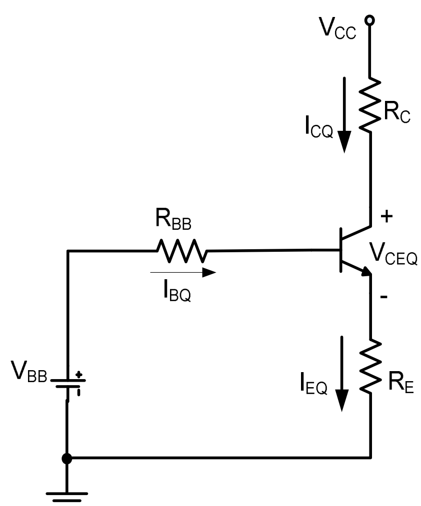
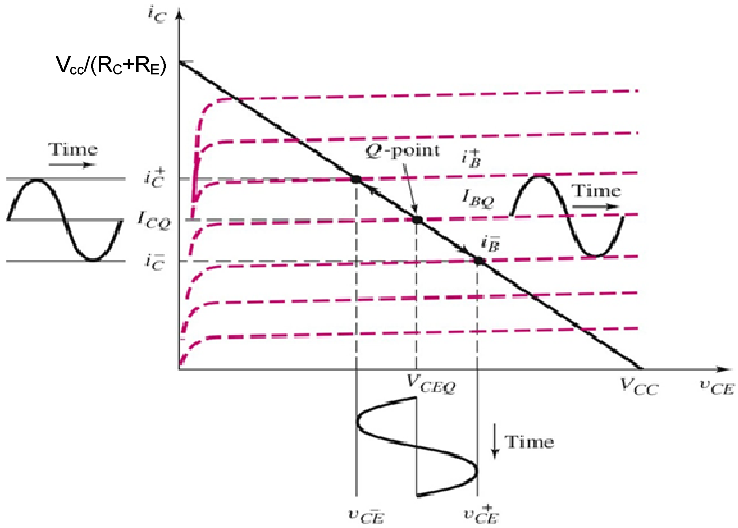
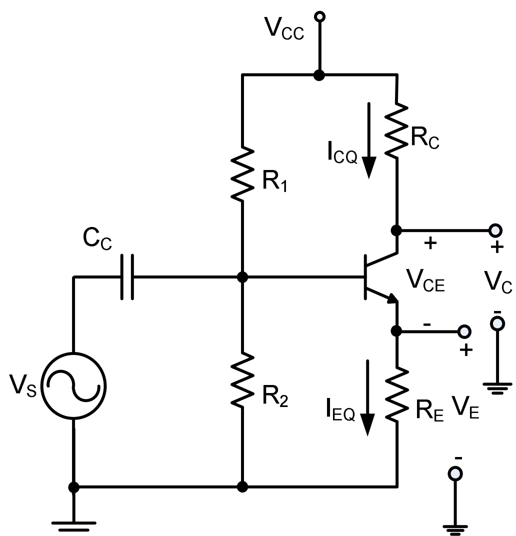


Fig. 1b



i_C
$V_{cc}/(R_C+R_E)$
Time
i_C^+
I_{CQ}
i_C^-
Q-point
i_B^+
I_{BQ}
Time
i_B^-
V_{CEQ}
V_{CC}
v_{CE}
Time
v_{CE}^-
v_{CE}^+

Fig. 2



V_{CC}
R_C
I_{CQ}
R_1
C_C
+
+
V_{CE}
V_C
-
-
+
V_S
R_2
I_{EQ}
R_E
V_E
-

Fig. 3

Experiment # 4

Transistor AC Amplifiers

(This experiment would be for two weeks so that the lab can be synchronizied with the lecture)

Goals:

To study AC transistor amplifiers

References:

Microelectronics-Circuit Analysis and Design, D. A. Neamen, McGraw-Hill, 4th Edition, 2007, ISBN: 978-0-07-252362-1

Equipment:

Oscilloscope: Tektronix DPO 4034 Digital Oscilloscope
Function Generator: Tektronix AFG3022 Dual Channel Function Generator
Power Supply: Agilent E3630A
2N2222 Bipolar Transistors
Breadboard
Capacitors available in the laboratory
Resistors available in the laboratory

Background Information:

A typical common emitter amplifier stage is shown in the Figure 1. The placement of the Q-point on the AC load line determines the maximum symmetrical AC component in the collector voltage and current.

With an arbitrary location of the Q-point on the AC load line, the maximum unclipped voltage or current will occur first on either the positive or negative cycles of the AC waveform, and as the input is increased the output will eventually be clipped on both cycles. The maximum unclipped output can be optimized (maximized) placing the Q-point at the center of the AC load line.

Pre-laboratory:

All the preparation parts must be computed before the experiments part. Consider the circuit of Fig. 1.

Let V_{CC} = 12 V, R_C = 6.2 kΩ, R_E = 1.8 kΩ, and R_L = 2.2 kΩ.

1) Calculate values of R_1, R_2 so that $I_{CQ} \approx 1$ mA and for good bias stability (or $R_{BB} = 0.1\times(\beta+1)\times R_E$).
2) Compute the Q-point and the maximum unclipped output voltage with C_E included (C_E = 100 μF).
3) Repeat 2 if capacitor C_E is removed.
4) With R_C, R_E and R_L the same as what used in 1), re-calculate R_1 and R_2 so that the operating point is at the center of the AC load line. Re-calculate the maximum unclipped output with C_E included (C_E = 100 μF).
5) Repeat 4 with the bypass capacitor C_E removed.
6) Change the value of R_C to 3.2 kΩ and re-calculate the DC operating point I_{CQ}. What do you notice?

You may find the following equations useful:

$$I_{CQ} \approx \frac{V_{BB} - V_{BE(on)}}{\frac{R_{BB}}{\beta} + R_E}, \quad V_{BB} = \frac{V_{CC} \times R_2}{R_1 + R_2}, \quad R_{BB} = \frac{R_1 \times R_2}{R_1 + R_2}, \quad V_{BE(on)} \approx 0.7V$$

Computer Simulation

Use a circuit simulation program to verify the results found in the preparation.

Experimental Procedure:

The purpose of the experiment is to verify the theoretical and simulation results. Use C_B = 1 μF, C_L = 1 μF, and C_E = 100 μF.

NOTE: Make sure capacitors are connected with the correct polarity.

1) Build the circuit in Fig.1 with the values you calculated in part (1) of the preparation. If necessary, re-adjust R_1, R_2 so that $I_{CQ} \approx 1$ mA.
2) Measure the maximum sinusoidal unclipped output. Set the input frequency to 5 kHz.
3) Repeat (2) with C_E removed.
4) Replace R_1, R_2 with the ones found in the pre-lab preparation part (4) and measure the new unclipped output.
5) Repeat (4) with C_E removed.
6) Change R_C to 3.2 kΩ and measure I_{CQ} after the change.

Report:

In your lab report, present experimental data and compare them with your expected results. Discuss any discrepancies, make comments, and write conclusions.

Your report will include the following information:
1. Laboratory partner.
2. Date and time data were taken.
3. The pre-laboratory results.
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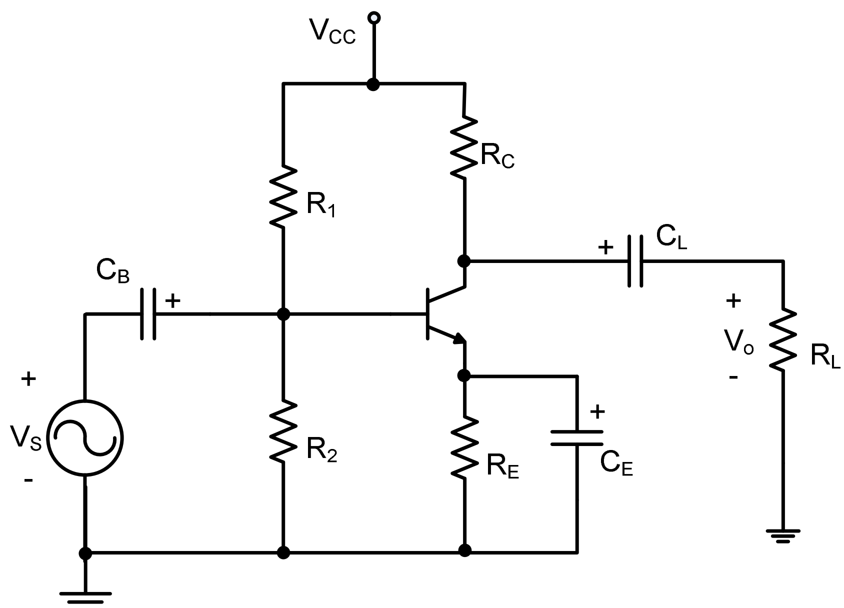
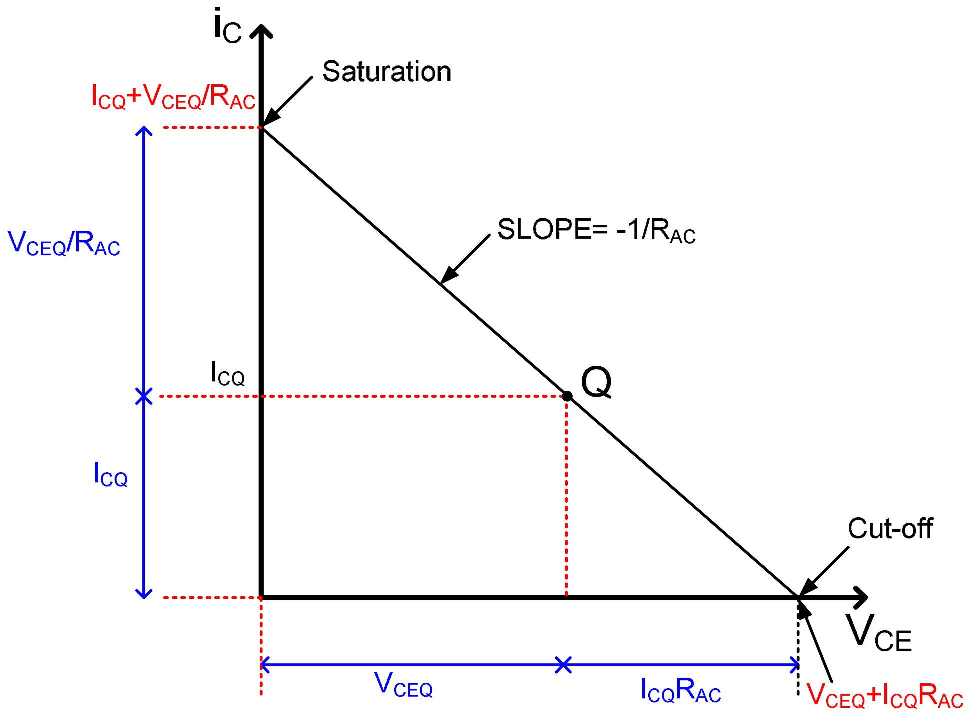


Fig. 1



iC
Saturation
ICQ+VCEQ/RAC
VCEQ/RAC
SLOPE= -1/RAC
ICQ
Q
ICQ
Cut-off
VCE
VCEQ
ICQRAC
VCEQ+ICQRAC

Fig. 2

Experiment # 5

Transistor Small-Signal Amplifiers

Goals:

To study small signal transistor amplifiers

References:

Microelectronics-Circuit Analysis and Design, D. A. Neamen, McGraw-Hill, 4th Edition, 2007, ISBN: 978-0-07-252362-1

Equipment:

Oscilloscope: Tektronix DPO 4034 Digital Oscilloscope
Function Generator: Tektronix AFG3022 Dual Channel Function Generator
Power Supply: Agilent E3630A
2N2222 Bipolar Transistors
Breadboard
Capacitors available in the laboratory
Resistors available in the laboratory

Background Information:

One of the earliest and important applications of bipolar transistors is in small-signal amplifiers. These are systems that accept input signal of small amplitudes (on the order of 100 mV) and deliver larger replicas. In this experiment we will study the common emitter (CE) and common collector (CC) configurations and a variation of the two. The common-collector amplifier is also known as the emitter follower.

Common Emitter Amplifier:

A typical common emitter amplifier stage is shown in the Figure 1.

Emitter Follower (or Common Collector Amplifier):

A typical emitter follower is shown in Fig. 2. The voltage gain of the emitter follower is close to one, but never equal to one. The input resistance is significantly higher than that of CE Amplifier and the output resistance is significantly lower.

Pre-laboratory:

Consider the circuit of Figure 1 with V_{CC} = 12 V, R_C = 6.2 kΩ, R_E = 1.8 kΩ, R_L = 2.2 kΩ, R_S = 1.8 kΩ, and C_E = 100 μF.

Common Emitter Amplifier:

1) Calculate the values R_1, R_2 so that $I_{CQ} \approx 1$ mA and good bias stability (see also preparation in Experiment #3).
2) Compute the Q-point and the maximum unclipped output voltage.
3) Compute the small-signal voltage gain $Av_i = v_o/v_i$ and $Av_s = v_o/v_s$.
4) Compute the input and output resistances.
5) Repeat 2) to 4) above if capacitor C_E is removed.

You may find the following equations for the CE amplifier useful.

For the common-emitter amplifier using a by-capacitor C_E, the voltage gain and input resistance are

$$Av_s = -g_m \times R_c \left(\frac{R_i}{R_i + R_S} \right), \quad R_i = R_1 \| R_2 \| r_\pi$$

$$g_m = \frac{I_{CQ}}{kT/q}, \; r_\pi = \frac{\beta}{g_m}, \; kT/q \approx 26mV.$$

For the common-emitter amplifier without a by-capacitor C_E, the voltage gain and input resistance become

$$Av_s = \frac{-\beta \times R_C}{r_\pi + (\beta+1) \times R_E} \left(\frac{R_i}{R_i + R_S} \right), \quad R_i = R_1 \| R_2 \| [r_\pi + (\beta+1) \times R_E]$$

Emitter Follower:

Consider the circuit of Figure 2. Repeat 1) through 4) in the Common Emitter Amplifier procedure above for the Emitter Follower.

The following equations are for the emitter follower:

$$Av_s = \frac{(\beta+1) \times (r_o \| R_E)}{r_\pi + (\beta+1) \times (r_o \| R_E)} \left(\frac{R_i}{R_i + R_S} \right), \quad R_i = R_1 \| R_2 \| [r_\pi + (\beta+1) \times (r_o \| R_E)]$$

$$R_o = \left(\frac{r_\pi + R_1 \| R_2 \| R_S}{\beta + 1} \right) \| R_E \| r_o,$$

$$r_\pi = \frac{\beta \times (kT/q)}{I_{CQ}}, \text{ and } r_o = \frac{V_A}{I_{CQ}}.$$

For 2N2222 bipolar transistor, the Early voltage V_A is above 100 V and current gain β is about 150.

Computer Simulation

Use a circuit simulation program to verify the results found in the preparation.

Experimental Procedure:

The purpose of the experiment is to verify the theoretical results.
Use C_B = 10 µF, C_1 =10 µF, C_E = 100 µF, and a sinusoidal input at 5 kHz.

Common Emitter Amplifier:

1) Connect the circuit of the Figure 1 with the component values you have calculated in the preparation.
2) Measure the small-signal voltage gains Av_s and Av_i.
3) Measure the voltages v_s and v_i and from these measurements calculate the input resistance (input resistance ≡ $(v_s^{peak}-v_i^{peak})/R_S$)
4) Measure the output voltage with the R_L connected and disconnected, respectively. Use the measurement results to compute the output resistance (output resistance = $R_L \times (v_o - v_L)/v_L$, where v_o is the maximum output voltage without R_L connected and v_L is the maximum output voltage with R_L connected).

Emitter Follower:

Connect the circuit of Figure 2 with component values as calculated in the preparation and repeat all the experimental parts from 1) through 4) in the common emitter amplifier above.

Report:

In your lab report, present experimental data and compare them with your expected results. Discuss any discrepancies, make comments, and write conclusions.

Your report will include the following information:
1. Laboratory partner.
2. Date and time data were taken.
3. The pre-laboratory results.
4. The experimental procedures.

5. All calculations or simulation results for each step.
6. All plots or waveforms for each step.
7. Short summary discussing what was observed for each of the steps given in experiment.
8. What you learned.

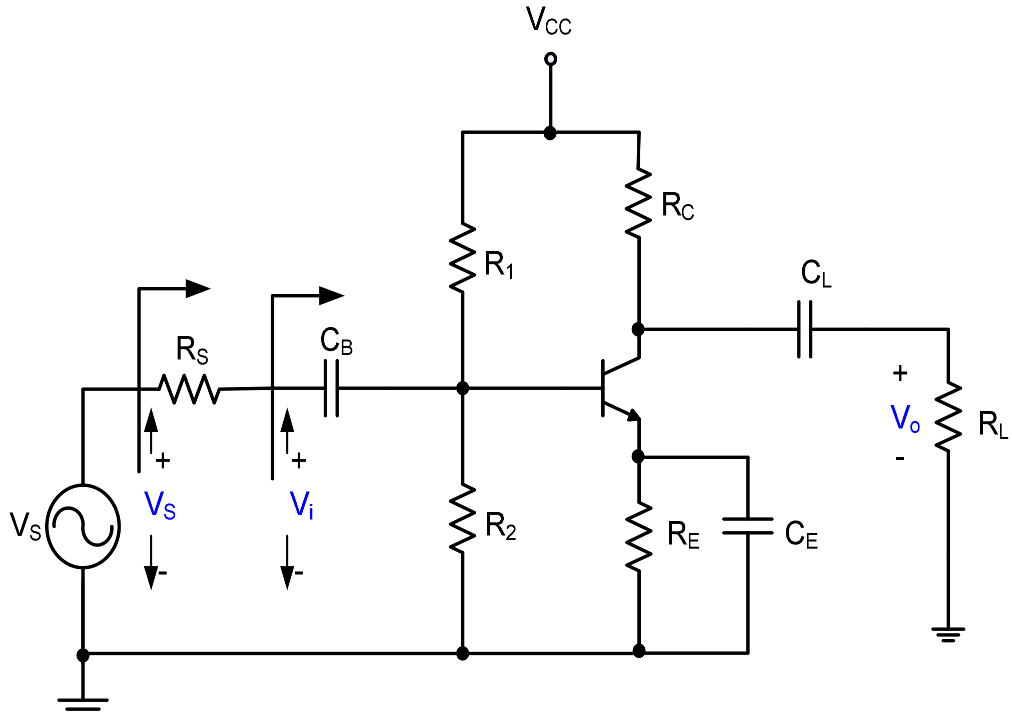


Fig. 1

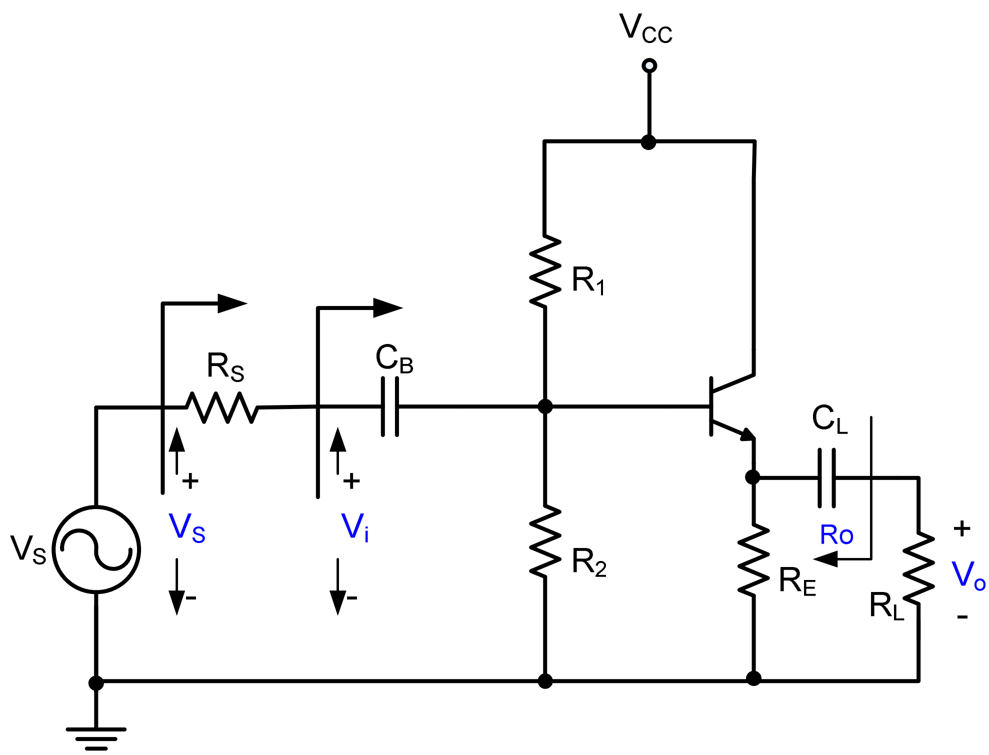


Fig. 2

Experiment # 6

Design Project

(This experiment should be for two weeks)

Goals:

To design a transistor amplifier that meets given specs.

Reference:

Microelectronics-Circuit Analysis and Design, D. A. Neamen, McGraw-Hill, 4th Edition, 2007, ISBN: 978-0-07-252362-1

Equipment:

Oscilloscope: Tektronix DPO 4034 Digital Oscilloscope
Function Generator: Tektronix AFG3022 Dual Channel Function Generator
Power Supply: Agilent E3630A
2N2222 bipolar tranisstors
Breadboard
Capacitors available in the laboratory
Resistors available in the laboratory

Problem Statement: Design a small-signal voltage amplifier that meets the following specifications:

1) Voltage gain of 50 or more

2) Minimum input resistance of 15 kΩ

3) Output resistance less than 100 Ω

4) Maximum unclipped output of 2V peak-to-peak

5) Power supply voltage of 9 V

6) Lower current drain from supply voltage

Hint:

You may use a multi-stage small-signal amplifier to achieve desirable input resistance, voltage gain, output resisntace, etc.

A common-emitter amplifier with an emitter resistance R_E, but without an emitter by-pass capacitor C_E is good for high input resistance, common-emitter amplifier using an emitter by-pass capacitor is good for high voltage gain, and the use of an emitter follower results in a low output resistance.

You may use some analytical equations in Experiment 4 and Experiment 5 to help you for calculation and/or anlysis.

Design Deliverables: A design document that includes at least the following:

1) Complete electrical schematics

2) Design steps with expectations

3) Computer simulation of the design

Note:

1) Each student must design his or her own amplifier and turn the design document into the lab instructor

2) During the experiment, students can choose one of the amplifiers desinged by the members for building and testing, or can test all designs.

Experiment:

Build one of the designed amplifiers, and measure all the parameters that have been specified.

Report:

Compare desired and obtained specifications and make comments.

Your report will also include the following information:
1. Laboratory partner.
2. Date and time data were taken.
3. The pre-laboratory results.

4. The experimental procedures.
5. All calculations or simulation results for each step.
6. All plots or waveforms for each step.
7. Short summary discussing what was observed for each of the steps given in experiment.
8. What you learned.

Experiment # 7

Frequency Response of a Common Emitter Amplifier Stage

Goals:

To study the frequency response of a common emitter amplifier stage and to experimentally verify theoretical results.

References:

Microelectronics-Circuit Analysis and Design, D. A. Neamen, McGraw-Hill, 4th Edition, 2007, ISBN: 978-0-07-252362-1

Equipment:

Oscilloscope: Tektronix DPO 4034 Digital Oscilloscope
Function Generator: Tektronix AFG3022 Dual Channel Function Generator
Power Supply: Agilent E3630A
2N2222 Bipolar Transistors
Breadboard
Capacitors available in the laboratory
Resistors available in the laboratory

Background Information:

The frequency response of an amplifier is limited in the low and high frequency bands because of the presence of capacitors. In the low frequency band the response is limited because of external capacitors used to provide DC isolation between stages. In the upper frequency band the frequency response is limited by internal parasitic capacitances of the transistor. For a more detailed analysis refer to the current textbook used.

Pre-laboratory:

Consider the common emitter amplifier stage you have designed in Experiment 4 (Also see Fig. 1 in this experiment).

1) Low Frequency

a) Replace C_B with a 0.1 μF capacitor and calculate the lower -3dB frequency (C_L = 10 μF and C_E = 100 μF).

b) Replace C_L with a 0.1 μF capacitor and calculate the lower -3dB frequency (C_B = 10 μF and C_E = 100 μF).

2) High Frequency

Because the transistor parasitic capacitances are not known and because the upper high frequency might be too high to measure, we do the following: Connect two capacitors between base-emitter and between base-collector as shown in Figure 2. Select the values between 100 pF to 400 pF based on availability. With these external capacitors connected, it may be reasonable to assume that C_π is approximately equal to the external capacitance and C_μ is approximately the external capacitance plus another 100 pF which is a typical value for the internal parasitic.

a) With the described assumptions and connections calculate the upper -3dB frequency of the amplifier.

Computer Simulation

Use a circuit simulation program to verify the results found in the preparation.

Experimental Procedure:

The purpose of the experiment is to verify the theoretical results and notice any discrepancies.

Low Frequency

Connect the CE amplifier in Fig. 1 and carry out all the preparation steps. For each case measure the lower -3dB frequency and compare it with the theoretical value.

High Frequency

a) Connect the two small capacitors as described in the preparation and measure the upper -3dB frequency and compare it with the theoretical value.

b) Remove the two small capacitors and measure the new upper -3dB frequency. How different is this compared to a) above?

Report:

In your lab report, present experimental data and compare them with your expected results. Discuss any discrepancies, make comments, and write conclusions.

Your report will include the following information:
1. Laboratory partner.
2. Date and time data were taken.

3. The pre-laboratory results.
4. The experimental procedures.
5. All calculations or simulation results for each step.
6. All plots or waveforms for each step.
7. Short summary discussing what was observed for each of the steps given in experiment.
8. What you learned.

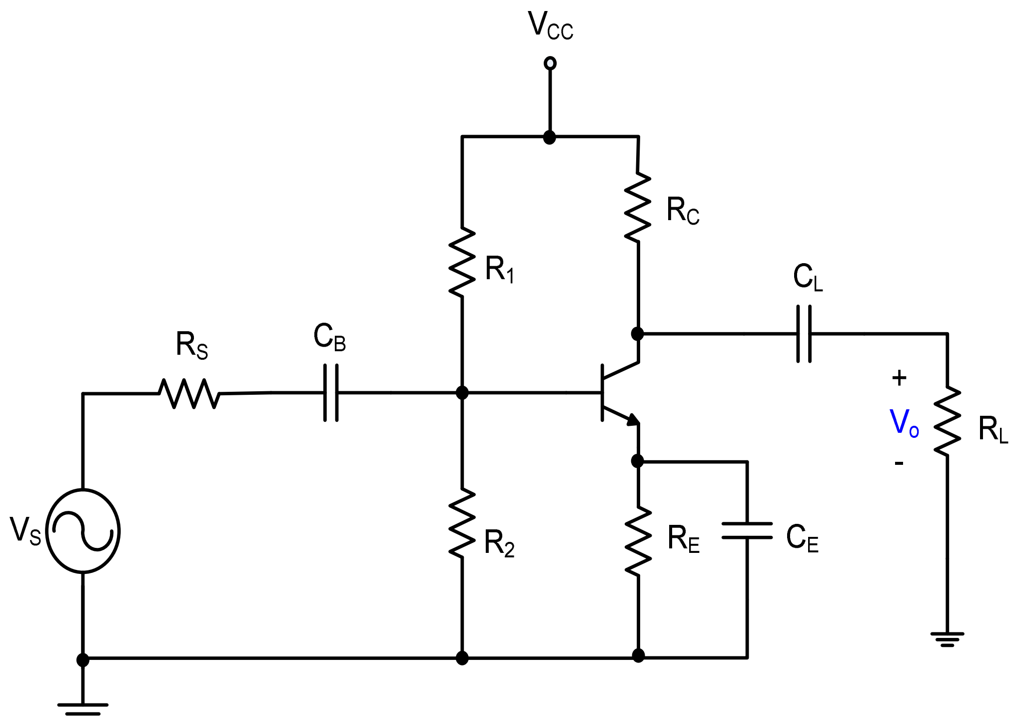


Fig. 1

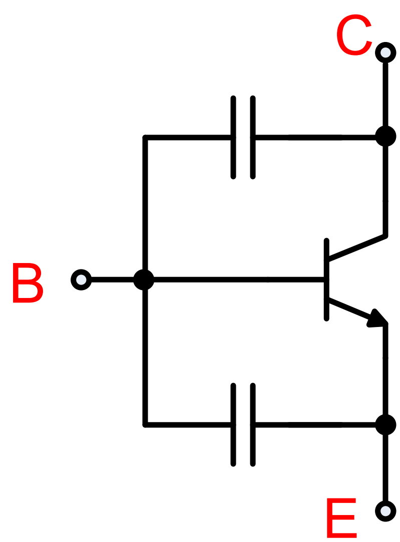


Fig. 2

Experiment # 8

Differential Amplifiers

Goals:

To study the characteristics of differential amplifiers.

References:

Microelectronics-Circuit Analysis and Design, D. A. Neamen, McGraw-Hill, 4th Edition, 2007, ISBN: 978-0-07-252362-1

Equipment:

Oscilloscope: Tektronix DPO 4034 Digital Oscilloscope
Function Generator: Tektronix AFG3022 Dual Channel Function Generator
Power Supply: Agilent E3630A
2N2222 Bipolar Transistors
Breadboard
Capacitors available in the laboratory
Resistors available in the laboratory

Background Information:

Differential amplifiers have two inputs and amplify the difference of two inputs. The most common differential amplifier is the differential pair shown in Figure 1. When the two transistors are identical (matched), this amplifier exhibits excellent thermal stability and is the basic building block of the Operational Amplifier. An improvement of this circuit is to replace R_E by a constant current source. This modification is shown in Figure 2. The lower bipolar transistor acts as a constant current source. In theory, this circuit has a much better common-mode rejection ratio (CMRR) than the circuit of Figure 1.

Pre-laboratory:

1) Assume equal inputs to the differential pair transistors and compute the DC current of each transistor in Figure 1.
2) With component values as shown, compute the differential-mode voltage gain (Av_d), common-mode voltage gain (Av_c), and common-gain rejection ratio (CMRR = 20 log(Av_d/Av_c) in Figure 1.
3) Compute the quiescent current I_{CQ} of each transistor in Figure 2.

4) With component values as shown, compute the differential-mode gain, common-mode gain, and common-mode rejection ratio in Figure 2.

Experimental Procedure:

The purpose of the experiment is to experimentally study the characteristics of the differential amplifier.

1) Connect the circuit of Figure 1. With the inputs connected together, drive the input (10 mV p-p at 5 kHz) from the function generator and measure the common-mode voltage gain.
2) Set one of the inputs to AC zero and measure the differential-mode voltage gain.
3) Compute the common-mode rejection ratio CMRR.
3) Repeat steps 1, 2, and 3 for the circuit in Fig. 2. Measure the quiescent current I_{CQ} of each transistor.

Report:

In your lab report, present experimental data and compare them with your expected results. Discuss any discrepancies, make comments, and write conclusions.

Your report will include the following information:
1. Laboratory partner.
2. Date and time data were taken.
3. The pre-laboratory results.
4. The experimental procedures.
5. All calculations or simulation results for each step.
6. All plots or waveforms for each step.
7. Short summary discussing what was observed for each of the steps given in experiment.
8. What you learned.

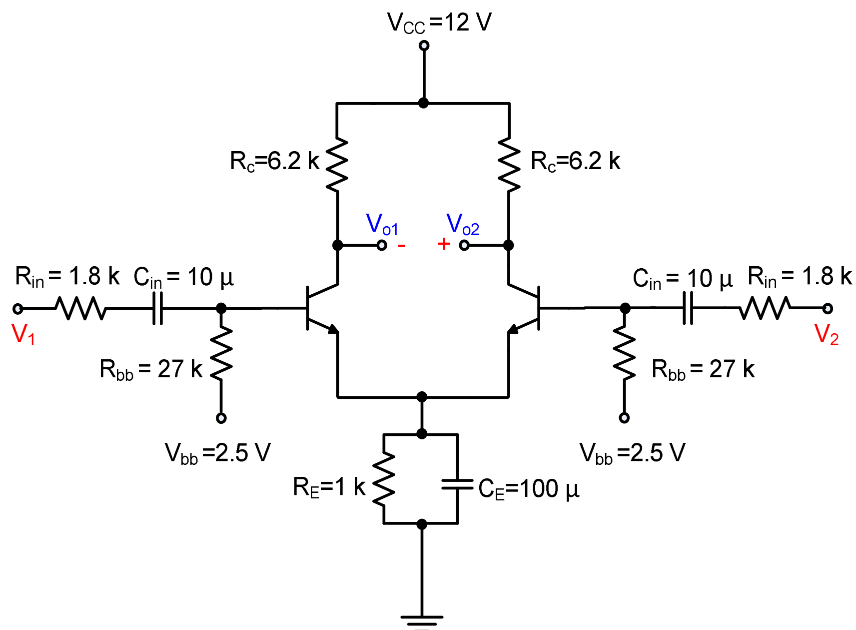
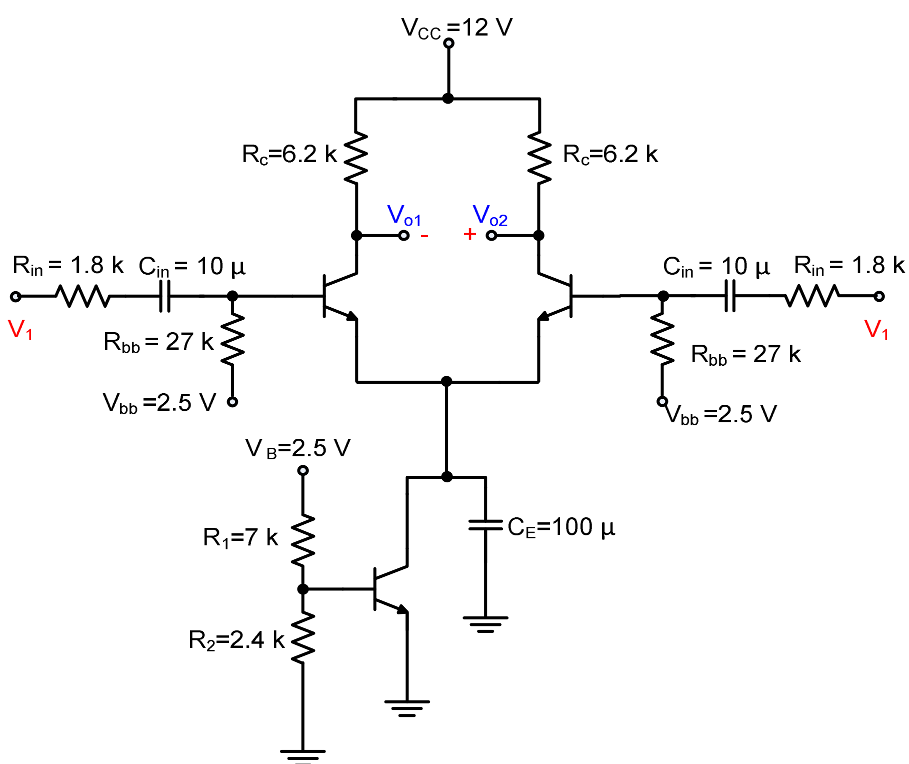

VCC =12 V
Rc=6.2 k
Rc=6.2 k
Vo1
-
+
Vo2
Rin = 1.8 k
Cin = 10 µ
Cin = 10 µ
Rin = 1.8 k
V1
V2
Rbb = 27 k
Rbb = 27 k
Vbb =2.5 V
Vbb =2.5 V
RE=1 k
CE=100 µ

Fig. 1


VCC =12 V
Rc=6.2 k
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Vo1
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Cin = 10 µ
Cin = 10 µ
Rin = 1.8 k
V1
V1
Rbb = 27 k
Rbb = 27 k
Vbb =2.5 V
Vbb =2.5 V
V B=2.5 V
R1=7 k
R2=2.4 k
CE=100 µ

Fig. 2