Analog-to-Digital Converters

Lab Summary: The purpose of this laboratory experiment is to introduce the concepts associated with the conversion of an analog signal to a digital signal utilizing an analog-to-digital converter (ADC). Calculations will be made on the circuits constructed from readily available components. At the completion of the laboratory experiment, the student will develop a written report associated with the converter circuit.

Lab Goal: The goal of this lab is to construct and operate an analog-to-digital converter circuit, identify its major components, and perform measurements associated with the operation of the converter and its specifications. This will be accomplished using an analog-to-digital converter circuit that uses LEDs to indicate the logic level of each digital output. The analog input signal is produced by a potentiometer that allows the input to be varied over the total input voltage range.

Learning Objectives

1. Construct an analog- to-digital converter test circuit.
2. Describe the function and operation of each major component of the circuit.
3. Measure the DC input voltage for various digital output signals.
4. Measure the DC input voltage required to produce turn on and off for each "bit" of the ADC binary output.
5. Measure the ADC parameters against the primary specifications for the ADC.

Grading Criteria: Your lab grade will be determined by your performance on the experiment, the lab questions, and the content and quality of your laboratory report.

Time Required: 2 to 4 hours

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.

Equipment and Materials

Part	Quantity
Equipment:	
DC Power Supply 15 volt	1
Digital Multimeter to measure DC voltage	1
Oscilloscope 50 MHz	1
Electronic Trainer or breadboard	1
Components:	
Hookup Wire	As required
SPST Switch	1
10 kΩ Fixed Resistor	1
20 kΩ Fixed Resistor	1
1.3 kΩ Fixed Resistor	8
10 kΩ Variable Resistor (preferably multi turn for improved control)	1
0.1 µF 100 V_{DC}	1
10 µF 35 V_{DC} Tantalum	1
150 pF 100 V_{DC}	1
LED (any color)	8
ADC0804 Analog-to-Digital Converter IC	1
LT1004 2.5 Voltage Reference	1

Introduction

One of the most common circuits used to convert an analog signal into a digital signal utilizes a circuit referred to as an analog-to-digital converter. The topography used within different ADCs is covered in the WRE Data Conversion Module, Part 2. The method used by the converter in this experiment is the successive approximation as it is the lowest cost and one of the simplest to use.

The accuracy of an analog-to-digital converter (ADC) is partially dependent on the accuracy of the voltage reference used in the circuit. This ADC converter circuit utilizes a LT1004 - 2.5 V_{DC} voltage reference which has output characteristics of 2.470 minimum and 2.520 maximum with 2.500 typical. The maximum reference voltage for this converter is 5 volts. One of the advantages of this converter is its ability to be operated using a reference voltage that is established by a resistor divider network. This method is termed as ratiometrically and it allows the reference voltage to be set at any value up to 5 V_{DC}. With a voltage reference of 2.500 V, the maximum un-corrected error is ±1 LSB. This means that if nothing is done to eliminate errors associated with this ADC, the maximum error we should see is ±1 LSB.

The analog input for this converter is a differential input, which allows the circuit to reduce the common mode noise found on noisy input leads. The maximum input voltage is determined by the magnitude of V_{CC} which is limited to 6.5 volts, but can range from a minimum of 4.5 V_{DC} to the 6.5 V_{DC} maximum. The range of input voltages for the ADC0804 is from a minimum of Gnd minus 0.05 V_{DC} and the maximum of V_{CC} + 0.05 V_{DC}. One characteristic of this ADC is the requirement that the analog and digital systems have separate grounds to avoid digital noise from getting into the analog input circuit. A separate bus should be used for each system ground and they should be connected together at only one point. This point should be the negative terminal of the 5 V_{DC} power supply.

When this ADC converted is first energized, it must have pins 3 and 5 momentarily connected to the digital ground bus to assure the conversion process will begin. Once the ADC has begun the conversion process, it requires a maximum of 114 µS to perform a conversion when the clock frequency is 640 kHz. The conversion process associated with the successive approximation register of an ADC0804 requires eight clock cycles for each bit that is tested. Therefore, it takes sixty four clock cycles for each complete conversion. With the clock frequency specified in the ADC specifications at 640 kHz, the ADC0804 requires 100 µS to complete a conversion. This can be calculated as follows:

$$f_{CLOCK} = 640 \text{ kHz}$$

$$t = \frac{1}{f_{CLOCK}} = \frac{1}{640 \text{ kHz}} = 1.5625 \times 10^{-6} \text{ sec/cycle}$$

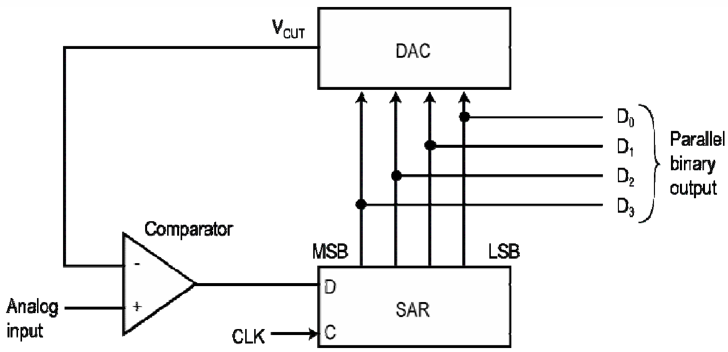
Conversion requires 64 clock cycles, then

$$\text{Total conversion time} = 64 \text{ clock cycles } \times 1.5625 \times 10^{-6} \text{ sec/cycle}$$

$$= 100 \times 10^{-6} = 100 \ \mu S$$

Therefore, this converter chip can convert an analog input voltage every 100 µS.

The ADC0804 converter, shown below as a simplified block diagram, requires a DAC and a successive approximation register controller to provide the digital output signal. One of the problems associated with the time required for conversion is the sixty four clock cycles. During the time required for sixty four clock cycles to occur the input analog signal may change. This will result in an output error. This error is the aperture error and is eliminated by using a circuit which captures the input analog signal and holds it for the required sixty four clock cycles. This circuit is known as a sample and hold circuit and is built on some converted chips. The ADC0804 does not have a sample and hold circuit and therefore can have aperture error if the input signal changes faster than the time required for a complete conversion cycle.

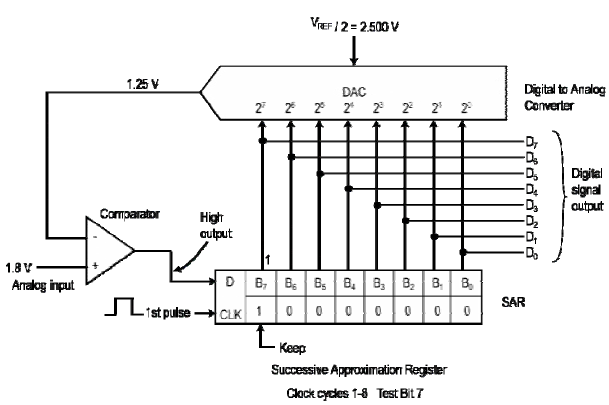


ADC0804 Converter Simplified

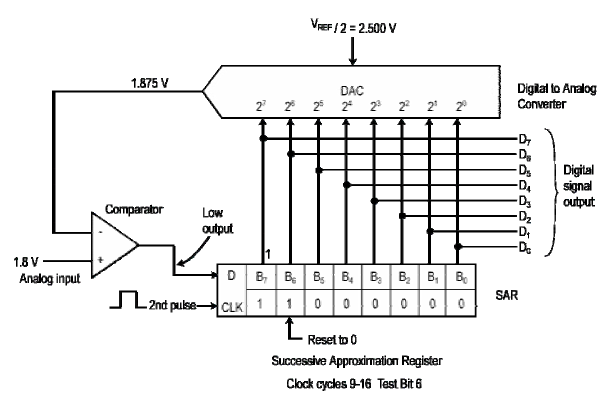
A complete block diagram for the ADC0804 is shown following the procedure. The detailed description can be found in the data sheet.

In the successive approximation converter the binary output value is tested against the analog input signal to determine the best binary value to represent the input analog signal. The successive approximation register (SAR) has two basic inputs, a Clock and D for data. The D input is a binary value of one or zero. At the beginning of the conversion cycle, the SAR is loaded with all zeros. The clock signal applied to the SAR causes the controller in the register circuit to place a binary one in the most significant digit (MSD) place, B_7. The DAC then has an input value of 10000000_2 and will produce a voltage proportional to the value of $V_{REF}/2$, which is 2.500 V, so for this input the DAC output is 2.5 V. The DAC output voltage is compared to the analog input signal and the comparator will have an output voltage which will represent a binary one or zero to the SAR. If a zero is applied to the D input of the SAR, the SAR controller will reset the value stored in B_7 to a zero and place a one in the next lowest bit, B_6. This process is repeated for each bit until all are tested. After the last bit has been tested, the SAR controller will transfer the binary content of the register to an output latch and take the $\overline{INTR}$, pin 5, low to indicate to other circuits that the converter has completed the conversion.

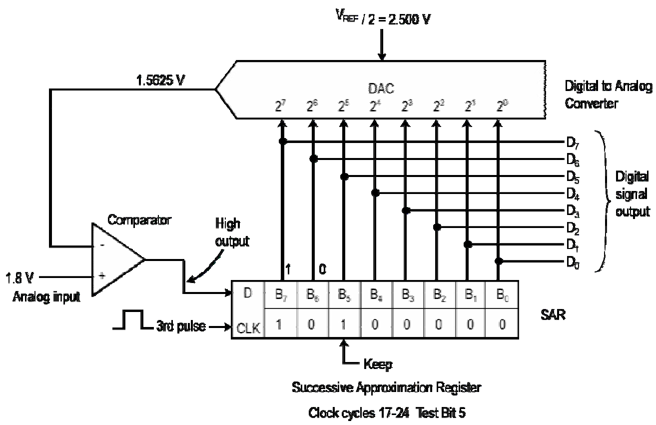
Study the following figures and see how each bit of the binary output affects the decision the SAR must make to arrive at the correct binary output. Note on each figure below the clock is shown a single "pulse" for each conversion, realize each clock "pulse" is eight clock cycles.



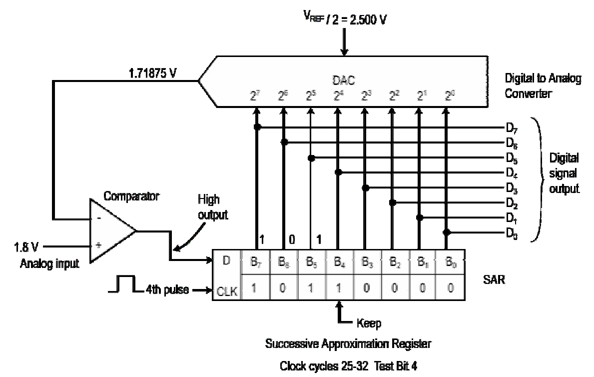
Text Bit 7



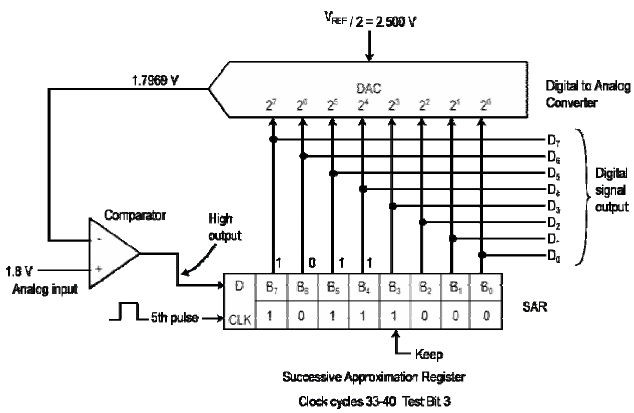
Test Bit 6



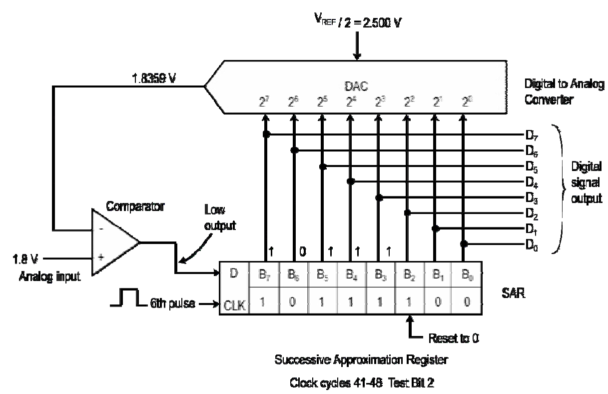
Test Bit 5



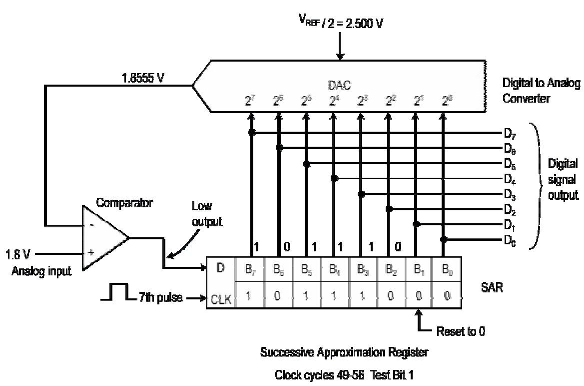
Test Bit 4



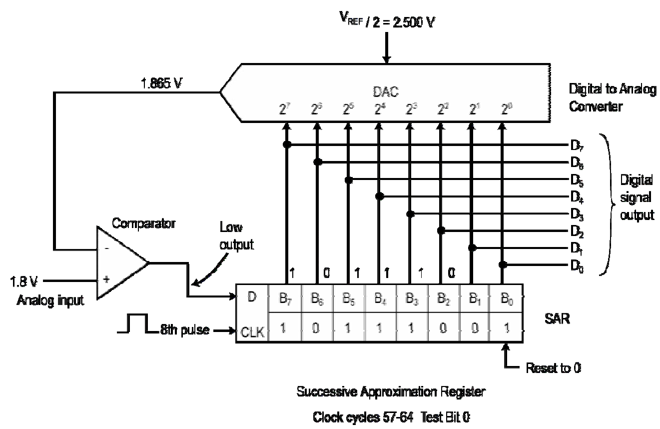
Test Bit 3



Test Bit 2

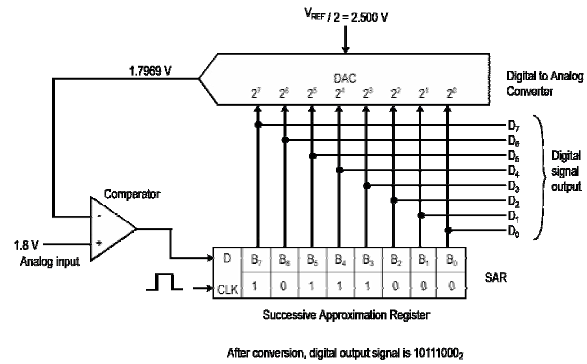


Test Bit 1



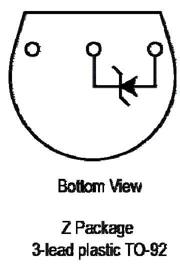
Test Bit 0

As you can see from the above figures, the successive approximation converter requires eight conversion periods which consist of eight clock cycles each. Upon completing the conversion process, the ADC has an output of 10111000_2 in the output latch.



After Conversion

The ADC circuit used in this experiment requires an external reference voltage that is applied to the $V_{REF}/2$ terminal (9). For this experiment, we will use a LF1004 -2.5 voltage reference IC. This IC comes in a three terminal TO-92 package (LF1004CZ-2.5) as shown below.



LF1004 -2.5 Voltage Reference IC

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.

Lab Procedure

Note: The Circuit schematic, tables, and questions follow the procedure.

1. Use the schematic following this procedure and construct Circuit 1.
2. Perform operational checks and specification measurements to determine if the ADC is operating within specifications.
3. Using the oscilloscope, measure the wave found on pins 4 and 19 of the ADC0804 chip. For your chip and components, calculate the total conversion time for the circuit and compare the value to the value specified in the data sheet.

   t_{Clock} = **103 µ** sec.

   Total conversion time = ______ sec.
4. After completing the construction of the circuit check your circuit one more time for correctness, then energize the 5 V_{DC} supply. Measure the voltage at the ADC0804 terminal 9 and enter the value below:

   $V_{REF}/2$ = ____________
5. Complete Table 1 by calculating the required analog input voltage for a specified binary output signal.

   $$\text{Analog Input Voltage} = \frac{B_{10}}{2^N} \times V_{REF}$$

   Where B_{10} = Decimal value of the binary output signal

   N = Number of bits in output

   V_{REF} = Reference voltage

   a. Table 1 has two areas labeled MS Group and LS Group. Each has four columns under each heading. MS represents the four most significant digits of the output and LS represents least significant digits of the output. An eight bit word could be represented by two HEX digits as indicated by the far left column.

   b. Complete the columns labeled VMS and VLS for the voltage which would be required at the analog input to cause the output to give the indicated binary output. As an example of the required calculation, the following is for the HEX number FF.

   $$15/16 \times V_{REF}/2 \times 2 = 15/16 \times 2.500 \times 2 = 4.6875\,\text{V}$$

   The LS value would be: $15/256 \times V_{REF}/2 \times 2 = 1/256 \times 2.500 \times 2 = 0.29296875\,\text{V}$

   c. Complete the table by calculating the required voltage for each output value.

NOTE: When making measurements, the group not being tested is set to all zeros. As an example, when testing the MS group for HEX D, the total binary value would be 11010000_2. When testing LS group the MS group is set to zeros. As an example HEX D, the total binary value would be 00001101_2.

6. Measure the analog input voltage on the constructed circuit required for each of the entries in Table 2.

NOTE: The binary output signal is driven by a latch which has an active low output. This means the LED will be illuminated when the binary value is zero.

7. Table 2 provides values of analog input voltages which will produce a given binary output. Compare the results in Table 2 with the calculations in Table 1.
8. Test the range of values of analog input voltages which will result in a given digital output.
9. Complete Table 3 for the analog input required to just produce the required binary output. Continue to raise the voltage until the binary value changes. Record the values and note the analog input must change an amount equal to approximately the value of the LSB to cause the binary output to change.

Table 1

HEX	BINARY	Fractional Binary Value For								Output Voltage Center Values with VREF/2 = 2.500	
		MS Group				LS Group				VMS Group	VLS Group
F	1111				15/16				15/256	4.6875	0.0.2930
E	1110			7/8				7/128			
D	1101				13/16				13/256		
C	1100		3/4				3/64				
B	1011				11/16				11/256		
A	1010			5/8				5/128			
9	1001				9/16				9/256		
8	1000	1/2				1/32					
7	0111				7/16				7/256		
6	0110			3/8				3/128			
5	0101				5/16				5/256		
4	0100		1/4				1/64				
3	0011				3/16				3/256		
2	0010			1/8				1/128			
1	0001				1/16				1/256		
0	0000										

Table 2

		Input Voltage Center Values with VREF/2 = 2.500	
HEX	**BINARY**	**VMS Group**	**VLS Group**
F	**1111**		
E	**1110**		
D	**1101**		
C	**1100**		
B	**1011**		
A	**1010**		
9	**1001**		
8	**1000**		
7	**0111**		
6	**0110**		
5	**0101**		
4	**0100**		
3	**0011**		
2	**0010**		
1	**0001**		
0	**0000**		

Table 3

BINARY	Input Voltage		
	Maximum Value	Minimum Value	Difference
10000000			
01000000			
00100000			
00010000			
00001000			
00000100			
00000010			
00000001			
00000000			

Post Lab Questions

1. Explain why a differential analog input is of value to this ADC.

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

3. What would be the affect of using a reference voltage, $V_{REF}/2$ = 256 mV?

4. Why would you desire to use such a low reference voltage?

5. Why were there two different waveforms when you measured the frequency on pins 4 and 19?

6. Why do you think this ADC requires eight clock cycles for each binary digit conversion?

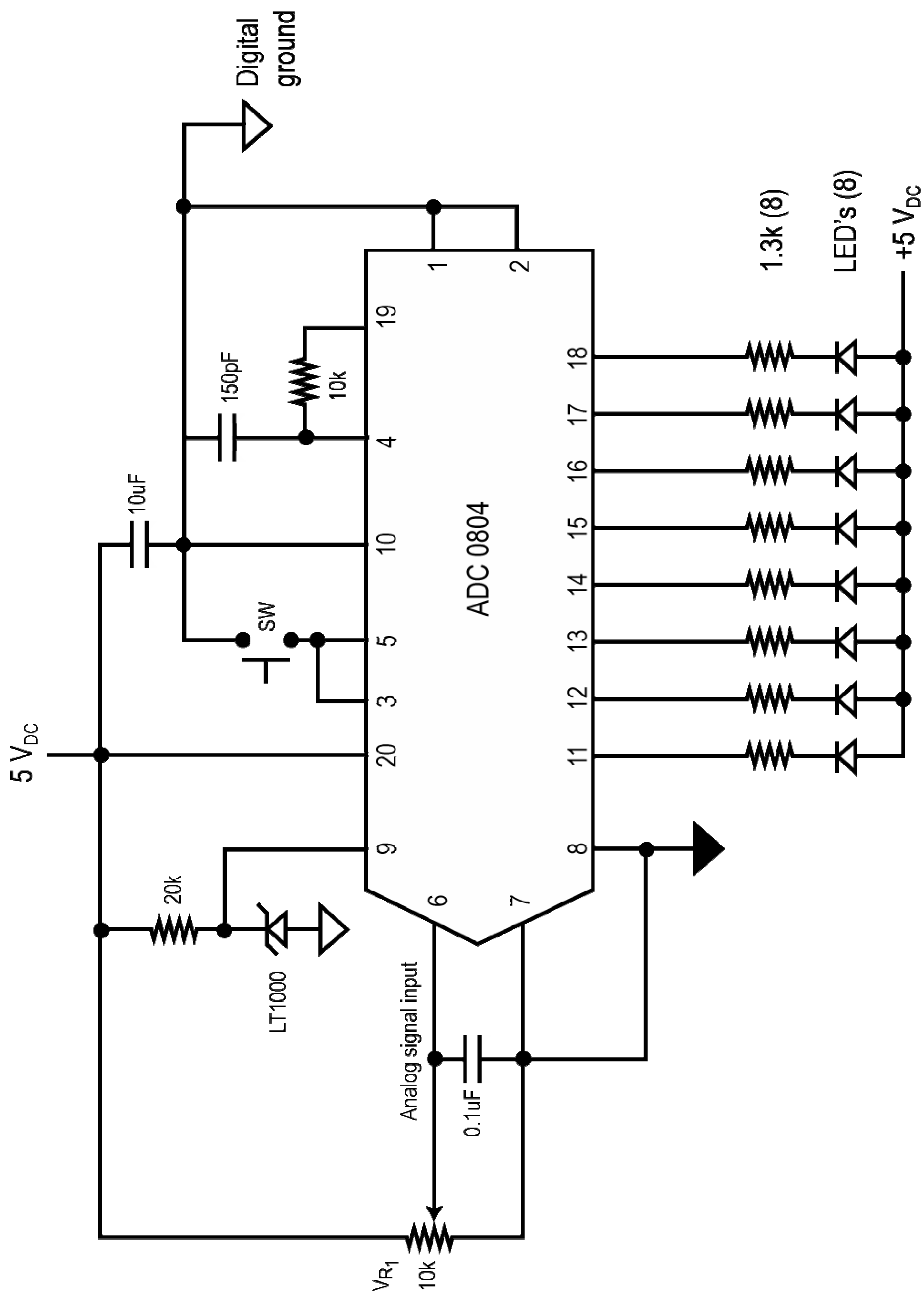
7. What was learned from the data associated with Tables 2 and 3?

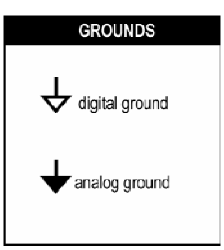
Pushing the Envelope (Requires Internet Research)

What affect would it have on the ADC performance if the clock pulse applied to pin 5 were to have a duty cycle of 10%?

Written Report: Write a report describing how you would use the knowledge you have gained in this experiment to build a test circuit to demonstrate the relationship between clock frequency and analog signal input frequency for an ADC converter circuit. The length of the report and the format are up to your instructor.

Circuit #1


Digital ground
1.3k (8)
LED's (8)
+5 V$_{DC}$
150pF
10k
10uF
SW
ADC 0804
1
2
19
4
10
5
3
20
9
6
7
8
11
12
13
14
15
16
17
18
5 V$_{DC}$
20k
LT1000
Analog signal input
0.1uF
VR$_1$
10k


GROUNDS
digital ground
analog ground

ADC0804 Block Diagram