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AnalogDialogue

StudentZone—ADALM2000 Activity: The Source Follower (NMOS)

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Objective

The objective of this activity is to investigate the simple NMOS source follower amplifier, also sometimes referred to as the common drain configuration.

Materials

- ADALM2000 Active Learning Module
- Solderless breadboard
- Jumper wires
- One 2.2 kΩ resistor (R_L)
- One small signal NMOS transistor (enhancement mode CD4007 or ZVN2110A for M1)

Directions

The breadboard connections are shown in Figure 1 and Figure 2. The output of the waveform generator, W1, is connected to the gate terminal of M1. Scope Input 1+ (single ended) is also connected to the W1 output. The drain terminal is connected to the positive (Vp) supply. The source 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 gate of M1 and 2– to the source.

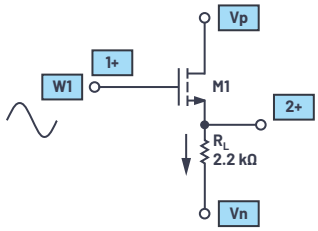

Figure 1. Source follower.

Hardware Setup

The waveform generator should be configured for a 1 kHz sine wave with 2 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 source. The scope is configured with Channel 1+ 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.

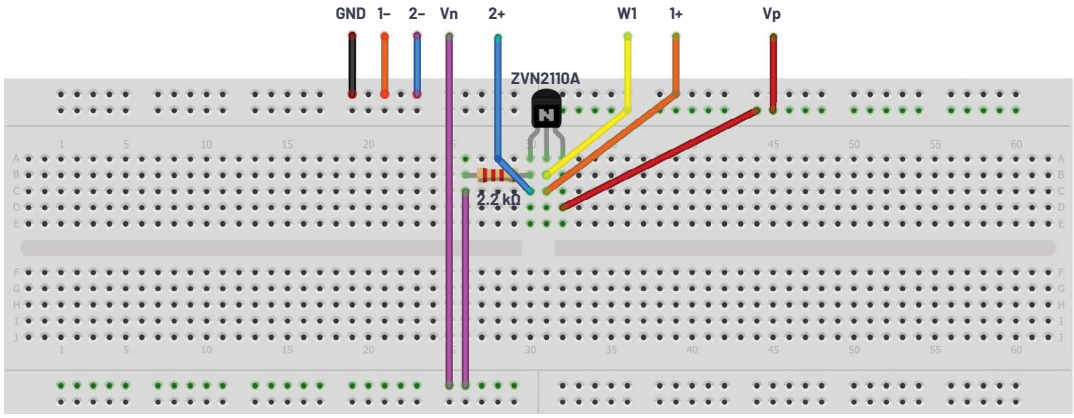

Figure 2. Source follower breadboard circuit.

Procedure

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

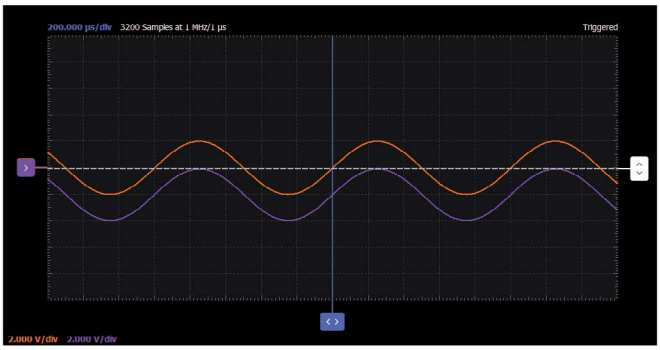

Figure 3. Source follower with both input and output waveforms.

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

$$A = \frac{R_L}{R_L + r_s} \quad (1)$$

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_s. We also know that r_s is a function of I_D and that as I_D increases, r_s decreases. Also, from the circuit we can see that I_D is related to R_L and that as R_L increases, I_D 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_s or increase R_L without affecting the other. It is important to remember that in MOS transistors, $I_D = I_s$ ($I_G = 0$).

$$I_D = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{GS} - V_{th})^2 (1 + \lambda V_{DS}) \quad (2)$$

where $K = \mu_n C_{ox}/2$ and λ can be taken as process technology constants.

Looking at the follower in another way, because of the inherent DC shift due to the transistor's V_{th}, the difference between input and output should be constant over the intended swing. Due to the simple resistive load, R_L, the drain current, I_D, increases and decreases as the output swings up and down. We know that I_D is a (square law) function of V_{GS}. In this +1 V to –1 V swing example the minimum I_D = 1 V/2.2 kΩ, or 0.45 mA, and the maximum I_D = 6 V/2.2 kΩ, or 2.7 mA. This results in a significant change in V_{GS}. This observation leads us to the first possible improvement in the source follower.

The current mirror from previous StudentZone activities is now substituted for the source load resistor to fix the amplifier transistor source current. 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_{GS}. Viewed another way, the very high output resistance of the current mirror has effectively increased R_L while r_s remains at a low value set by the current.

Improved Source Follower

Additional Materials

- One 3.2 kΩ resistor (use a 1 kΩ in series with a 2.2 kΩ)
- One small signal NMOS transistor (ZVN2110A for M1)
- Two small signal NMOS transistors (CD4007 for M2 and M3)

Directions

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

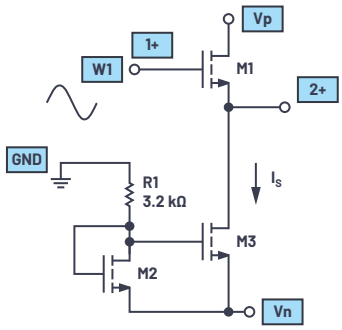

Figure 4. Improved source follower.

Hardware Setup

The waveform generator should be configured for a 1 kHz sine wave with 2 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 source. The scope is configured with Channel 1+ 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.

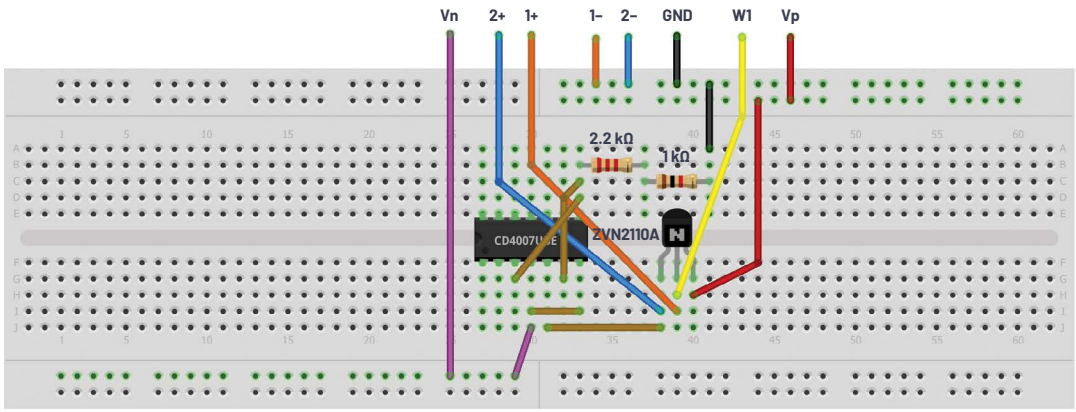

Figure 5. Improved source follower breadboard circuit.

Procedure

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

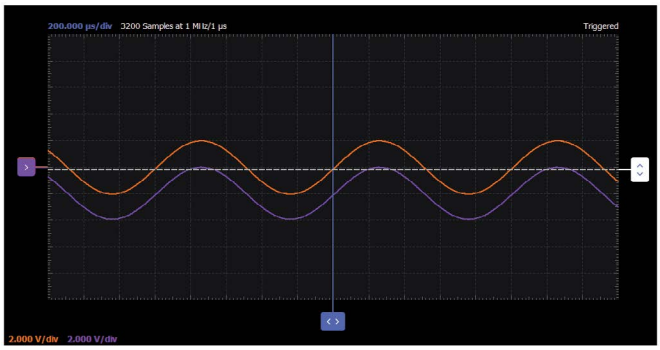

Figure 6. Improved source follower waveform.

Source Follower Output Impedance

Objective

An important aspect of the source follower is to provide power or current gain—that is, to drive a lower resistance (impedance) load from a higher resistance (impedance) stage. Thus, it is instructive to measure the source follower output impedance.

Materials

- One 4.7 kΩ resistor
- One 10 kΩ resistor
- One small signal NMOS transistor (CD4007 or ZVN2110A for M1)

Directions

The circuit configuration in Figure 7 and Figure 8 adds a resistor, R2, to inject a test signal from AWG1 into the emitter (output) of M1. The input, the base of M1, is grounded.

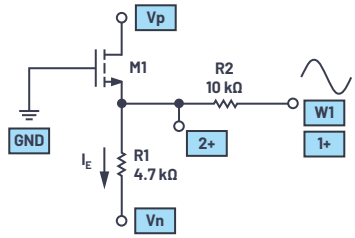

Figure 7. Output impedance test.

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 minus the V_{GS} of M1 (approximately –V). This injects a ±0.1 mA (1 V/10 kΩ) current into M1's source. Scope Input 2+ measures the change in voltage seen at the source.

Procedure

Plot the measured voltage amplitude seen at the source. Configure the oscilloscope instrument to capture several periods of the two signals being measured. A plot example is presented in Figure 9.

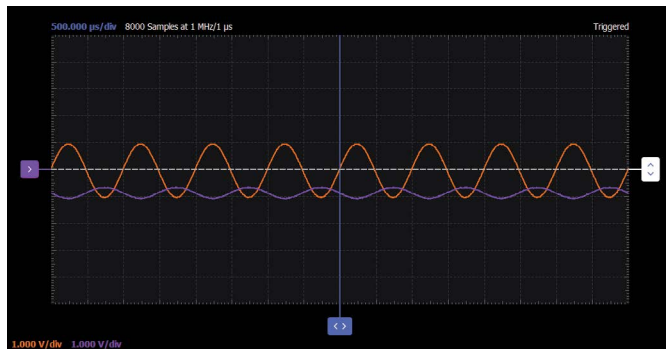

Figure 9. Output impedance test waveform.

Question:

Can you briefly describe two ways in which the gain of the source follower can be improved (closer to 1)?

You can find the answers at the StudentZone blog.

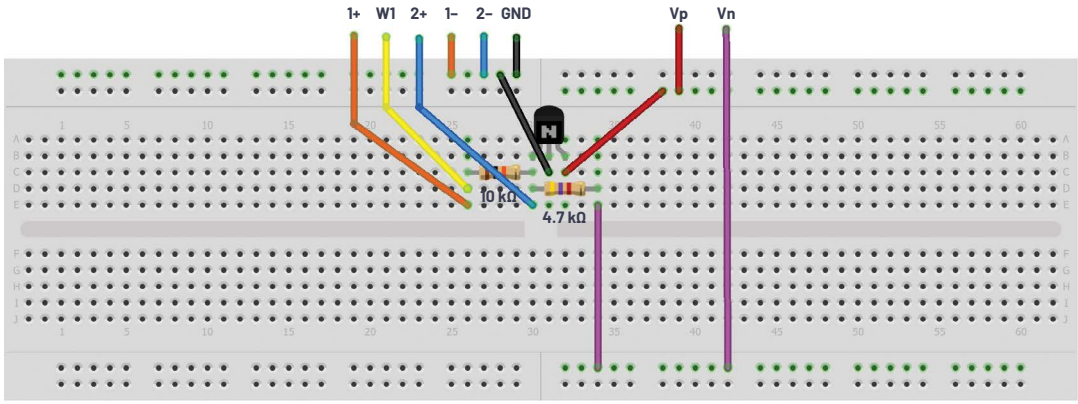

Figure 8. Output impedance test breadboard circuit.

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.