Lab 2: Transistor Amplifiers

In this lab, you will examine how transistors can be used to create amplifiers and will identify the important characteristics and applications of a transistor amplifier. In each section of this two-part lab, you will investigate the behavior of a different transistor amplifier configuration.

In Section 1, you will measure and calculate the voltage gains of a common emitter amplifier, then compare your results for simulation and implementation.

In Section 2, you will simulate an emitter-follower amplifier and investigate how its current gain can be controlled with resistor values.

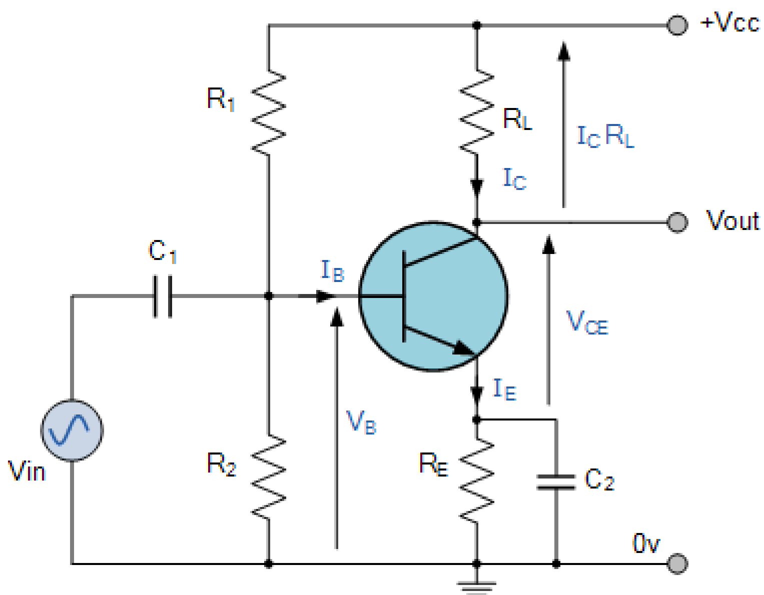

Figure 1 Transistor Amplifier Circuit Diagram

Learning Objectives

After completing this lab, you will be able to complete the following activities.

1. Discuss the characteristics, operation and applications of a transistor amplifier.
2. Measure voltage and current gains of different transistor amplifier circuits.
3. Design an amplifier circuit to achieve the given gain using a desired gain value.

Required Tools and Technology

Platform: NI ELVIS III

Instruments used in this lab:

- Instrument 1: IV Analyzer
- Instrument 2: Function Generator
- Instrument 3: Oscilloscope
- Instrument 4: Bode Analyzer
- Instrument 5: Variable Power Supply

Note: The NI ELVIS III Cables and Accessories Kit (purchased separately) is required for using the instruments.

- ✓ View User Manual: http://www.ni.com/en-us/support/model.ni-elvis-iii.html
- ✓ View Tutorials: https://www.youtube.com/playlist?list=PLvcPIuVaUMIWm8ziaSxv0gwtshBA2dh_M
- ✓ Install Soft Front Panel support: http://www.ni.com/documentation/en/ni-elvis-iii/latest/getting-started/installing-the-soft-front-panel/

Hardware: NI ELVIS III Default Prototyping Board

- ✓ View Breadboard Tutorial: http://www.ni.com/tutorial/54749/en

---

Hardware: TI Electronics Kit

Components used in this lab:

Section 1 Components

- (1) 560 Ω resistor
- (1) 1 kΩ resistor
- (1) 8.2 kΩ resistor
- (1) 18 kΩ resistor
- (1) 1 µF capacitor
- (1) 22 µF capacitor
- (1) 100 µF capacitor
- (1) NPN 2N3904 transistor

Section 2 Components

- (1) 2 kΩ resistor
- (1) 5 kΩ resistor
- (2) 20 kΩ resistors
- (2) 1 µF capacitors
- (1) NPN 2N3904 transistor

Software: NI Multisim Live

- You will run several pre-built circuits with Multisim Live, in order to observe the amplification achieved by various transistor configurations.
- **Tinkercad**

✓ Access online at: http://multisim.com

✓ View Multisim Help: https://www.multisim.com/help/

https://www.tinkercad.com/

Expected Deliverables

In this lab, you will collect the following deliverables:

- ✓ Calculations of voltage gain
- ✓ Analysis questions
- ✓ Observations about the behavior of transistor amplifiers

Your instructor may expect you complete a lab report. Refer to your instructor for specific requirements or templates.

Section 1: Transistor Amplifiers

1.1 Theory and Background

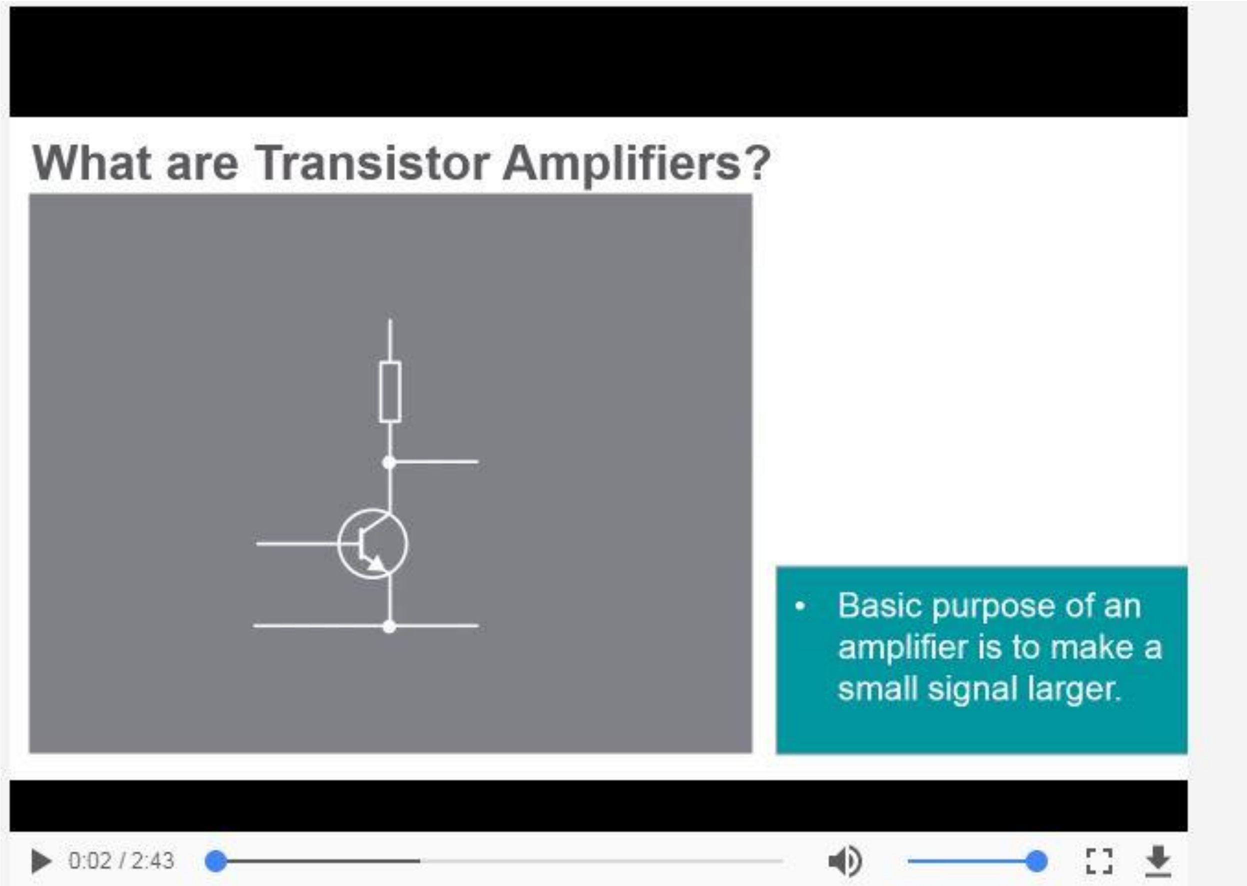

Figure 1-1 Video Screenshot. View the video here: youtu.be/ZCj_WE30oHQ

Video Summary

- An amplifier is designed to make smaller input signals larger by increasing the signal voltage.
- Transistor amplifiers are common to most electronics we use every day.
- There are three types of common amplifiers: common collectors, common base amplifier, and the common emitter amplifier.

What Are Transistor Amplifiers?

The main role of an amplifier is to take a relatively small input signal and make it larger by increasing the signal voltage. There are many different varieties of amplifiers. There are three standard configurations for Bipolar Junction Transistors (BJT): the common base amplifier, the common collector amplifier and the common emitter amplifier.

Why Are Transistor Amplifiers Important?

Transistor amplifiers are commonly found in a variety of electronics, and many applications would not exist without them.

How Can We Use Transistor Amplifiers?

The common collector amplifier, known as an emitter follower, is one of the three basic single-stage BJT topologies. This configuration is typically used as a voltage buffer. In this configuration, the base is used as the input, the emitter as the output, and the collector is common to both. The circuit's impedance particularities make it ideal to use it as a voltage buffer, where the circuit provides current gain instead of voltage gain. A small change to the input current results in a large change in output current. This configuration is often used in combination with a Zener diode to create a voltage regulator. You will build an emitter follower amplifier in *Section 2*.

The common base amplifier is another one of the three basic single-stage BJT amplifier topologies. This configuration is typically used as a current buffer or a voltage amplifier. This amplifier uses the emitter terminal as the input and the collector terminal as the output. The base is connected to ground or "common". This type of amplifier is occasionally used as a microphone preamp due to its unusually low input impedance. It is more popular in high frequency amplifiers in the VHF and UHF ranges, where its isolation between input and output help to prevent feedback and lead to higher stability.

The common emitter amplifier is the last of the three basic single-stage BJT amplifier topologies. This configuration is typically used as a voltage amplifier and this is the type of amplifier you will build in *Section 1*.

This type of amplifier uses the base terminal as the input and the collector as the output. The emitter is common to both: either tied to a group reference or a power supply rail. Common uses for these types of amplifiers are in radio frequency circuits and low-noise amplifiers.

Note: Each of the three types of single-stage BJT amplifiers have different circuits that they are best suited for. Very often, one type of amplifier is used in conjunction with another depending on the needs of the circuit.

Check Your Understanding

Note: The following questions are meant to help you self-assess your understanding so far. You can view the answer key for all "Check your Understanding" questions at the end of the lab.

1-1 What is the main role of an amplifier?

A. An amplifier's main role is to take a large input signal and make it smaller by decreasing the signal voltage.
B. An amplifier's main role is to take a small input signal and keep it unchanged.
C. An amplifier's main role is to take a small input signal and make it larger by increasing the signal voltage.
D. An amplifier's main role is to take a large input signal and keep it unchanged.

How Does a Transistor Amplifier Work?

When operating in the active region, a transistor can be used as an AC signal amplifier. Consider the following example of a common-emitter amplifier:

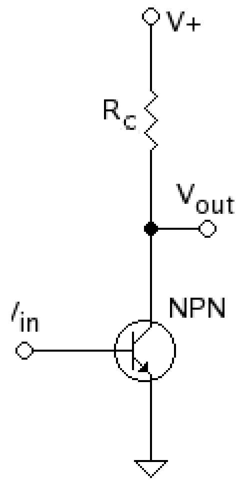

Figure 1-2

In the ***active region***, the transistor behaves in a linear manner, so the following formula applies:

$$I_C = \beta I_B$$

Equation 1-1

where β is the transistor's current gain.

It is necessary to polarize the transistor for it to amplify properly. A transistor's polarization consists in the application of a base voltage that ensures it will operate in the active region. A voltage divider connected to the power supply V_{CC} is usually used.

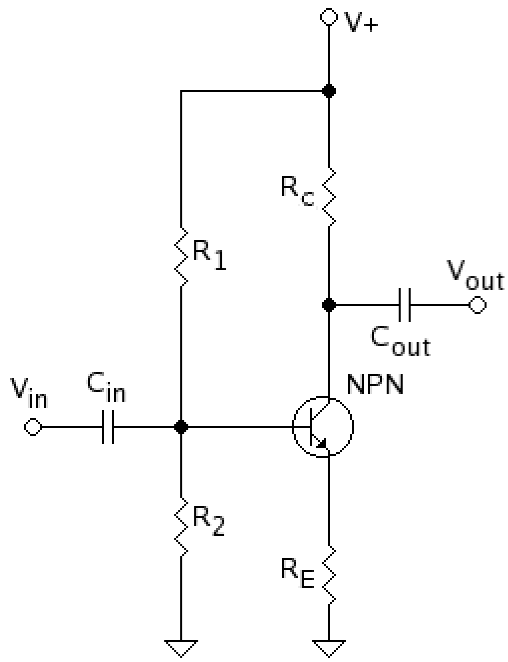

Figure 1-3

To find the base voltage, Thevenin's equivalent is applied to calculate Thevenin's voltage (V_{Th}) and resistance (R_{Th}).

In this case, V_{Th} is simply the divided voltage of V_{CC} between resistors R_1 and R_2:

$$V_{Th} = V_{CC} \frac{R_2}{R_1 + R_2}$$

Equation 1-2

R_{Th} for this circuit is the parallel resistance of R1 and R2:

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

Equation 1-3

You can calculate the emitter current I_E using the following expression:

$$I_E = \frac{V_{Th} - V_{BE}}{R_E + \frac{R_{Th}}{\beta}}$$

Equation 1-4

Taking $I_E \approx I_C$ we can say that I_E is βI_B. If you replace I_E in the formula above, and use 0.7 V as V_{BE}, you get the following expression:

$$I_B = \frac{V_{Th} - 0.7}{\beta R_E + R_{Th}}$$

Equation 1-5

All of these equations are used to design a circuit that works within the linear operation limits of an amplifier and allow us to select the proper resistor and capacitor values.

Voltage Gain

Voltage gain is the relationship between the output and input voltages of the amplifier:

$$A_v = \frac{v_{out}}{v_{in}}$$

Equation 1-6

For an amplifying circuit to work properly, it must operate in the linear region without saturating the transistor.

Gain is also expressed in dB:

$$A_v = 20 \log \frac{v_{out}}{v_{in}}$$

Equation 1-7

Note: It is important to remember that you are working with AC signals and that the amplifier gain changes based on the frequency. A Bode graph is used to find the gain variation.

1-2 What is true about voltage gain?

A. Voltage gain is independent of signal frequency.
B. Voltage gain is measured in volts.
C. Voltage gain is equal to V_{out}/V_{in}.

1.2 Simulate: Explore the Behavior of a Transistor Amplifier

In this section of the lab, you will simulate the behavior of a transistor amplifier in Multisim Live. You will also compare the simulated results with real world results later in the lab.

1. Click the link below to open the Multisim Live circuit.
2. https://www.multisim.com/content/LpZjfREW4Tir7MEbPeTY2Z/interactive-trannsistor-amplifiers-circuit/open
3. Examine the Multisim Live common-emitter transistor amplifier circuit.

Note: The AC signal source produces a 100 Hz, 0.2 Vpp (0.1 V Pk) sine wave.

4. Click **Run** to begin the interactive simulation.

5. Observe:

   - The *source sine wave* graphed in *green* by PR1
   - The *output sine wave* graphed in *blue* by PR2

Note: The amplitude of the output sine wave is much larger than that of the source sine wave.

6. Once the graph has been produced, click **Stop**.

1-3 What is the calculated gain of the simulated circuit?

Note: Voltage gain = $A_V = \frac{V_{output}}{V_{source}}$ =3/0.1=30

AC Sweep: Frequency Response

Multisim Live includes a tool to sweep through different signal frequencies and measure gain called AC Sweep Analysis. You will now use the AC Sweep tool to observe how gain in the simulated common-emitter circuit changes relative to input signal frequency.

1. Click the link below to open the Multisim Live Circuit
2. https://www.multisim.com/content/Lzs7FJchJbqEdgALhSXZu3/ac-sweep-transistor-amplifiers-circuit/open

- This AC Sweep has been configured to change the signal frequency provided by the AC voltage source, V1.
- Values start at 10 Hz and end at 5 kHz.
- A Bode plot is produced showing the circuit's frequency response, i.e. magnitude (dB) and phase shift (º) of the output signal (as compared to input signal) vs. the sweeping source frequency.

3. Click **Run** to begin the AC sweep simulation.
4. Move the cursor to measure the gain at 100 Hz.

1-4 What is the gain at 100 Hz?
A_V= 30

5. Click **Stop** when you are done.

1.3 Implement: Transistor Amplifiers

You will now expand what you know about transistor amplifiers by completing the following activity.

1. Use the NI ELVIS III to set up the circuit shown in the following illustration:

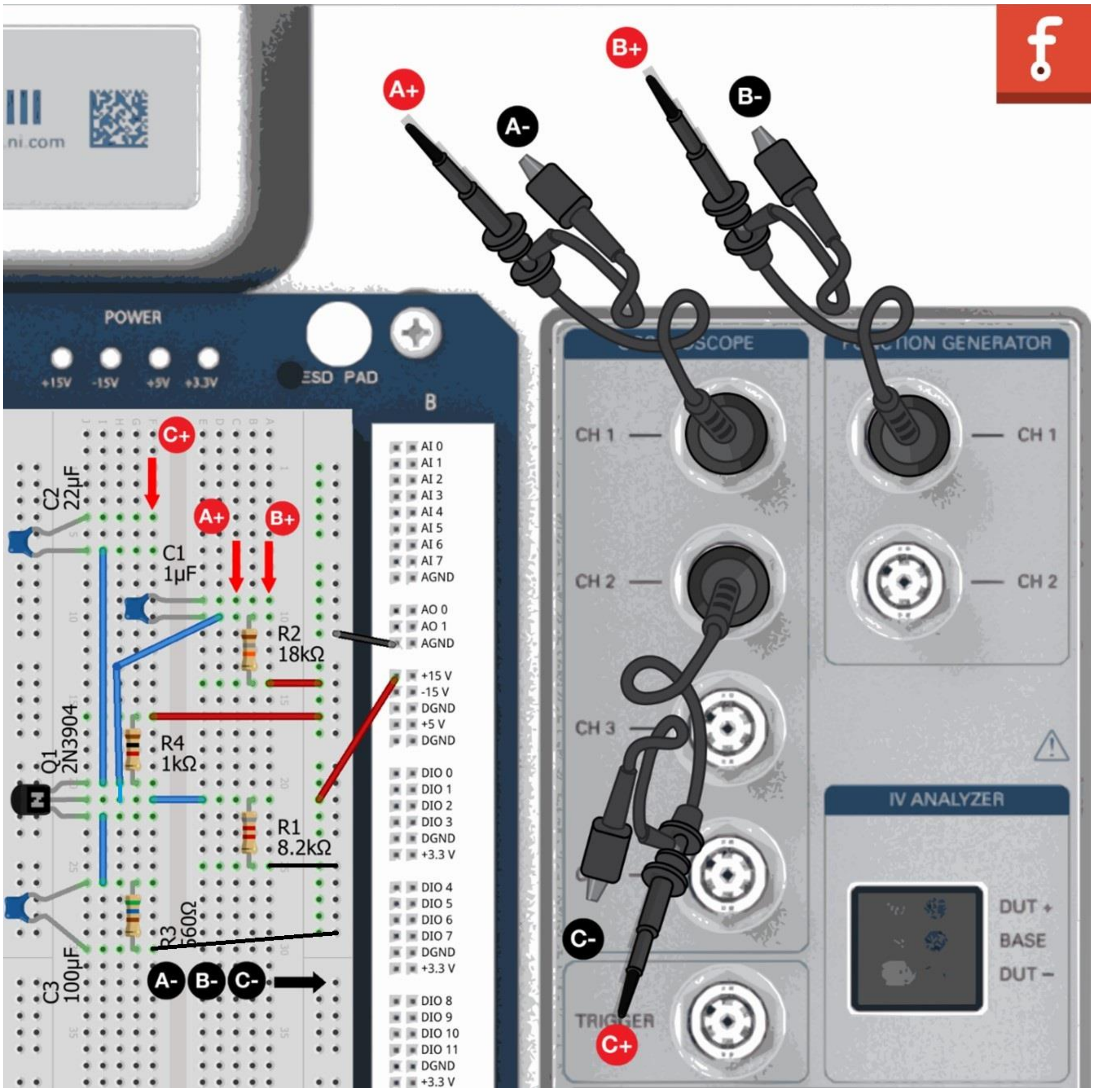

Figure 1-4 Circuit Set-up

2. From the Instruments tab of Measurements Live, open the following instruments:

   - Digital Multimeter (DMM)
   - Function Generator (FGen-Arb)
   - Oscilloscope

Note: For more information about accessing Measurements Live and launching instruments, visit http://www.ni.com/documentation/en/ni-elvis-iii/latest/getting-started/launching-soft-front-panels/.

3. Start the Function Generator with the following settings:

Table 1-1 Function Generator settings

Frequency	100 Hz
Amplitude	0.2 Vpp

1-5 Given a β of 100 and V_{BE} of 0.7, calculate I_B and I_E, and write the calculated results in Table 1-2 below.

After you have calculated your results, use the DMM to measure I_B and measure I_E. You can measure from the exposed metal leads or create a measurement point using a wire or header pin. Write the measured values in Table 1-2 below.

Table 1-2

Data	Calculated Value	Measured Value
IB	34.3µA	31µA
IE	3.433 mA	3.45mA

1-6 Do the measured values correspond to the calculates values? Why or why not?
Yes the measured value correspond to the calculated value as we have made a few rounding up in the calculation and also considered that IE is nearly equal to IC and so it mos tly correspond to value.

Determine Gain Using the Oscilloscope

1. Using your oscilloscope measure:

   - The function generator's signal at one channel
   - The amplifier's output on the other channel

2. Adjust the Time/Div and Volts per division to see both signals at once.

1-7 Calculate linear gain (Output Vpp/ Input Vpp). Calculate gain in dB and write the results below.

Oscilloscope Gain (dB) = Output Vpp/ Input Vpp=3/0.1=30

1.4 Exercise: Frequency Response of the Amplifier

1. Click **Stop** on the Function Generator and the Oscilloscope.
2. Open the Bode Analyzer.
3. Set the Bode Analyzer as indicated below:

Table 1-3 Bode Analyzer Settings

Stimulus Channel	
Start Frequency	10 Hz
Stop Frequency	5 kHz
Cursors	On

4. Perform the reading and analyze the results by pressing **Run**.

1-8 Use the cursors to find the gain at 100 Hz and write it down.
Bode Gain (dB) =29.7
1-9 Does the measured gain coincide with the gain found using the oscilloscope?
In this experiment the values do coincides as their will be a small errors while measuring.

1-10 How do these values compare to the values measured in simulation? Why might they be different?
Note: Keep in mind that simulated values are for linear gain while measured values are for dB gain.
The values are compared to close to each other's the small difference may be because of the internal resistance of wires and all other instruments

1.5 Analysis

These questions will help you review and interpret the concepts learned in this section of the lab.

1-11 Record any observations that you haven't noted above.
the one observation we did not notice is in the graph we can notice the phase difference of 90 degree and that can be confirmed in ac sweep and bode analyzer graphs

1-12 List the most important characteristics and applications of a transistor amplifier.
The most important characteristics of a transistor amplifier are depending on circuits it can help in increase the voltage or current or power of a signal. Transistor amplifiers are applicable for voltage regulators, microphone preamp, radio frequency.

1-13 Discuss how, in the previous steps, you measured the voltage gain of a transistor amplifier circuit.
To measure voltage gain use oscillocsope from measurement live and the set time per division to 2ms/div and run the oscilloscope with function generator and get the graph on oscilloscope. Now from the graph find the peak values and calculate the voltage gain.

1-14 What happens to the amplified signal from a transistor amplifier if we increase the input signal amplitude?
If we increase the input signal amplitude the amplified signal's amplitude will also increase proportionally.

Section 2: Emitter Follower Amplifiers

2.1 Simulate: Emitter Follower Amplifiers - Voltage Response

As you saw in *Section 1*, the main role of a transistor is to take a relatively small input signal and make it larger by increasing the signal voltage. You also looked at the three standard BJT amplifier configurations.

In this section, you will build a configuration of components that form a commonly-used transistor amplifier called the emitter follower or common collector. With this amplifier, the voltage gain is always slightly less than 1. This means the voltage will not increase but the current gain can be higher than 1. Emitter followers are commonly used to amplify the current of a signal, usually for a low impedance load such as a speaker.

In this activity, you will investigate the voltage response of an emitter follower circuit using Multisim Live.

1. Click the link below to open the Multisim Live circuit.
2. https://www.multisim.com/content/zGWUhynstWEfCHexu6GREc/emitter-follower-v/open

Observe the Voltage Response

1. Examine the emitter follower circuit, simulated with Multisim Live.

Note: The AC signal source produces a 10 kHz, 5 Vpp (2.5 V Pk) signal.

2. Click **Run**.

3. Measure the voltage response using the probes PR1 and PR2.

   - PR1 and PR2 should display essentially the same waveform. Hover your cursor over different points on the output curve and observe how the cursor shifts between the *blue input plot* and the *green output plot*.

Note: The output voltage has almost exactly the same phase and amplitude as the input voltage. This is the reason that this amplifier is called a follower. The voltage output follows the voltage wired to the base of the transistor

Observe the Current Response

1. You will now observe the current gain in an emitter follower amplifier.
2. Click the link below to open the Multisim Live circuit
3. https://www.multisim.com/content/B2DuX5YtreVZMtNVj6r2gW/emitter-follower-a/open

Record Peak-to-Peak Current Values

1. Click **Run**.
2. Measure the current response using the probes PR1 and PR2.

2-1 Use the table below to record the peak-to-peak current from Probe 1 and Probe 2.

Table 2-1

Probe	Peak-to-Peak Current (µA)

Probe 1 – Input Current	41.7-7.5=34.2
Probe 2 – Output Current	500-(-500)=1000

2-2 Calculate the current gain using the following equation:

$A_I = \frac{I_{out}}{I_{in}}$ = 1000/34.2=29.23

3. Click **Stop** when you are done.

Identify the Relationship between Resistors and Current Gain

Typically, the load of a circuit (RL, in this simulation) is not going to change. If we assume that the load in a real-life example of this circuit is an audio speaker, the speaker is not going to change its physical properties.

It would be more appropriate to change the resistance RE to examine how the current gain will respond.

1. Modify the resistance of RE by clicking its value and typing or using the slider to select a new one.

2-3 Calculate the circuit gain for a range of resistance values by:

- Modifying the resistance (RE)
- Running the simulation
- Making the measurement
- Stopping the simulation

Then, complete Table 2-2 below:

Table 2-2

Resistance of RE	Probe 1 – Input Current (µA)	Probe 2 – Output Current (µA)	Gain
1k	76-17.5=58.5	1000	17
2k	34.2	1000	29
3k	29.5-3.7=25.8	1000	38.7
5k	20-0.5=19.5	1000	51.2

Note: The relationship between RE and gain is non-linear. Because the load is going to be different for every application, the combination of resistors in a transistor amplifier is often customized for a specific application.

2.2 Conclusion

These questions will help you review and interpret the concepts learned in the lab.

2-4 Summarize any observations from the lab that haven't been addressed elsewhere.
In this lab we mostly focused on current and voltage gain but with this also the power of the signals get amplified and we also noticed that both the signals are not in same phase.

2-5 In your own words, talk about the purpose of an emitter follower amplifier.
Emitter follower amplifier is mostly used for voltage buffer that means it amplifies current instead of voltage. In this configuration the voltage(amplitude) of signals is unchanged.

2-6 Give a few application examples of a transistor amplifier.
The application examples of transistor amplifier are as follows:

- Current amplifier
- Voltage amplifier
- Power amplifier
- Voltage Buffer
- Audio amplifier
- Current Buffer