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StudentZone—ADALM2000 Activity: BJT Multivibrators

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Background

This article explains the three main types of multivibrator circuits and how to build each one. A multivibrator circuit generally consists of two inverting amplifier stages. The two amplifiers are connected in series or cascade, and a feedback path connects from the output of the second amplifier back to the input of the first. Because each stage inverts the signal, the overall feedback around the loop is positive.

There are three main types of multivibrators: astable, monostable, and bistable. In the astable multivibrator, capacitors are used to couple the two amplifier stages and provide the feedback path. Since the capacitors block any DC signals from passing from one stage to the next, the astable multivibrator has no stable DC operating point and is thus a free-running oscillator. In the monostable multivibrator, the coupling from one of the stages to the other uses one capacitor while the second connection is through a DC path. Thus, the monostable multivibrator has one stable DC stage. Hence, the monostable multivibrator is sometimes referred to as a one-shot. The circuit maintains this single stable state except when a triggering pulse is applied. Then, the state changes for a predetermined length of time set by the RC time constant of the AC-coupled part of the signal path. In the bistable multivibrator, both coupling paths are DC-coupled and thus the circuit has two different stable states and uses no capacitors. The bistable multivibrator is also called a flip-flop, with either of two DC stable states.

The Astable Multivibrator

Objectives

The objective of this first experiment is to build an astable multivibrator. Two identical resistance-capacitance networks determine the frequency at which oscillation will occur. The amplifying devices (transistors) are connected in a common-emitter configuration, as shown in Figure 1.

Materials

- ADALM2000 Active Learning Module
- Solderless breadboard
- Jumper wires
- Two 470 Ω resistors
- Two 20 kΩ resistors
- Two small signal NPN transistors (2N3904)
- One red LED
- One green LED
- Two 47 µF capacitors

Directions

Construct the circuit as shown in Figure 1 on your solderless breadboard. Note that there is no input from the ADALM2000 board, just the power supply. The first inverting amplifier stage consists of Q1 with R1 and the red LED serving as the output load. The second inverting amplifier stage consists of Q2 with R2 and the green LED serving as the load. C1 couples the output of the first stage at the collector of Q1 to the input of the second stage at the base of Q2. Similarly, C2 couples the output of the second stage at the collector of Q2 back to the input of the first stage at the base of Q1.

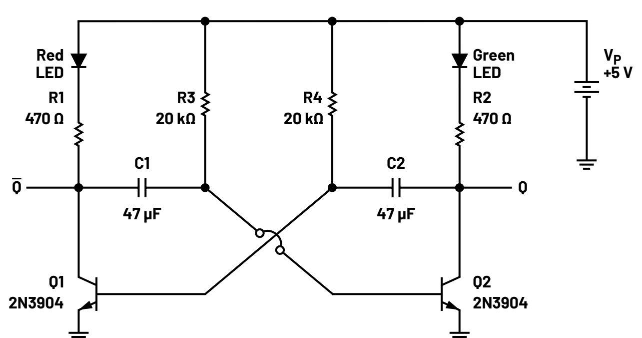


Figure 1. An astable multivibrator.

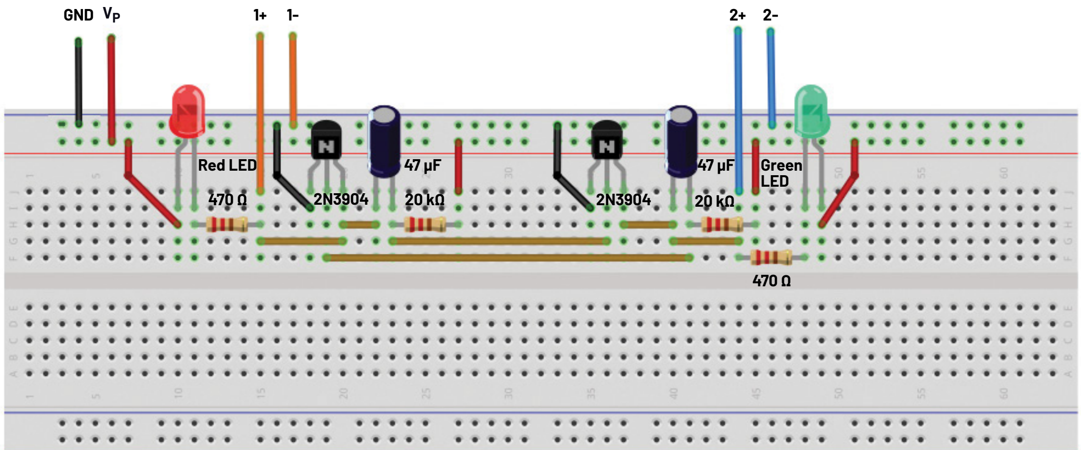


Figure 2. An astable multivibrator breadboard circuit.

Hardware Setup

Breadboard connections are presented in Figure 2.

Procedure

Turn on the V_P power supply only after you have completely built and checked the circuit. The red and green LEDs should alternately blink on and off at about a 1 second interval. You can also use the scope channels to monitor the output waveforms (Q and Q-bar).

The frequency of oscillation is very slow due to the large values of capacitors C1 and C2. Replace C1 and C2 with 0.1 µF capacitors. The circuit should oscillate much faster now such that both LEDs are on at the same time. Using the scope channels, you should now measure the frequency and period of the output waveforms.

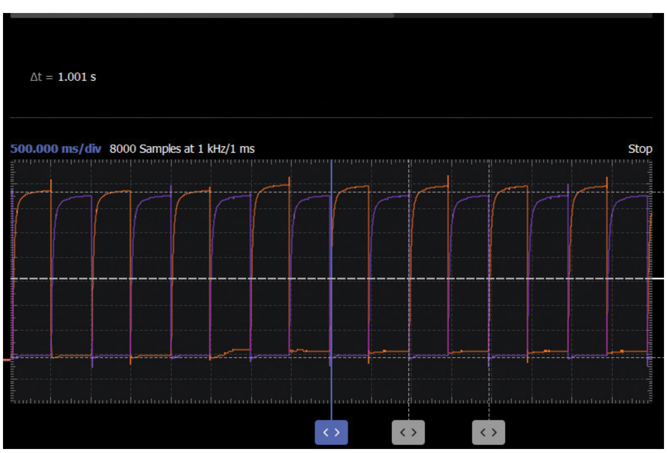


Figure 3. Astable multivibrator interval at 47 µF capacitor.

Figure 4. Astable multivibrator interval at 0.1 µF capacitor.

The Monostable Multivibrator

Objectives

The objective of this second experiment is to build a monostable multivibrator. One resistance-capacitance network determines the duration of the one-shot output. The amplifying devices (transistors) are connected in a common-emitter configuration, as shown in Figure 2.

Materials

- ADALM2000 Active Learning Module
- Solderless breadboard
- Jumper wires
- Two 470 Ω resistors
- One 1 kΩ resistor

- One 20 kΩ resistor
- One 47 kΩ resistor
- One small signal diode (1N914)
- Two small signal NPN transistors (2N3904)
- One red LED
- One green LED
- One 47 µF capacitor

Directions

Construct the circuit shown in Figure 5 on your solderless breadboard. Starting with the circuit from Experiment 1, remove one of the 20 kΩ resistors (old R3) and replace capacitor C1 with a 47 kΩ resistor (new R3). Add diode D1 and resistor R5 as shown to the base of Q2. Be sure to replace C2 with the original 47 µF capacitor.

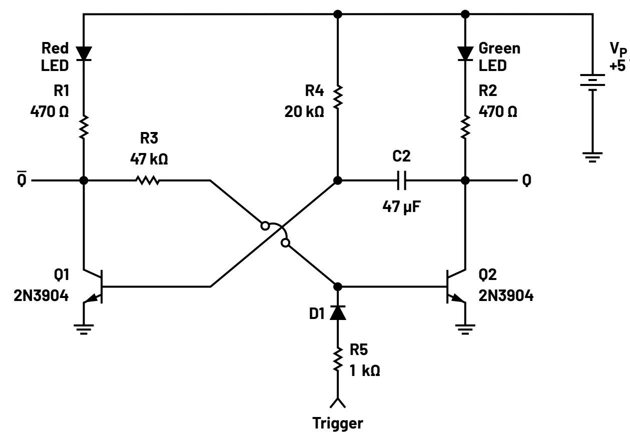


Figure 5. A monostable multivibrator.

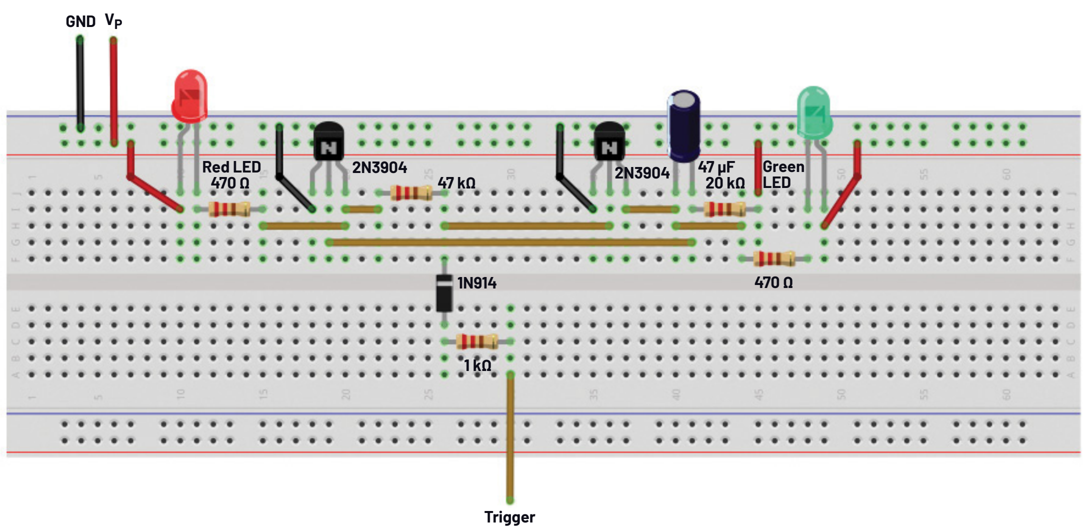


Figure 6. Monostable multivibrator breadboard circuit.

Hardware Setup

Breadboard connections are presented in Figure 6.

Procedure

Turn on the V_P power supply only after you have completely built and checked the circuit. The red LED should be lit, and the green LED should be dark. With a length of wire, momentarily touch the trigger input (end of R5) to V_P and immediately let go. The red LED should go out and the green LED come on for about a second and then go back to the stable state with the red on and green off. Try this a few times.

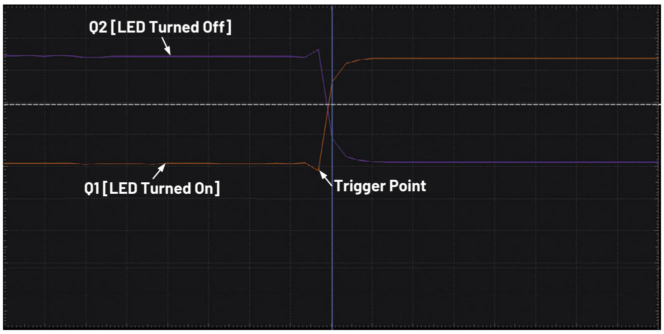


Figure 7. Monostable multivibrator behavior on trigger.

The Bistable Multivibrator (or Flip-Flop)

Objectives

The objective of this third experiment is to build a bistable multivibrator. The amplifying devices (transistors) are connected in a common-emitter configuration, as shown in Figure 8.

Materials

- ADALM2000 Active Learning Module
- Solderless breadboard
- Jumper wires
- Two 470 Ω resistors
- Two 1 kΩ resistors
- Two 47 kΩ resistors
- Two small signal NPN transistors (2N3904)
- Two small signal diodes (1N914)
- One red LED
- One green LED

Directions

Construct the circuit as shown in Figure 8 on your solderless breadboard.

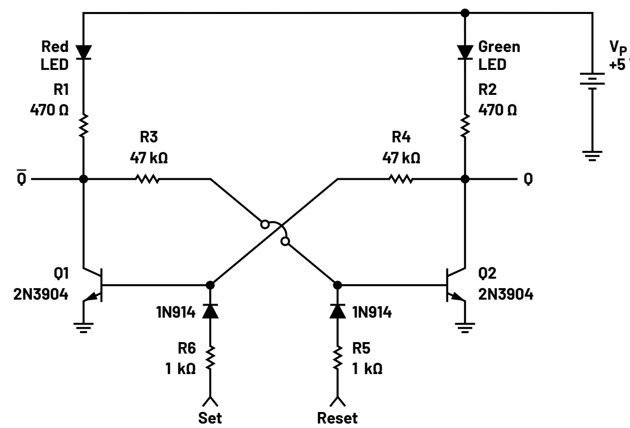


Figure 8. Bistable multivibrator.

Hardware Setup

Breadboard connections are presented in Figure 9.

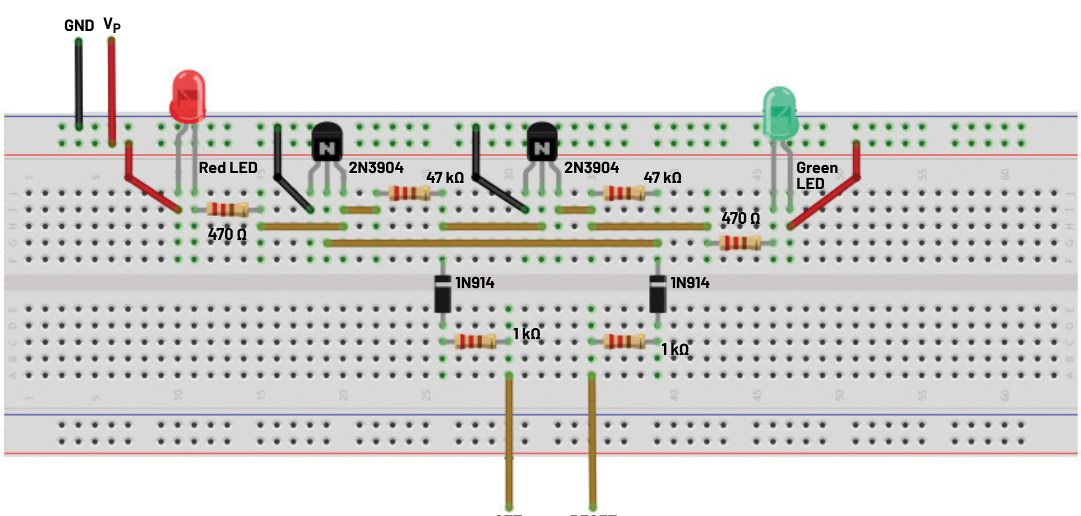


Figure 9. Bistable multivibrator breadboard circuit.

Procedure

Turn on the V_P power supply only after you have completely built and checked the circuit. Either the red LED should be lit and the green LED dark, or the green LED should be lit and the red LED dark. With a length of wire, momentarily touch either the SET or RESET input (end of R5 or R6) to V_P and immediately let go. The LEDs should change state or toggle back and forth depending which input is touched to V_P. Try this a few times.

Figure 10. Bistable multivibrator behavior triggering the SET pin.

Figure 11. Bistable multivibrator behavior triggering the RESET pin.

D-Type Flip-Flop

Objectives

The objective of this fourth experiment is to use the bistable or SET-RESET flip-flop from Experiment 3 to build what is known as a D-type flip-flop.

Materials

- ADALM2000 Active Learning Module
- Solderless breadboard
- Jumper wires
- Three 1 kΩ resistors
- One 100 kΩ resistor
- Two 200 kΩ resistors
- Two 47 kΩ resistors
- Three small signal NPN transistors (2N3904)
- Two small signal diodes (1N914)
- Two 39 pF capacitors
- Two 100 pF capacitors

Directions

Construct the D-type flip-flop circuit as shown in Figure 12 on your solderless breadboard. Note that the polarity of the two diodes is reversed compared to Figure 8. Because this experiment will be done at much higher frequencies, the LEDs have been removed and simple 1 kΩ load resistors are used.

Switching between the two flip-flop states is achieved by applying the D (data) signal and a single clock pulse that, depending on the state of the D input with respect to the current state, will cause the ON transistor to turn off and the OFF transistor to turn on on the negative or falling edge of the clock pulse. The true D signal and complementary DB signal (output of Q3, R7 inverting stage) are used to bias diodes D1 and D2 to steer the clock pulse to the correct base, the equivalent of the SET and RESET inputs in Figure 8.

To illustrate how the circuit operates, we will assume that the circuit is in one of its two stable states with the QB output low (collector voltage of Q1 at 0 V), and the Q output high (collector voltage of Q2 high at 5 V). With the D input low (DB high), D1 has a low voltage on its cathode via R6 and a high voltage (VBE of on transistor Q1) on its anode via R4, making it forward biased. D2 has a high voltage (from DB) on its cathode via R5 and a low voltage on its anode via R3 (VBE of off transistor Q2), making it reverse biased.

A negative going pulse on the clock input, coupled through C1 and C2, is steered to the base of Q1 since D1 is forward biased, but blocked from the base of Q2 by reverse biased D2. Q1 is turned off and Q2 is turned on by the cross-coupled connection through the parallel combination of C3 and R3. This happens very quickly because of the positive feedback effect we saw earlier in the simple bistable multivibrator. The circuit is now in the other stable state with the Q output high and the QB output low. The circuit will remain in that state until the D input becomes high and after another negative going clock pulse arrives.

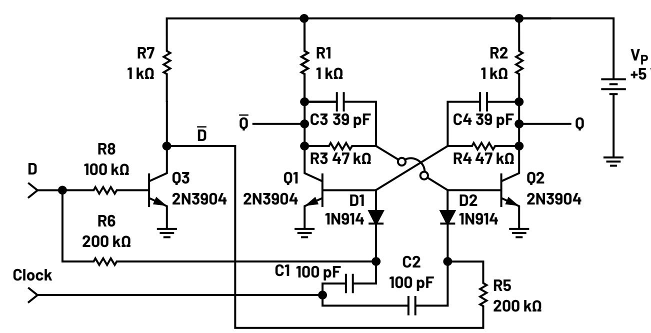


Figure 12. D-type flip-flop.

Hardware Setup

Breadboard connections are presented in Figure 13.

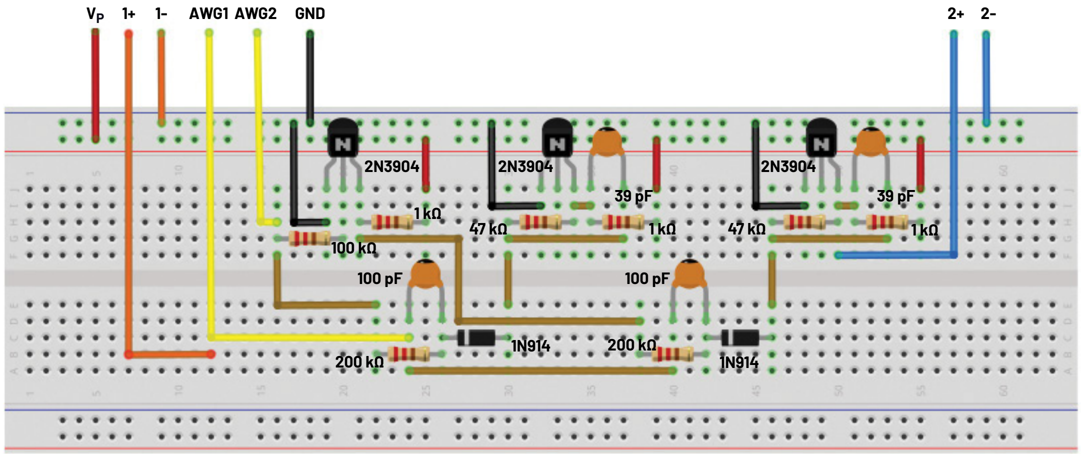


Figure 13. D-type flip-flop breadboard circuit.

Procedure

The AWG1 output should be connected to the input marked clock in Figure 12. The AWG2 output should be connected to the D input. The first Scope Channel 1 input should also be connected to the clock input. The second input Scope Channel 2 should be connected to the Q output of the flip-flop in Figure 12. Both the AWG1 and AWG2 should be configured as a square wave with a 5 V amplitude peak-to-peak and 2.5 V offset (0 V to 5 V swing). Set the frequency of AWG1 to 10 kHz and set the frequency of AWG2 to 5 kHz. Set the phase of AWG2 to 45 degrees. Be sure to configure the two AWG outputs to operate synchronously.

Turn on the V_P power supply and enable the AWG outputs only after you have completely built and checked the circuit. You should observe a square wave on the Q output that is aligned with the falling edge of the clock input signal. Change the phase of AWG2 (D input signal) while observing this alignment. Does this change as the phase of the D input change? Move the Channel 1 scope input to the D input. You should see a similar square wave signal but ahead in time with respect to the Q output. In other words, the Q output is delayed until the falling edge of the clock signal.

Figure 14. Plot of Q and clock signal.

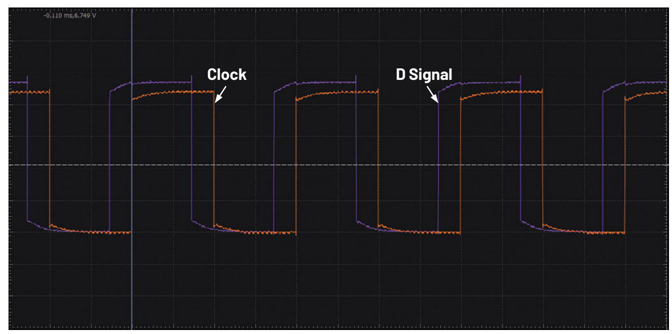


Figure 15. Plot of Q and D signal.

Divide-by-2 Flip-Flop

Objectives

The objective of this fifth experiment is to modify the D-type flip-flop from Experiment 4 to build a circuit that divides the frequency of an input signal by 2.

Materials

- ADALM2000 Active Learning Module
- Solderless breadboard
- Jumper wires
- Two 1 kΩ resistors
- Two 200 kΩ resistors
- Two 47 kΩ resistors
- Two small signal NPN transistors (2N3904)
- Two small signal diodes (1N914)
- Two 39 pF capacitors
- Two 100 pF capacitors

Directions

Modify the D-type flip-flop from Experiment 4 to construct the divide-by-2 circuit as shown in Figure 16 on your solderless breadboard.

Switching between the two states is achieved by applying a single clock pulse that, in turn, will cause the ON transistor to turn off and the OFF transistor to turn on on the negative or falling edge of the clock pulse. The circuit will switch sequentially by applying a pulse to each base in turn and this is achieved from a single input clock pulse used to bias the two diodes to steer the pulse to the correct base based on the current state of the flip-flop.

To illustrate how the circuit operates, we will assume that the circuit is in one of its two stable states with the collector voltage of Q1 low (0 V), and that of Q2 high (5 V). D1 has a low voltage on its cathode via R6 and a high voltage (VBE of on transistor Q1) on its anode via R4, making it forward biased. D2 has a high voltage on its cathode via R5 and a low voltage on its anode via R3 (VBE of off transistor Q2), making it reverse biased.

An external negative going pulse, coupled through C1 and C2, is steered to the base of Q1 since D1 is forward biased but blocked from the base of Q2 by reverse biased D2. Q1 is turned off and Q2 is turned on by the cross-coupled connection through the parallel combination of C3 and R3. This happens very quickly because of the positive feedback effect we saw earlier in the simple bistable multivibrator.

The circuit is now in its second stable state and waits for another negative going clock pulse.

Since the collector voltage of Q2, the Q output node, changes state for every clock pulse, there is one pulse appearing at the output for every two clock input pulses. It can therefore be used as a divide-by-two circuit.

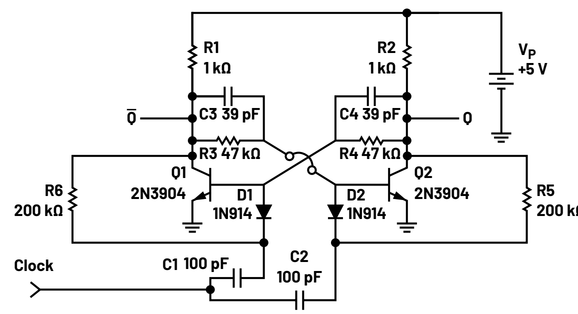


Figure 16. Divide-by-2 circuit.

Hardware Setup

Breadboard connections are presented in Figure 17.

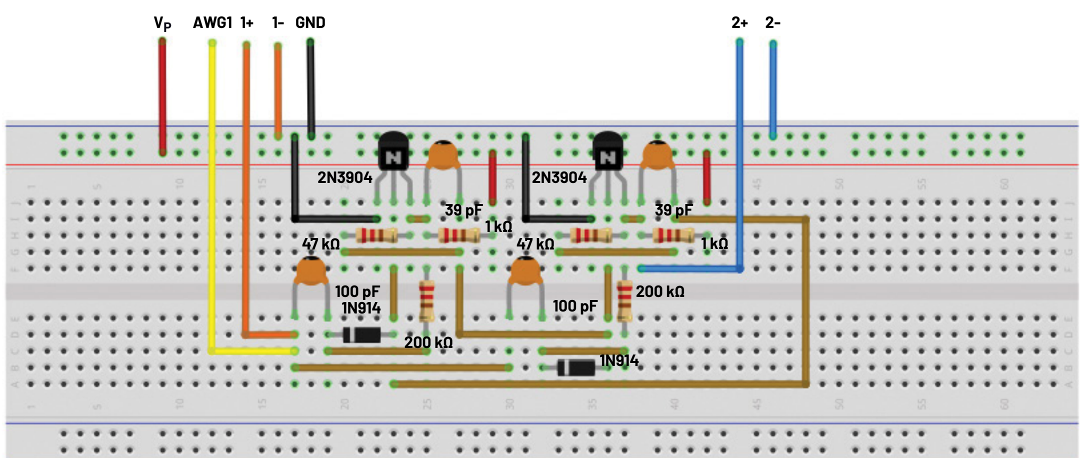


Figure 17. Divide-by-2 flip-flop breadboard circuit.

Procedure

The AWG1 output and Scope Channel 1 input should both be connected to the input marked clock in Figure 16. The second input Scope Channel 2 should be connected to the Q output of the flip-flop in Figure 16. The AWG1 should be configured as a square wave with a 5 V amplitude peak-to-peak and 2.5 V offset (0 V to 5 V swing). Set the frequency to 10 kHz.

Turn on the V_P power supply and enable the AWG1 output only after you have completely built and checked the circuit. You should observe a square wave on the Q output that is one half the frequency of the AWG1 signal. Move the Channel 2 scope input to the QB output. You should see a similar square wave signal but inverted with respect to the Q output.

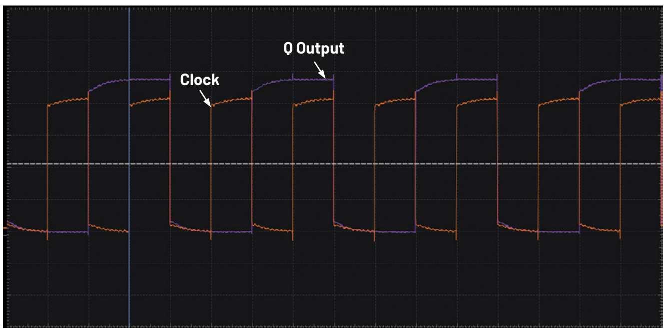


Figure 18. Plot of clock and Q output.

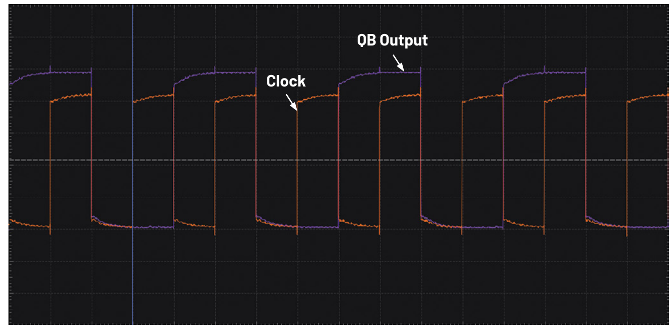
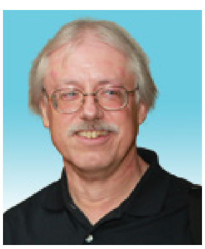


Figure 19. Plot of clock and QB output.

Question

For the circuit in Figure 1, what would be the effect of increasing or decreasing the value of both capacitors?

You can find the answer at the StudentZone blog.



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 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.

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 ADI 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.