StudentZone— ADALM2000 Activity: The Emitter Follower (BJT)

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Objective

The objective of this activity is to investigate the simple NPN emitter follower amplifier, also sometimes referred to as the common collector configuration.

Materials

▶ ADALM2000 Active Learning Module
▶ Solderless breadboard
▶ Jumper wires
▶ One 2.2 kΩ resistor (R_L)
▶ One small signal NPN transistor (2N3904 for Q1)

Directions

The breadboard connections are shown in Figure 2. The output of the arbitrary waveform generator, W1, is connected to the base terminal of Q1. Scope Input 1+ (single ended) is also connected to the W1 output. The collector terminal is connected to the positive (Vp) supply. The emitter terminal is connected to both the 2.2 kΩ load resistor and Scope Input 2+ (single ended). The other end of the load resistor is connected to the negative (Vn) supply. To measure the input to output error, Channel 2 of the scope can be used differentially by connecting 2+ to the base of Q1 and 2– to the emitter.
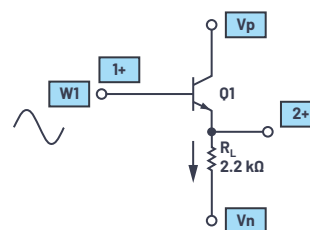

Figure 1. Emitter follower.

Hardware Setup

The waveform generator should be configured for a 1 kHz sine wave with 4 V amplitude peak-to-peak and 0 offset. The single-ended input of Scope Channel 2 (2+) is used to measure the voltage at the emitter. The scope configured with Channel 1+ is connected to display the AWG generator output. When measuring the input to output error, Channel 2 of the scope should be connected to display the 2+ and 2– differential.
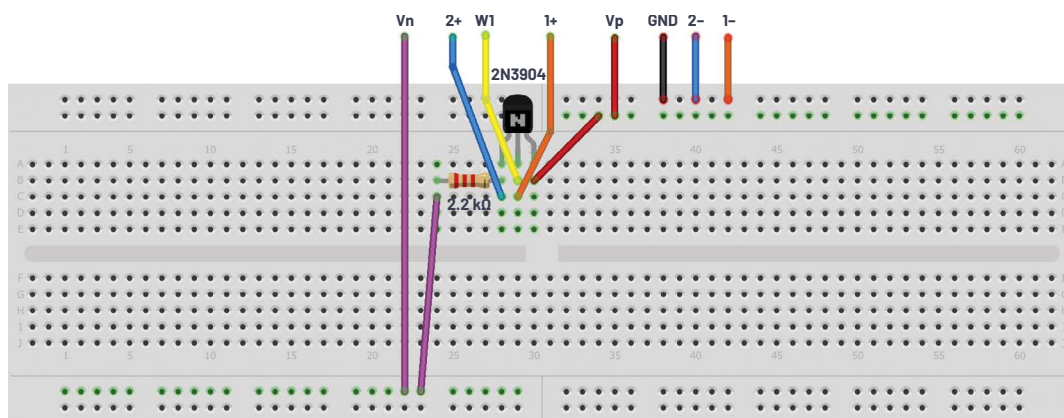

Figure 2. Emitter follower breadboard circuit.

Procedure

Configure the oscilloscope instrument to capture several periods of the two signals being measured. A plot example is presented in Figure 3.
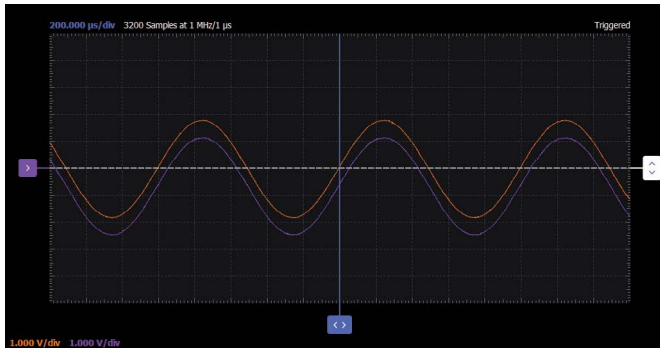

Figure 3. Emitter follower waveforms.

The incremental gain (V_{OUT}/V_{IN}) of the emitter follower should ideally be 1 but will always be slightly less than 1. The gain is generally given by the following equation:

$$A = \frac{R_L}{R_L + r_e} \tag{1}$$

From the equation we can see that in order to obtain a gain close to 1 we can either increase R_L or decrease r_e. We also know that r_e is a function of I_E and that as I_E increases, r_e decreases. Also, from the circuit we can see that I_E is related to R_L and that as R_L increases, I_E decreases. These two effects work counter to each other in the simple resistive loaded emitter follower. Thus, to optimize the gain of the follower we need to explore ways to either decrease r_e or increase R_L without affecting the other. Looking at the follower in another way, because of the inherent DC shift due to the transistor's V_{BE}, the difference between input and output should be constant over the intended swing. Due to the simple resistive load, R_L, the emitter current, I_E, increases and decreases as the output swings up and down. We know that V_{BE} is an exponential function of I_E and will change approximately 18 mV (at room temperature) for a factor of 2 change in I_E. In this +2 V to –2 V swing example, the minimum $I_E = 2$ V/2.2 kΩ or 0.91 mA and the maximum $I_E = 6$ V/2.2 kΩ or 2.7 mA. This results in a 28 mV change in V_{BE}. This observation leads us to the first possible improvement in the emitter follower. To fix the amplifier transistor emitter current, the current mirror from the "ADALM2000 Activity: BJT Current Mirror" is now substituted for the emitter load resistor. A current mirror will sink a more or less constant current over a wide range of voltages. This more or less constant current flowing in the transistor will result in a fairly constant V_{BE}. Viewed another way, the very high output resistance of the current source has effectively increased R_L while r_e remains at a low value set by the current.

Improved Emitter Follower

Additional Materials

▶ One 3.2 kΩ resistor (use a 1 kΩ in series with a 2.2 kΩ)

▶ One small signal NPN transistor (2N3904 for Q1)

▶ Two small signal NPN transistors (SSM2212 for Q2 and Q3) selected for best V_{BE} matching

Directions

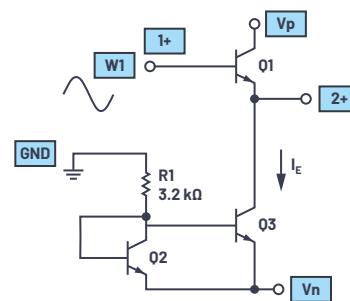The breadboard connections are shown in Figure 4 and Figure 5.

Figure 4. Improved emitter follower.

Hardware Setup

The waveform generator should be configured for a 100 Hz triangle wave with 3 V amplitude peak-to-peak and 0 offset. The single-ended input of Scope Channel 2 (2+) is used to measure the voltage at the emitter of Q1. The scope configured with Channel 1+ is connected to display the AWG generator output. When measuring the input to output error, Channel 2 of the scope should be connected to display the 2+ and 2– differential.
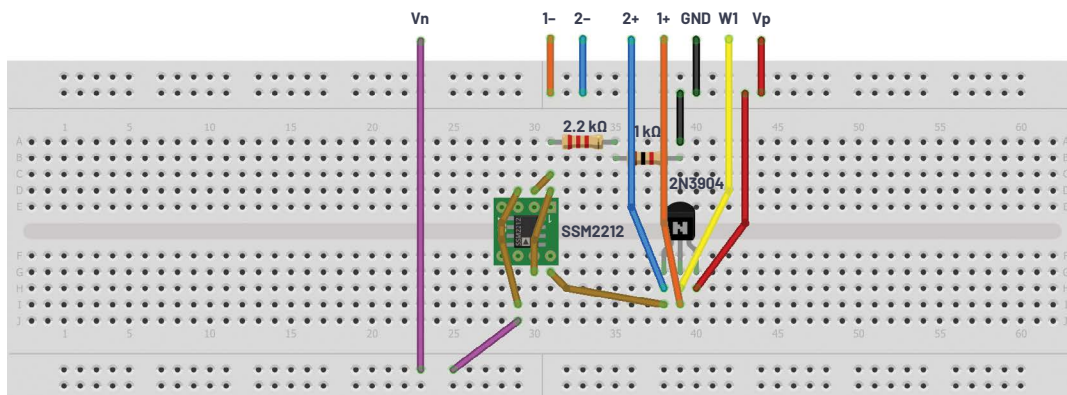

Figure 5. Improved emitter follower breadboard circuit.

Procedure

Configure the oscilloscope instrument to capture several periods of the two signals being measured. A plot example is presented in Figure 6.
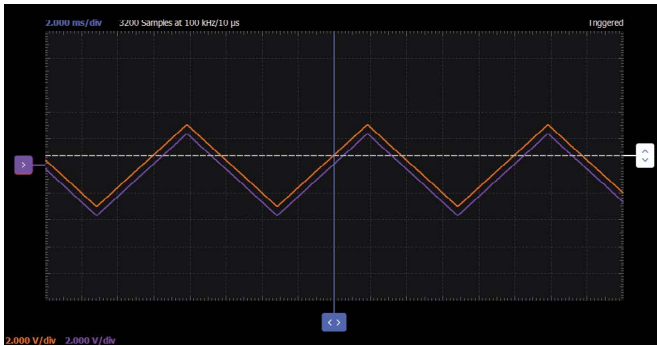

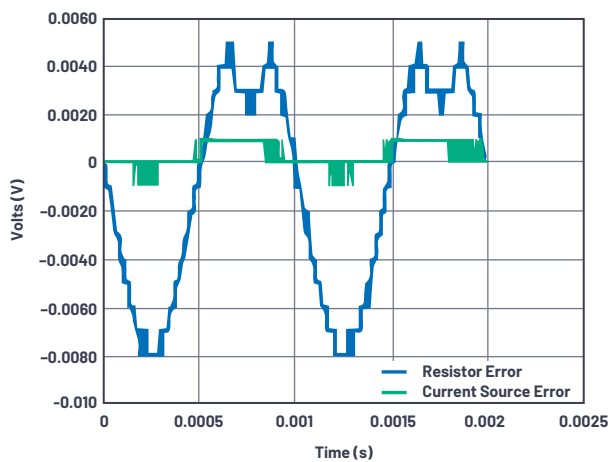*Figure 6. Improved emitter follower waveforms.*

Figure 7. An Excel plot example of input vs. output error for resistor and current source load.

Low Offset Follower

The follower circuit we have investigated so far has a built-in offset of $-V_{BE}$. The circuit shown next uses the V_{BE} shift up of a PNP emitter follower to partially cancel the V_{BE} shift down of an NPN emitter follower.
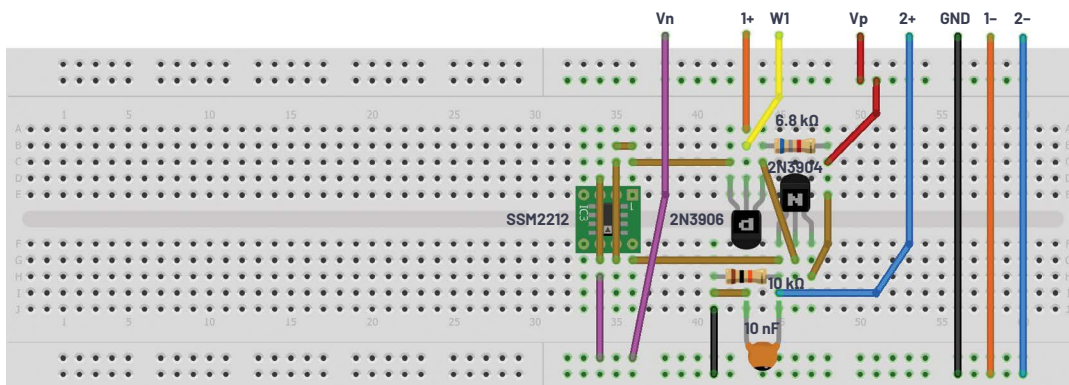
Materials

▶ One 6.8 kΩ resistor
▶ One 10 kΩ resistor
▶ One 0.01 µF capacitor
▶ One small signal PNP transistor (2N3906 for Q1)
▶ Three small signal NPN transistors (2N3904 or SSM2212 for Q2, Q3, and Q4)

Directions

The breadboard connections are shown in Figure 8 and Figure 9. The output of the function generator is connected to the base terminal of PNP transistor Q1. The collector terminal of Q1 is connected to diode connected NPN Q3, which is the input of a current mirror. The emitter terminal is connected to both resistor R1 and the base terminal of NPN transistor Q2. Scope Input 2+ is connected to both the emitter of Q2 and the collector of Q4. The emitters of both Q3 and Q4 are connected to the negative (Vn) supply. For best transistor matching, use the SSM2212 matched NPN pair for Q3 and Q4.
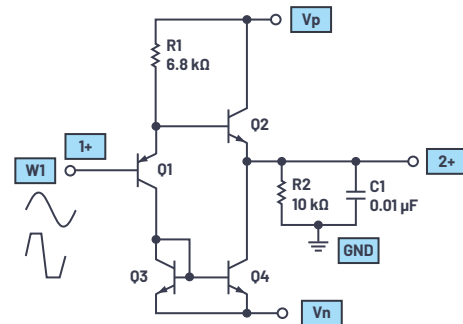

Figure 8. Low offset follower.

Hardware Setup

The waveform generator should be configured for a 1 kHz sine wave with 4 V amplitude peak-to-peak with the offset set equal to 0. Scope Input Channel 2 is set to 500 mV/div.

Figure 9. Low offset follower breadboard circuit.

Procedure

Configure the oscilloscope instrument to capture several periods of the two signals being measured. A plot example is presented in Figure 10.
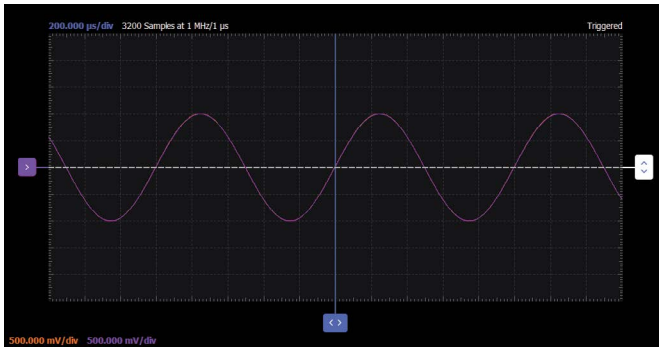

Figure 10. Low offset follower waveforms.

A problem can be identified when the simple emitter follower drives a capacitive load. The rise time of the output can be relatively fast as the emitter current is limited only by beta times the base current that can be supplied by the signal source driving the base. The fall time can be much slower and is limited by either the emitter resistor or current source.

Balanced Slew Rate Follower

Materials

- Two 2.2 kΩ resistors
- One 10 kΩ resistor
- One 0.01 μF capacitor
- Three small signal PNP transistors (2N3906 or SSM2220 for Q2, Q3, and Q4)
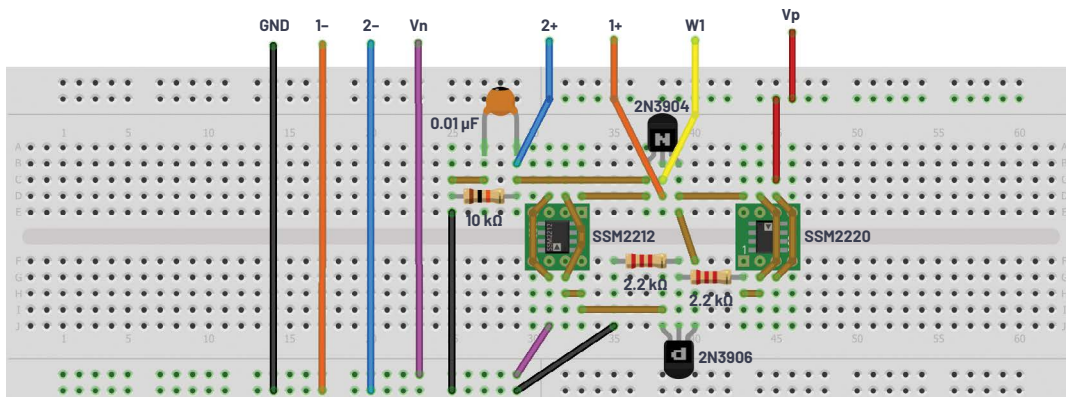- Three small signal NPN transistors (2N3904 or SSM2212 for Q1, Q5, and Q6)

Directions

The circuit shown in Figure 11 uses feedback to adjust the current in the emitter follower as the current in the load changes. The current to pull the output negative can be as much as N (the gain of the NPN mirror) times the current in PNP Q3. For best transistor matching, use the SSM2220 matched PNP pair for Q3 and Q4 and the SSM2212 matched NPN pair for Q5 and Q6 (NPN mirror gain will be 1. Add a second SSM2212 in parallel with Q5 to increase the mirror gain).
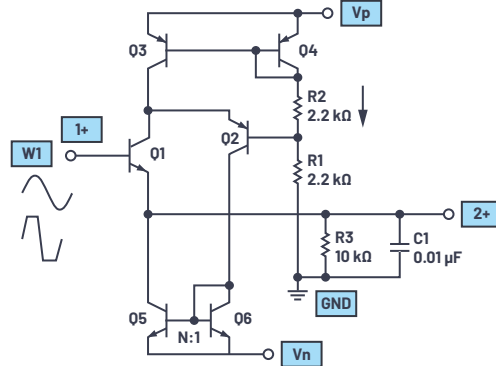

Figure 11. Balanced slew rate follower.

Hardware Setup

The waveform generator should be configured for a 1 kHz sine wave with 4 V amplitude peak-to-peak with the offset set equal to 0. Scope Input Channel 2 is set to 1 V/div.

Figure 12. Balanced slew rate follower breadboard circuit.

Procedure

Configure the oscilloscope instrument to capture several periods of the two signals being measured. A plot example is presented in Figure 13.
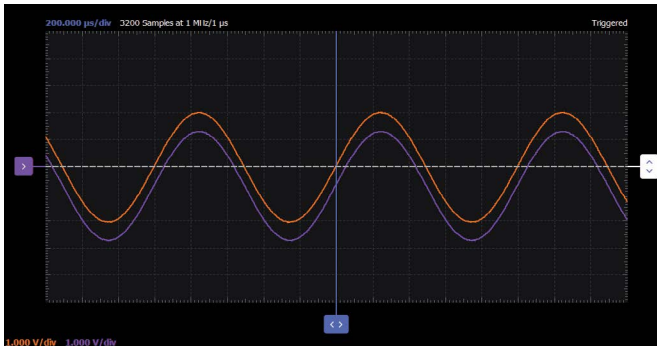

Figure 13. Balanced slew rate follower waveforms.

An alternate approach to improving the emitter follower is to reduce the effective r_e through negative feedback. Reducing r_e can be addressed by adding a second transistor to increase the negative feedback factor by increasing the open-loop gain. The single transistor is replaced by a pair with 100% voltage feedback to the emitter of the first transistor. This is often referred to as a complementary feedback pair. The value of R2 is crucial to good linearity, as it sets the I_c of transistor Q1, and also determines its collector loading.

Complementary Feedback Pair Emitter Follower

Materials

▶ One 2.2 kΩ resistor
▶ One 10 kΩ resistor
▶ One small signal NPN transistor (2N3904 for Q1)
▶ One small signal PNP transistor (2N3906 for Q2)

Directions

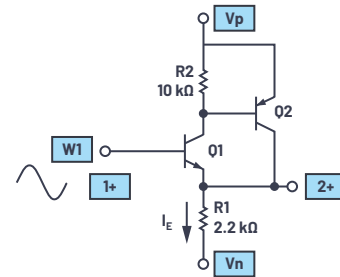The breadboard connections are shown in Figure 14 and Figure 15.

Figure 14. Complementary feedback pair emitter follower.

Hardware Setup

The waveform generator should be configured for a 1 kHz sine wave with 2 V amplitude peak-to-peak with the offset set equal to 0. Scope Input Channel 2 is set to 1 V/div.

Procedure

Configure the oscilloscope instrument to capture several periods of the two signals being measured. A plot example is presented in Figure 16.
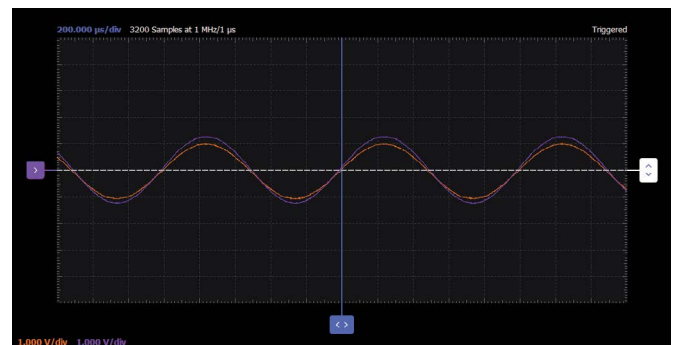

Figure 16. Complementary feedback pair emitter follower waveforms.

Question:

Can you name three specific characteristics of the emitter follower circuits?

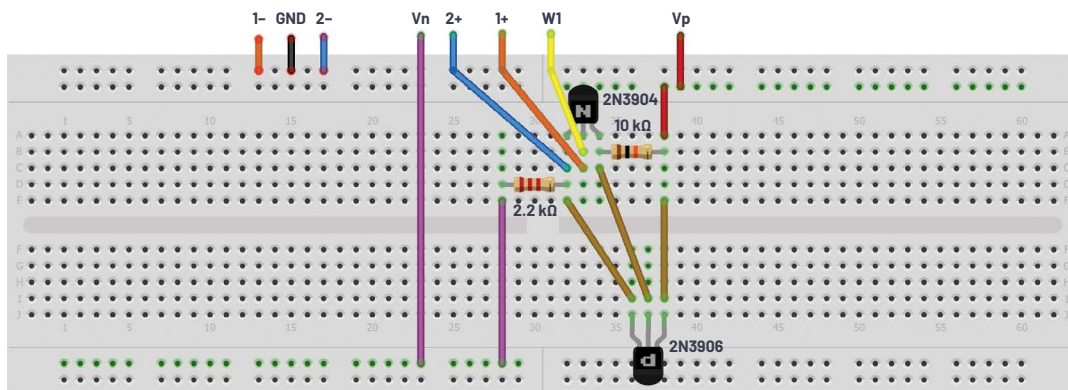You can find the answer at the StudentZone blog.

Figure 15. Complementary feedback pair emitter follower breadboard circuit.

About the Author

Doug Mercer received his B.S.E.E. degree from Rensselaer Polytechnic Institute (RPI) in 1977. Since joining Analog Devices in 1977, he has contributed directly or indirectly to more than 30 data converter products and he holds 13 patents. He was appointed to the position of ADI Fellow in 1995. In 2009, he transitioned from full-time work and has continued consulting at ADI as a Fellow Emeritus contributing to the Active Learning Program. In 2016 he was named Engineer in Residence within the ECSE department at RPI. He can be reached at doug.mercer@analog.com.

About the Author

Antoniu Miclaus is a system applications engineer at Analog Devices, where he works on ADI academic programs, as well as embedded software for Circuits from the Lab®, QA automation, and process management. He started working at Analog Devices in February 2017 in Cluj-Napoca, Romania. He is currently an M.Sc. student in the software engineering master's program at Babes-Bolyai University and he has a B.Eng. in electronics and telecommunications from Technical University of Cluj-Napoca. He can be reached at antoniu.miclaus@analog.com.