

Lab 4: Emitter Follower (Week of May 4th)

GOAL

To understand how to make voltage buffers with a bipolar junction transistor (BJT).

OBJECTIVES

To build, test, simulate, and understand emitter followers based on the following circuits:

- 1) Regulated DC power supply based on a zener follower
- 2) Speaker driver based on a Darlington pair.

GENERAL GUIDELINES

- 1) Each student must build, test, and demo all circuits.
- 2) During the lab session, students must share test stations.
- 3) Students are allowed (even encouraged) to help each other. Of course, Buma will be around to provide assistance as well. Use neat wiring for your circuits! A messy circuit will cost you 10 pts from your lab demo grade.
- 4) Do not worry if you need lots of help during the lab. Just make sure you know your stuff for the exams. **In addition to the written exams, there will be two laboratory exams where each student is tested on basic skills in circuit construction and simulation.**
- 5) Ask questions! The more questions you ask, the more you learn (assuming Buma can provide adequate answers ☺).
- 6) Build your circuits with neat wiring! Messy circuits will result in a 10 pt deduction from your lab demo grade.
- 7) Please keep your lab kit and work area organized.

PARTS AND MATERIALS

- Lab kit (breadboard, wire stripper, wire)
- Digital oscilloscope, scope probes, function generator, coaxial cable (with alligator clips), benchtop power supply
- Transistors: 2N3904 (1), 2N2222 (1), TIP31A (1)
- Resistors:

16 ohm	(brown/blue/black)	(1)
68 ohm	(blue/gray/black)	(1)
100 ohm	(brown/black/brown)	(3)
330 ohm	(orange/orange/brown)	(1)
33 kohm	(orange/orange/orange)	(1)
100 kohm	(brown/black/yellow)	(1)
- Capacitors: 10 uF (1), 470 uF (1)
- DC motor
- 16 ohm speaker

• PART 1: ZENER FOLLOWER

In this section you will build and test a 5V DC power supply using a 5.6V zener buffered by a 2N2222 transistor. The load is a DC motor, which is a fairly complicated electrical load involving coils, back emf, and torque. Some motor comments:

- A DC motor is typically specified by its rated voltage, current, and speed. For example, your motor is rated at 12V, 74 mA, and 120 rpm.
- For the same applied voltage, a motor draws more current under heavier mechanical load. A sufficiently high load causes the motor to stall. This “stall current” is typically several times higher than the rated current. Your motor’s stall current is around 200 mA.
- Starting a DC motor requires MORE current (roughly equal to the stall current) than maintaining steady operation. This means the motor driver must be able to provide at least 200 mA to start your motor.



• Step 1a: Build the zener follower shown in Fig. 1.

- The 1N4734A zener is the orange (with black band) component.
- The “tab” on the 2N2222 transistor is the emitter (see datasheet on course website).
- The +9V comes from the breadboard’s RED terminal.
- The GND comes from the breadboard’s GREEN terminal.
- Properly wire up the benchtop supply!
 - The (+) output should go to your board’s RED terminal.
 - The (-) output should go to your board’s GREEN terminal.
 - Use a wire to connect the power supply’s black and green terminals to each other.
- The motor has two wires:
 - The red wire is connected to the transistor’s emitter.
 - The black wire is connected to ground.
- When you turn on the power supply, the motor should turn!
- After about a minute, the transistor should feel pretty warm (this is normal).

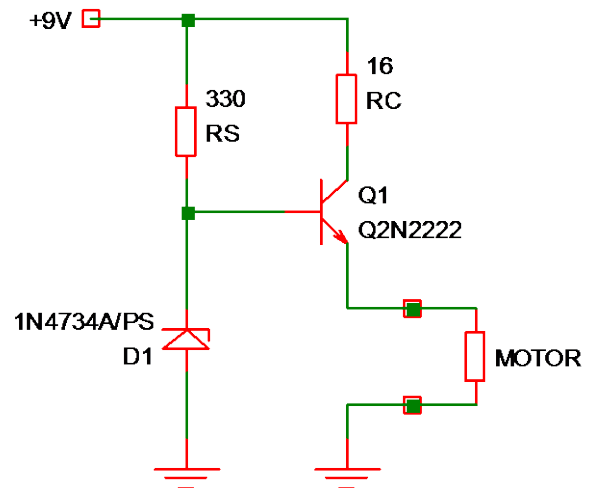


Fig. 1: Zener follower using a 2N2222 transistor to drive a DC motor with 5V.

• Step 1b: Configure the scope.

- Press the “Default” button on the scope. This resets the scope.
- Make sure your scope probe is set to 10X.

- Step 1c: Make some voltage measurements while the motor is running.
 - Use CH1 of the scope to measure V_B , V_C , and V_E of the transistor.
 - Set the vertical scale to 2V/div and adjust the zero position to see the voltage.
 - Use “Measure >> Mean” to measure DC voltages.
 - Record these values for your report.
 - No scope snapshots are necessary. ☺
 - Based on V_B , is your 5.6V zener working properly?
 - Compute the zener supply current I_S (should be around 10 mA).
 - Based on V_C , determine the collector current I_C (should be around 60 mA).
 - Assuming $\alpha = 0.99$, determine the emitter current I_E , which is the same as the load current I_{LOAD} .

NOTE: You should find that I_{LOAD} is roughly 60 mA, which is much greater than the zener supply current I_S !
Zener drop out is avoided due to the “buffering action” of the emitter follower.

- The transistor power dissipation is approximately $P = I_E V_{CE}$. Compute this value.

NOTE: The power dissipation should be roughly 180 mW, which is enough to make the transistor pretty warm!

- Step 1d: Directly attach the motor to the zener.
 - Attach the scope probe to the zener.
 - Remove the motor’s red wire from the transistor emitter.
 - Connect the motor’s red wire to the zener. The motor should STOP running!
 - Measure the zener voltage. It should be less than 1V, which obviously means the zener has dropped out!

NOTE: Starting the motor requires more current than the zener can provide!

DO NOT DISASSEMBLE THIS CIRCUIT!

(see next page for Part 2)

• PART 2: AUDIO SPEAKER

As we had discussed in lecture, an audio speaker is a low impedance load (16 ohm for this lab). Directly attaching a speaker to a common emitter amplifier will cause the voltage gain to take a nose dive. Why? Common emitter amplifiers typically have an output impedance R_{OUT} of a few kohm, which is much larger than a speaker impedance. This is a highly undesirable situation ...



- Step 2a: Build the circuit shown in Fig. 2.
 - This mimics the situation where a high impedance source (e.g. common emitter) is driving a low impedance load.
 - Set the Agilent function generator to “High Z” and a 1 V_{pp} sine wave at 880 Hz.
 - The 1 kohm resistor, in series with the 50 ohm output impedance of the function generator, produces an overall source impedance $R_S = 1050$ ohm.
 - The speaker is the load.

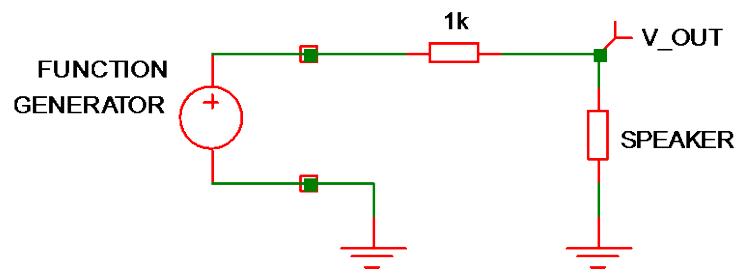


Fig. 2: Driving a low impedance load with a high impedance source.

- Step 2b: Measure the output voltage.
 - Based on your prelab simulation, adjust the scope’s vertical and horizontal settings to display a few cycles of the output voltage.
 - Measure the peak-to-peak value of V_{OUT} .
 - Compute the gain V_{OUT}/V_S . NOTE: V_S is the 1 V_{pp} sine wave at 880 Hz.
 - Use “swave” to record a snapshot of V_{OUT} for your lab report.

YOU CAN DISASSEMBLE THIS CIRCUIT (SURPRISE!)

(see next page for Part 3)

• PART 3: SPEAKER DRIVER

The extra high β of a Darlington pair allows a tiny base current to control a large emitter current. This means the low speaker impedance (16 ohm) looks like a much larger impedance to the source (over 10 kohm!). Although circuit analysis is easiest when a transistor is biased with a stiff voltage divider, a “firm” divider is more useful. A firm divider is defined by $R1/R2 < 0.1 (\beta+1)R_E$. The factor of 10 is important, since it raises the input impedance R_{IN} by a factor of 10.

- Step 3a: Build the Darlington follower shown in Fig. 3.

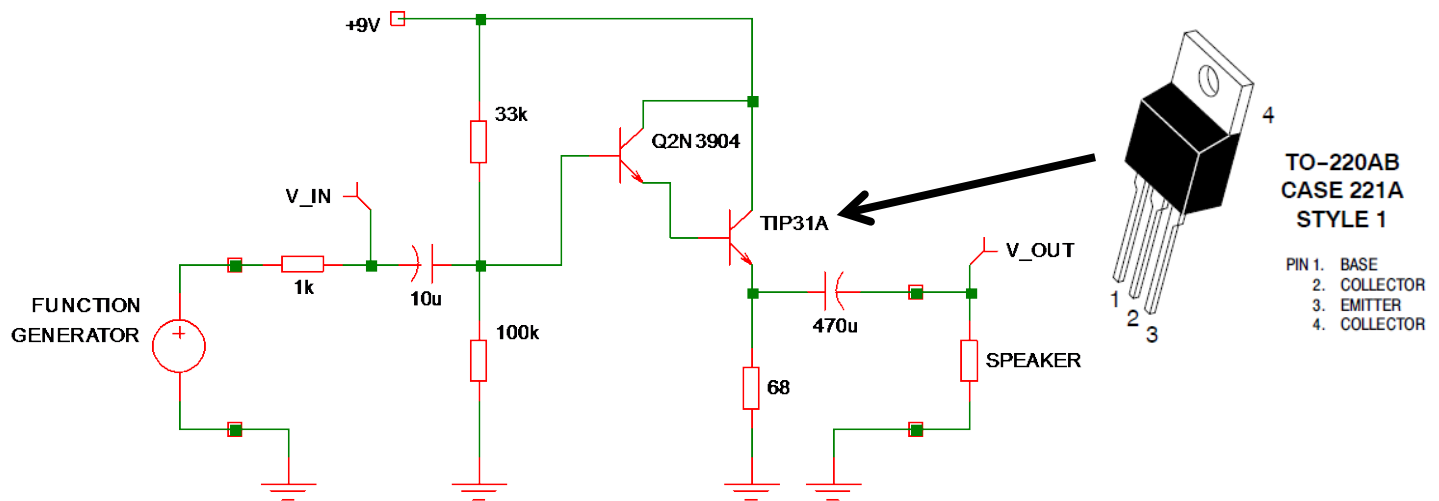


Fig. 3: Darlington follower using a 2N3904 with a TIP31A power transistor. The TIP 31A pin diagram is shown on the right.

- The function generator settings are the same as in the previous task.
 - The TIP31 power transistor is the much bigger case (TO-220AB style).
 - Your circuit works when you can the speaker emits a well-defined pitch (A5 = one octave above Concert A).
- Step 3b: Make some voltage measurements.
 - Use the digital multimeter to record the base voltage of the 2N3904 (should be about 6.5V).
 - Use the digital multimeter to record the emitter voltage of the TIP31A (should be roughly 5.1V).
 - Use the scope to display a few cycles of V_{OUT} .
 - Measure the peak-to-peak value of V_{OUT} .
 - Use “swave” to record a snapshot of V_{OUT} for your lab report.
 - Now use the scope to display a few cycles of V_{IN} .
 - Measure the peak-to-peak value of V_{IN} .
 - Use “swave” to record a snapshot of V_{IN} for your lab report.
 - Compute the voltage gain V_{OUT}/V_{IN} and signal gain V_{OUT}/V_S .
 - Based on your measured gains, compute the input impedance R_{IN} .

(see next page for Part 4)

PART 4: CIRCUIT DEMO

Buma will reset the scope and function generator.

- Motor Driver (10 pts of lab demo grade)
 - Plug the motor into the emitter of the 2N2222 transistor.
 - The motor should be running.
 - Adjust the scope to show the motor voltage.

- Speaker Driver (20 pts of lab demo grade)
 - Function generator settings:
 - High Z output, $1V_{PP}$ sine wave at 880 Hz
 - CH1 of the scope displays a few cycles of the speaker voltage.
 - Measure the peak-to-peak voltage of the speaker voltage.

NOTE: When you demo your circuits, Buma will ask you to operate the scope WITHOUT USING THE AUTOSCALE BUTTON. Buma will deduct 700 pts from your lab grade if you press Autoscale!

(End of Lab 4)