# ARRL Periodicals Archive – Search Results
## A membership benefit of ARRL and the ARRL Technical Information Service

**ARRL Members:** You may print a copy for personal use. Any other use of the information requires permission (see Copyright/Reprint Notice below).

**Need a higher quality reprint or scan?** Some of the scans contained within the periodical archive were produced with older imaging technology. If you require a higher quality reprint or scan, please contact the ARRL Technical Information Service for assistance. Photocopies are $3 for ARRL members, $5 for nonmembers. For members, TIS can send the photocopies immediately and include an invoice. Nonmembers must prepay. Details are available at www.arrl.org/tis or email photocopy@arrl.org.

**QST on CD-ROM**: Annual CD-ROMs are available for recent publication years. For details and ordering information, visit www.arrl.org/qst.

**Non-Members:** Get access to the ARRL Periodicals Archive when you join ARRL today at www.arrl.org/join. For a complete list of membership benefits, visit www.arrl.org/benefits.



**QST Issue:** Mar 2003
**Title:** Experiment #2--The Emitter-Follower Amplifier
**Author:** H. Ward Silver, N0AX

Click Here to Report a Problem with this File

# Experiment #2—The Emitter-Follower Amplifier

Our second experiment will again focus on a transistor amplifier—the emitter-follower. This handy amplifier doesn't offer much in the way of voltage gain (it has none), but it provides buffering or isolation for sensitive amplifiers and muscle to output circuits for driving loads like headphones or coaxial cables. It has relatively high input impedance with low output impedance and good *power* gain, as we'll see later.

## Background

The emitter-follower (EF) amplifier configuration, also called the common collector, is found in applications where an amplifier must have both high input impedance (to avoid loading a sensitive or low-power circuit) and low output impedance (to drive a heavy load).

The EF provides no voltage gain; in fact, its voltage gain is always less than 1. The collector of the transistor is connected directly to the power supply, without a resistor and the output is taken across the emitter resistor. There is no 180° phase shift as seen in the common-emitter configuration of experiment #1—the output signal follows the input signal with 0° phase shift. This is the origin of the name—the emitter voltage "follows" the input signal voltage.

Why does the EF configuration have a high input impedance? Let's start by looking directly into the base of the transistor at base voltage, $V_b$ and base current, $I_b$. Remember that $\beta$ is the transistor current gain, or the ratio of collector to the base current.

$\beta = I_c / I_b$ so $I_c = \beta I_b$

$I_e = I_b + I_c$

Therefore, $I_e = I_b + \beta I_b = I_b (\beta + 1)$

$$V_b = V_{be} + I_e R_e = V_{be} + [I_b (\beta + 1)] R_e \quad [1]$$

The base impedance, $Z_b$, is the ratio of the change ($\Delta$) in $V_b$ to the resulting change in $I_b$. Biasing will keep the transistor current "turned on" so $V_{be}$ doesn't change much and can be treated as constant. So, small changes in $V_b$ due to the input signal will cause a corresponding change in $I_b$.

$$\Delta V_b \approx \Delta I_b \ (\beta + 1) R_e \text{ and...} \quad [2]$$

$$Z_b = \Delta V_b / \Delta I_b \approx (\beta + 1) R_e \quad [3]$$

This equation shows that the small changes in $I_b$ amplified by $\beta$ effectively also multiplies $R_e$ by the same amount. The base impedance (not counting the biasing network R1 and R2) is essentially the current gain, $\beta$, multiplied by the emitter resistor, $R_e$.

The input source doesn't just drive the base, of course; it also has to drive the combination of R1 and R2, the biasing resistors. From an ac point of view, both R1 and R2 can be considered as connected to "ac ground" (the power supply supplies a constant dc voltage; it should present a low impedance, which is effectively an ac short) and they can be treated as if they were connected in parallel. When R1 // R2 are considered along with the transistor base impedance, $Z_b$, the impedance the input signal source "sees" is:

$$Z_{in} = R1 \,//\, R2 \,//\, Z_b = 1 / [1/R1 + 1/R2 + 1/R_e (\beta + 1)] \quad [4]$$

Let's figure the output impedance, $Z_{out}$, too. Looking back into the connection between the transistor emitter and $R_e$, $Z_{out}$ is made up of three components. The first is $R_e$, which is connected to ground. The second, $Z_e$, is the series combination of the transistor's internal emitter impedance, $r_e$, (note the lower-case "r" which distinguishes it from the external resistance, $R_e$) and the combined impedance of the signal source, $R_s$, and the biasing resistors R1 and R2. Using the same explanation of current gain's effect on input impedance—in reverse this time—the impedance presented at the emitter, $Z_e$, is:

$$Z_e = (R_s \,//\, R1 \,//\, R2) / (\beta + 1) + r_e \quad [5]$$

From the physics of silicon transistors, at room temperature, $r_e = 25 \text{ mV} / I_{eq}$, where $I_{eq} \approx I_{cq}$ in mA, so, for most designs, $r_e$ will be much less than 50 Ω. Similarly, in our experiment, R1 and R2 are likely to be much higher than $R_s$, the signal source impedance—which is usually less than 1 kΩ. When $R_e$ and $Z_e$ are combined, the output impedance of the circuit becomes:

$$Z_{out} = Z_e \,//\, R_e \quad [6]$$

We see, therefore, that our emitter follower has a relatively high input impedance and a low output impedance, making it ideal for driving low-impedance loads.

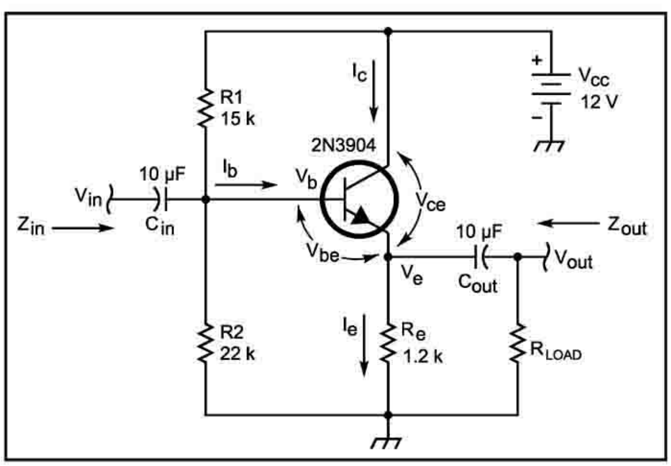


**Figure 1—The common emitter circuit. This is a current or power amplifier, offering high input impedance and low output impedance. It is useful for driving low impedance loads, buffering and isolation.**

## Terms to Learn

Input (Output) Impedance—the equivalent ac impedance looking into the input (output) of a circuit.

Cascade—two circuits connected such that the output of the first is connected to the input of the second.

Power Gain—the ratio of output power to input power.

Buffer—an amplifier used to provide isolation between two circuits.

//—in parallel with.

## Key Equations

$$I_c \approx I_e, \ I_c = I_b \beta \quad [7]$$

$$V_{cc} \approx V_{ce} + I_c R_e \quad [8]$$

$$V_b \approx V_{be} + I_c R_e \quad [9]$$

H. Ward Silver, NØAX ♦ 22916 107th Ave SW, Vashon, WA 98070 ♦ n0ax@arrl.org

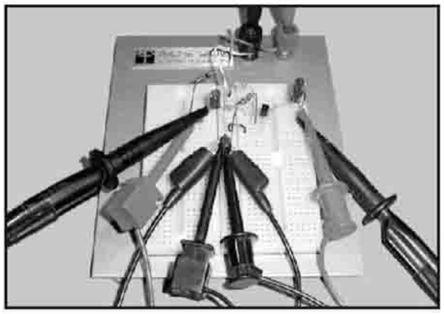

**Figure 2—This photo shows the construction of the EF (emitter follower) circuit. Note that the input connection is on the right and the output connection is on the left. This keeps the input and output leads away from each other and helps prevent oscillation. All ground leads (black clips) are connected together at a single point.**

**Figure 3—An oscillating circuit—with a 1 kHz sine wave input, both the input (top) and output (bottom) signals show significant oscillation at more than 1 MHz. Experiment with lead placement and circuit component placement to learn what causes and prevents oscillation.**

## Designing the Amplifier

Choose the circuit's operating requirements:

$V_{cc}$ = 12 V *(our power supply voltage)*

Q-point of $I_{cq}$ = 5 mA and $V_{ceq}$ = 6 V *(rule of thumb, ½ $V_{cc}$ allows the maximum output voltage swing)*

Assume the transistor's $\beta$ is 150 and base-to-emitter voltage, $V_{be}$ = 0.7 V

1. $R_e = (V_{cc} - V_{ceq}) / I_{cq}$ = 1.2 kΩ *(Eq 8)*
2. Base current, $I_b = I_{cq} / \beta$ = 33 µA *(Eq 7)*
3. Current through R1 and R2 = 10 $I_b$ = 330 µA *(a rule of thumb simplifying calculations and keeping $I_b$ stable with a "stiff" bias supply).*
4. Voltage across R2 = $V_{be} + I_c R_e$ = 0.7 + 5 mA (1.2 kΩ) = 6.7 V *(Eq 9)*

R2 = 6.7 V / 330 µA = 20.3 kΩ (use 22 kΩ). *(Ohm's Law)*

5. Voltage across R1 = $V_{cc}$ – 6.7 V = 5.3 V. *(Voltage divider)*

R1 = 5.3 V / 330 µA = 16.06 kΩ (use 15 kΩ). *(Ohm's Law)*

$Z_{in} = 1 / [1/R1 + 1/R2 + 1/R_e (\beta + 1)] \approx 8.5$ kΩ *(Eq 4)*

Assuming $R_s$ = 50 Ω, $Z_{out} \approx r_e // R_e$ = 5 Ω // 1.2 kΩ ≈ 4.99 Ω *(Eq 5 and 6)*

That's where our emitter follower shines!

## Testing the Amplifier

Connect the power supply after double-checking all connections, especially the transistor leads. Figure 2 shows the breadboard circuit.

1. Use a VOM to measure the dc voltage from collector to emitter (it should be about 6 V), from base to emitter (0.6 – 0.7 V) and from emitter to ground (6 V). Replace R1 with a 100 kΩ potentiometer, set to 15 kΩ. Start with a value of 10 kΩ for $R_{load}$.

2. Set the signal generator to output a 1 kHz sine wave at 1 $V_{p-p}$, then connect it to $C_{in}$. You should see a sine wave at the output of $C_{out}$ with an amplitude of about 1 $V_{p-p}$ and in phase with the input. (A VOM measuring ac voltage will show 700 mV rms at the input and output.)

3. You will find later that the emitter follower has a very high bandwidth. This can lead to oscillation at several hundred kHz or higher, if you're not careful. This instability is visible as the "fuzzy" oscilloscope trace shown in Figure 3. Those of you using voltmeters only might see intermittent or jumpy ac signal voltages. It's important to keep input leads away from output leads and use the single-point ground as shown in the breadboard circuit of Figure 2. Sometimes, just moving the leads around will cause the oscillation to start and stop, so don't be afraid to experiment.

4. Increase the input signal to 5 $V_{p-p}$. Adjust R1 in each direction and observe the output signal with the oscilloscope. As you lower the collector current ($V_b$ decreasing), you will see the output waveform clip on negative peaks as the collector current is cut off. Raising collector current will eventually result in distortion on positive peaks as the transistor enters saturation.

5. Substitute 1 kΩ, 100 Ω, and 10 Ω resistors for $R_{load}$, reducing the input voltage at each value, so that the output waveform remains undistorted. Lower resistance loads can only be driven at lower voltages because the ac currents in the transistor are much higher at lower values of load resistance. You can read about ac load lines in the reference texts for a detailed explanation. You'll also see the output signal begin to "lag" behind the input signal at these low load values. Why? The impedance of the output coupling capacitor at 1 kHz becomes significant for loads below 100 Ω, introducing phase shift in a series RC circuit.

6. If the input power is $(V_{in})^2 / Z_{in}$ and the output power is $(V_{out})^2 / R_{load}$, compute the power gain of the amplifier for the maximum undistorted values of input and output voltage at the different loads.

$$\text{Power Gain} = P_{out} / P_{in} = [(V_{out})^2/R_{load}]/[(V_{in})^2/Z_{in}] \qquad [10]$$

If $V_{in} \approx V_{out}$, then power gain = $Z_{in} / R_{load}$ ! See how closely this approximation agrees with your measurements.

7. Now that you have a working circuit—experiment with it!

- Rework the math for a Q-point with 5 times more and 10 times less collector current. Calculate $Z_{in}$ and $Z_{out}$ for those currents.
- Raise the input frequency to see if you can find where the gain drops to 70% of the peak value; this is the upper –3 dB frequency of the amplifier.
- Drive both the CE and EF amplifiers with a square-wave at the highest frequency your generator can reach, using a 1 kΩ load resistor. Use the 'scope to determine which circuit will follow the input more accurately thus indicating wider bandwidth.

## Suggested Reading

- "Transistor Amplifier Design—A Practical Approach" in Chapter 8 of *The ARRL Handbook*.
- "Low-Frequency Transistor Models" in Chapter 10 of The *ARRL Handbook*.
- For a more complete discussion of the Emitter-Follower amplifier, check out Chapter 2 of *The Art of Electronics*, by Horowitz and Hill.

## Shopping List

You'll need the following components:

- 100 kΩ potentiometer.
- ¼ W resistors of the following values: 10 Ω, 100 Ω, 1 kΩ, 1.2 kΩ, 10 kΩ,15 kΩ, 22 kΩ.
- 2-10 µF capacitors with a voltage rating of 25 V dc or more (electrolytic or tantalum are fine).
- 2N3904 transistor.

## Next Month

We shift gears next month to operational amplifiers—usually known by their nickname "op amps." Be prepared to buffer, invert, add and subtract! QST