Digital-to-Analog Converters

<u>Lab Summary</u>: The purpose of the laboratory experiment is to introduce the concepts associated with the conversion of a digital signal to an analog signal utilizing a digital-to-analog converter (DAC). Calculations will be made on circuits constructed from readily available components. Voltage and timing measurements will be made during this experiments that will require the student to have knowledge associated with the WRE Fourier Theory Module to select an oscilloscope to be used to make settling time measurements. At the completion of the laboratory experiment, the student shall develop a written report of their finding associated with the converter circuit they investigated.

<u>Lab Goal</u>: The observation of the operation of a digital-to-analog converter and its major components and perform measurements associated with the operation of the converter and its specifications.

<u>Learning Objectives</u>

1. Construct a digital-to-analog converter test circuit.
2. Describe the function and operation of each major component of the circuit.
3. Measure the DC output voltage for various digital input signals.
4. Measure the DAC parameters against specified values.

<u>Grading Criteria</u>: Your lab grade will determine by your performance on the experiment, the lab questions, and the content and quality of your laboratory report.

<u>Time Required</u>: 2 to 4 hours

Equipment and Materials

Part	Quantity
Equipment:	
Power Supply 15 volt	2
Digital Multimeter/ DC voltage	1
Oscilloscope	1
Function Generator	1
Electronic Trainer/breadboard	1
Components:	
Hookup Wire as needed	
SPDT Switches	8
DPDT Switch	1
10 kΩ Fixed Resistor	3
20 kΩ Fixed Resistor	1
25 kΩ Variable Resistor (preferably multi turn)	1
7404 Hex Inverter	1
DAC0800 Digital-to-analog Converter IC	1
LT1004 2.5 Voltage Reference	1
1N5230 4.7 Volt Zener Diode ½ Watt	1
LF356 Operational Amplifier	1
74HC193 4-bit Synchronous Counter	2

Special Safety Requirements: No serious hazards are involved in this laboratory experiment, but be careful to connect the components with the proper polarity to avoid damaging them.

Lab Preparation

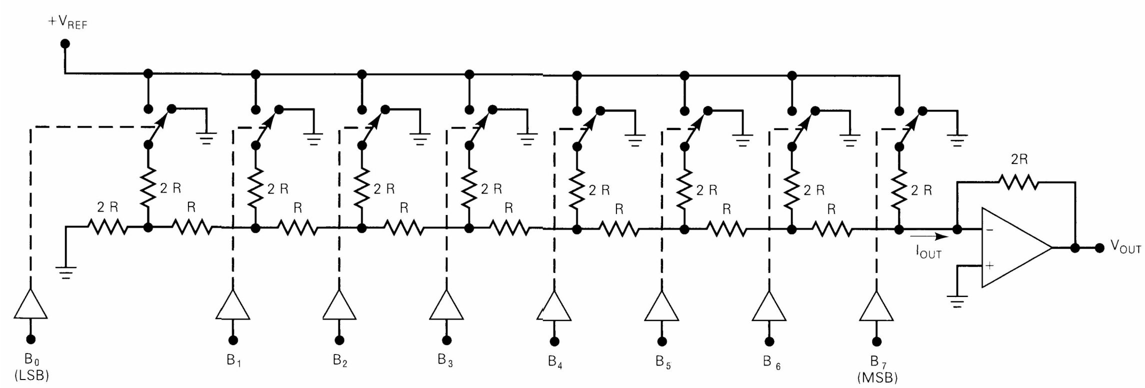
- Read this document completely before you start on this experiment.
- Acquire required test equipment and appropriate test leads.
- Gather all circuit components and the breadboard.
- Review and print the laboratory experiment procedure that follows.

Introduction

One of the most common circuits used to convert a digital binary or binary coded decimal signal into an analog signal utilizes a circuit referred to as an R-2R resistor ladder network. This circuit uses thin film defused integrated circuit resistors, which are made on a monolithic chip and are laser trimmed to achieve the desired values with great precision.

The accuracy of a digital-to-analog converter (DAC) is partially dependent on the accuracy of the voltage reference used in the circuit. The DAC converter circuit used here utilizes a LT1004 - 2.5 V_{DC} voltage reference with output characteristics of 2.470 minimum and 2.520 maximum with 2.500 typical.

A resistive ladder network is used as a voltage divider to divide the voltage reference down to a level which is proportional to the binary value presented to the input control circuit of the DAC. The binary input signal is applied to the inputs $B_7B_6B_5B_4B_3B_2B_1B_0$. The DAC used here has eight input bits but the principle can also be demonstrated with a four bit ladder network.



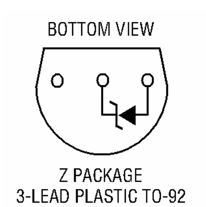
8 Bit Digital-to-Analog Converter

The circuit operates by applying a binary signal to the B_N terminals, which in turn will cause a transistor, represented by a SPDT switch, to switch between ground (0 volts) and the V_{REF} bus. The result of the applied digital signal is to cause the various switches inside the ladder network to connect to either 0 volts or V_{REF}. The results of this will be an output voltage that is determined by the binary input signal magnitude and the value of the V_{REF} voltage. The output can be found from the following equation:

$$V_{OUT} = \frac{-V_{REF}}{256} \times (B)_{10}$$

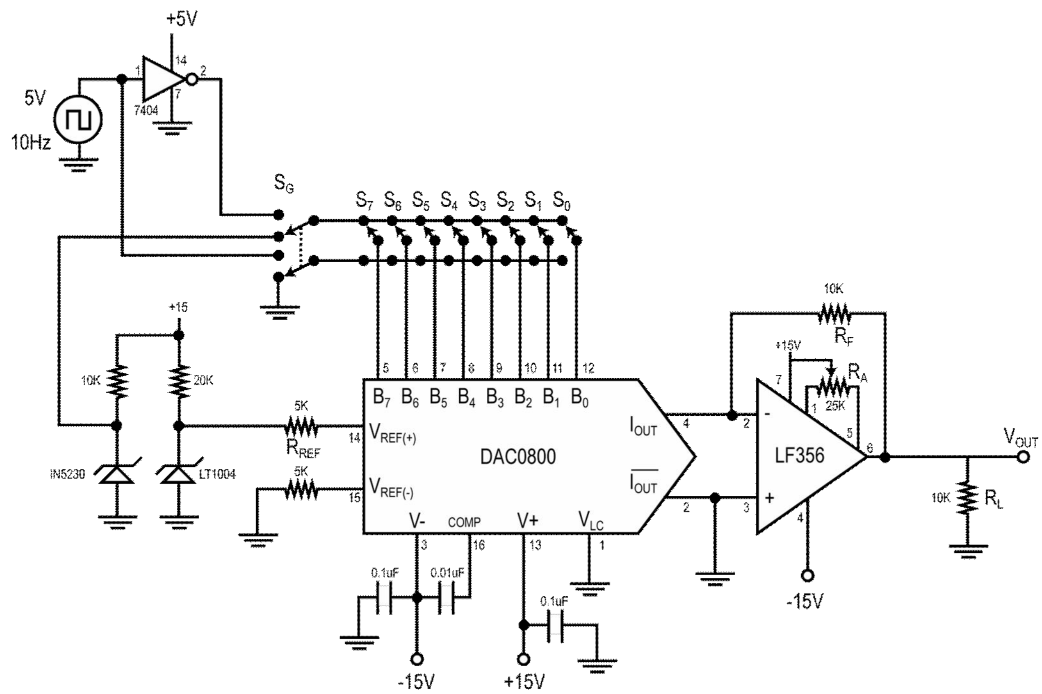
$(B)_{10}$ is the decimal value of the binary input.

The DAC circuit used in this lab requires an external reference voltage be applied to the V_{REF} (+) terminal (14). For this experiment, a LF1004 -2.5 voltage reference IC is used. This IC comes in a three terminal TO-92 package.



Although the symbol used for this IC function is a Zener diode, it actually is a complex circuit which uses a band gap reference diode. An LT1004-2.5 IC is used to develop the required 2.500 volt reference.

When the circuit is complete, operational checks and specification measurements will determine if the DAC is operating within specifications.



Circuit #1 Schematic

The V_{OUT} for this DAC circuit can be calculated as follows:

$$V_{OUT} = \frac{V_{REF} \times (\text{Binary Input})_{10} \times R_L}{R_{REF} \times 256}$$

The $(\text{Binary Input})_{10}$ is the decimal (base 10) value on the digital binary value.

The SPDT switches identified as S_7 through S_0 are connected to the digital inputs B_7 through B_0 and will allow you to set the binary value for each binary bit. The DPDT switch identified as S_G will allow you to toggle the value on the binary inputs between 0 and 1 using a square wave generator. The operational amplifier will provide an output voltage proportional to the binary signal applied to the DAC.

Note there are two voltages being developed at the left side of the schematic. The voltage developed by the LT1004 is the $2.500V_{DC}$ reference voltage for the DAC. The other circuit is a 4.7 volt source for the binary input voltage to represent a binary 1.

Lab Procedure

1. Construct the Circuit #1 found at the end of this procedure. Pay close attention to the pin out for the DAC, operational amplifier, and the precision voltage reference.

2. Measure the following values as accurately as possible:
   (a) V_{REF} ___________
   (b) R_{REF} ___________
   (c) R_L ___________

3. Set the binary input to 00000000_2 then adjust the resistor R_A to set the V_{OUT} to as close to zero as possible.

4. Calculate the expected values when the binary data switches are set for the digital values in Table 1 and the S_G switch set for the DC voltages.

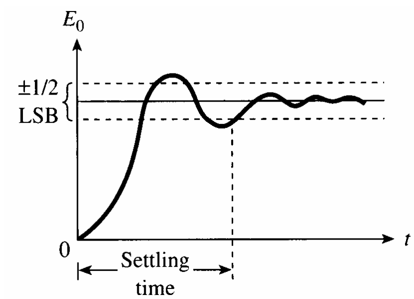
5. Set the binary switches and the DC voltages for the S_G switch. Measure the output voltage for each of the given binary values and complete the Table 1.

6. The circuit uses a V_{REF} = 2.500 volts. What is the calculated resolution for this circuit? ____________. When the digital input value is 11111111_2, what is the expected output voltage? _____________ What is the measured value? ______________

7. One of the important specifications associated with a DAC IC is its settling time or conversion time. Set the output of the function generator for a square wave output with an amplitude of 4.5 volts. Place switch S_G in the position to connect the output of the function generator to the switches S_7 through S_0.
8. Set switches S_7 through S_0 to the same position so they have the same input signal from the function generator. We now have a signal which toggles between 11111111_2 and 00000000_2. Set the frequency of the function generator to 1 kHz.

9. Access the Internet and locate the specification sheet for a DAC 0800. Determine the maximum settling time. Review the data sheet for a DAC 0800 digital-to-analog converter. Locate the value of t_s, the settling time for the device. The DAC settling time is measured from the binary input of 00000000_2 to 11111111_2. This requirement can be found in the data sheet in the row for t_s. Since frequency is the inverse of time, we can calculate the equivalent frequency the settling time represents. For this converter, it is approximately 10 MHz. The reason we calculate this frequency is to select an oscilloscope, which allows us to accurately measure the settling time of the converter. (NOTE: Review the WRE Fourier Series Module for the effect of not being able to measure the 5^{th} harmonic of a square wave and the resulting loss of measurement accuracy associated with the time measurement.) An oscilloscope with a bandwidth five times the signal being measured must be used. Therefore, for this converter we must use a 50 MHz oscilloscope.

10. Attach channel 1 of a dual channel oscilloscope to the output of the 7404 inverter. Attach channel 2 to the DAC output $I_{OUT\,(1)}$, pin 4. Trigger the oscilloscope from channel 1. Measure the time from the output of the inverter changing until the DAC output to settle within ½ LSB of the correct value.



Settling Time

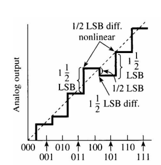
11. Enter your measured value and the specified value below:
    a. Measured Value: _____________
    b. Specified Value: _____________

12. Another important characteristic of a DAC is its monotonicity. To verify if a DAC is monotonic, vary the digital input signal from 00000000_2 to 11111111_2 and monitor the output to determine that it continues to increase as the digital signal increases.

13. In order to accomplish this test of the DAC specification you must modify Circuit #1 as shown in Circuit #2 at the end of this procedure. We will vary the binary input signals via a synchronous 8-bit counter.

14. In order to accomplish this test of the DAC specification you must modify Circuit #1 as shown in Circuit #2 at the end of this procedure. We will vary the binary input signals via a synchronous 8-bit counter.
    a. Momentarily close the reset switch and apply a 1 to the counters master reset. This will place the counters in the 0000000_2 state.
    b. Place the clock input switch in the count up position. As clock pulses are applied to the count up input, the binary output of the counters will increment one unit at a time toward the maximum binary input of 11111111_2.
    c. Monitor the V_{OUT} of the DAC circuit to determine that as the binary input increased the value of V_{OUT} always increased from zero to the maximum output value. If the DAC always increases for an increasing binary input then the DAC is monotonic.

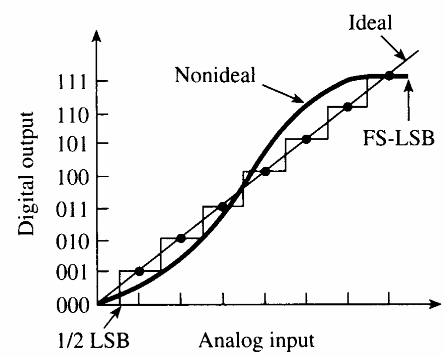
15. A graph of a DAC, which is non-monotonic, is shown below. Note the value of the analog output falls for a binary value of 100 when the binary input was 011. This reduced output is the definition on non-monotonic.



nonmonotonic
(must be $>\pm\frac{1}{2}$ LSB nonlinear)

16. By using a 74HC193 counter we are able to place the square wave from the function generator on either the up or down count input. We just completed the observation of the DAC output voltage for increasing binary input values; now switch the function generator output to the count down input. Observe the output voltage from an input of 11111111_2 to 00000000_2. The output should continue to decrease for each decrease of the binary input signal. Determine if the output voltage of the DAC go down for each of the decreasing binary input values.

17. Another specification associated with a DAC is its linearity. Linearity error is the maximum deviation from a straight line passing through the endpoints of the DAC transfer characteristics. Linearity error is measured by comparing the expected value for a specific binary input to the analog value measured at the output of the DAC. An example of linearity error is shown here.



relative accuracy;

Linearity

18. Calculate the expected V_{OUT} for the DAC for the values and enter them in Table 2 below.

19. Measure the V_{OUT} and calculate the linearity error for this DAC for each of the binary input value.

Table 1

Binary Value	Decimal Value	Expected V_{OUT}	Measured V_{OUT}
00000000	0		
00000001	1		
00000010	2		
00000100	4		
00001000	8		
00010000	16		
00100000	32		
01000000	64		
10000000	128		

Table 2

Binary Value	Decimal Value	Expected V_{OUT}	Measured V_{OUT}	Linearity Error
00000000	0			
00000001	1			
00000010	2			
00000100	4			
00001000	8			
00010000	16			
00100000	32			
01000000	64			
10000000	128			
11111111	255			

Lab Questions

1. Explain why an R-2R network is used in the DAC 0800.

2. Why was a LF1004 used as the voltage reference?

3. Could a voltage reference of 10 V_{DC} be used? If it were, what happens to the resolution for the converter circuit?

4. What is the maximum frequency we can change the binary input values and expect the DAC to convert correctly?

5. Why is linearity important for a DAC?

6. Why is a DAC being monotonic important?

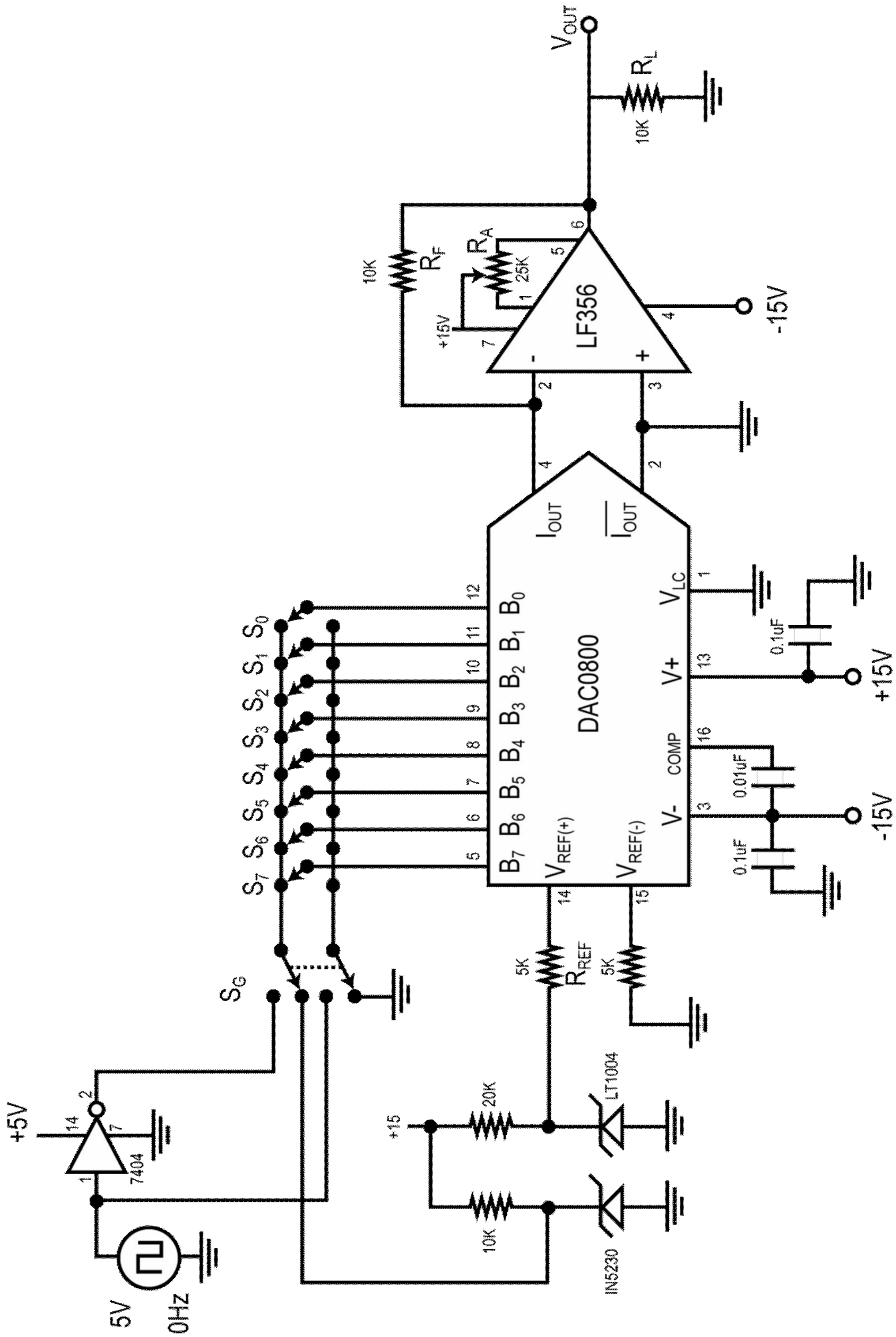
Pushing the Envelope (Requires Internet Research)

How would you modify Circuit 2 to cause it to output a sine wave at a frequency of 10 kHz? This will

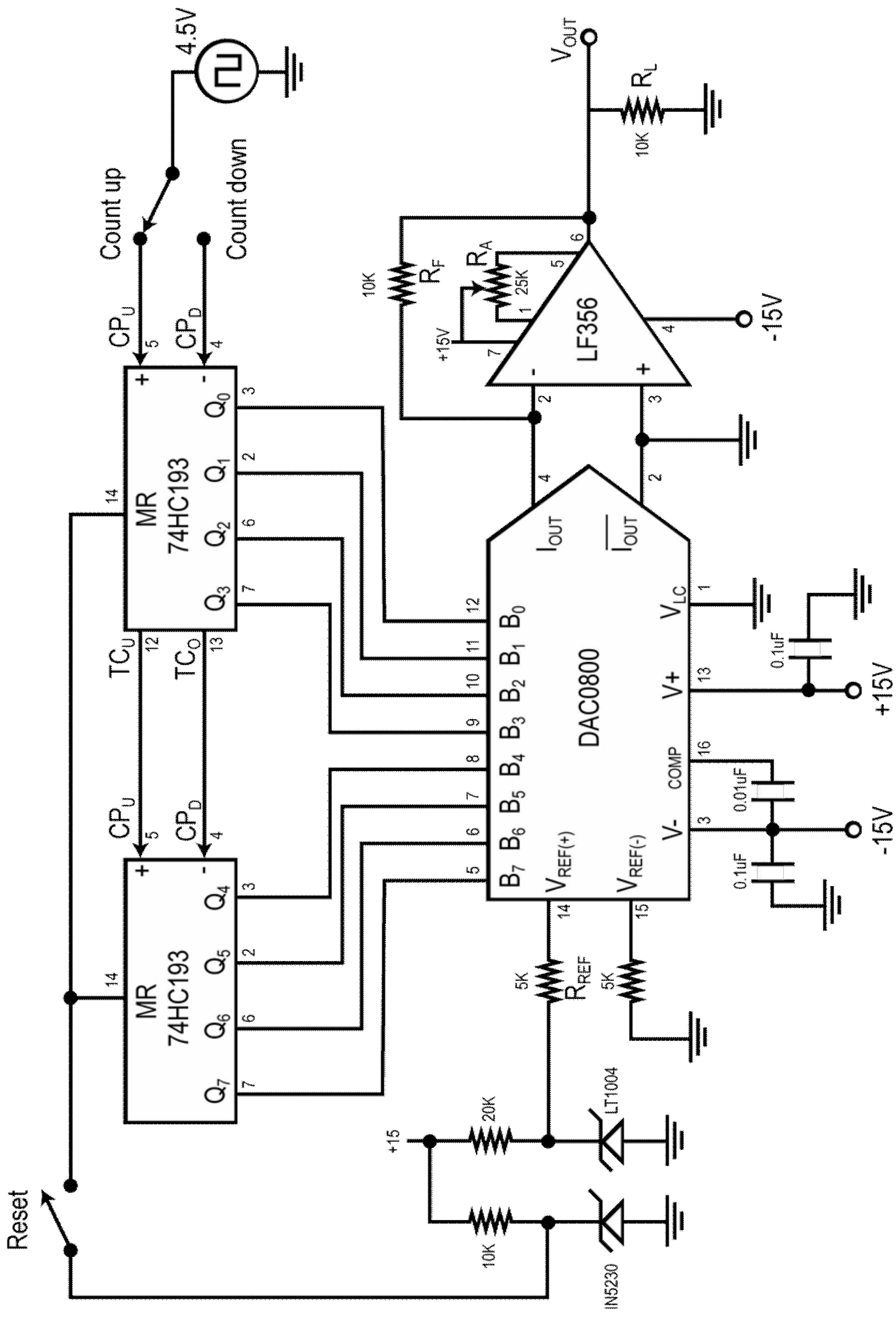
Written Report

Write a report, which describes how Circuit #1 could be controlled or modified to produce a triangular wave voltage at the V_{OUT} terminal of the DAC circuit. If you modify the circuit, provide a drawing showing your proposed modifications. The length of the report and the format are up to your instructor.

Circuit #1


V_OUT
R_L
10K
R_F
10K
R_A
25K
+15V
LF356
-15V
DAC0800
I_OUT
I_OUT
B_0
B_1
B_2
B_3
B_4
B_5
B_6
B_7
S_0
S_1
S_2
S_3
S_4
S_5
S_6
S_7
S_G
V_LC
V+
COMP
V-
V_REF(+)
V_REF(-)
0.1uF
0.01uF
0.1uF
+15V
-15V
5K
R_REF
5K
20K
10K
+15
LT1004
IN5230
7404
+5V
5V
10Hz

Circuit #2


4.5V
Count up
Count down
Reset
CP_U
CP_D
TC_U
TC_O
MR
74HC193
74HC193
DAC0800
LF356
V_OUT
R_L
10K
R_F
10K
R_A
25K
+15V
-15V
-15V
+15V
I_OUT
V_LC
V+
V-
COMP
V_REF(+)
V_REF(-)
0.1uF
0.01uF
0.1uF
R_REF
5K
5K
20K
10K
+15
LT1004
IN5230