# Analog-to-Digital / Digital-to-Analog

**Acknowledgements:** Developed by Ronnie Wilson, Faculty of Austin Community College, Austin, Texas. Special thanks to Electronic Workbench for providing this simulation as a stand-alone activity.

**Special Notes:** This simulation should be completed after the WRE Data Conversion Part 2 Module and before starting the Analog-to-Digital/Digital-to-Analog Converters Lab.

**Approximate Time Required:** 1 hour

**Equipment:** This simulation requires no special software to run, but your computer needs to have internet access to download the required simulation file from the WRE web site.

**Simulation Summary:** The purpose of this interactive simulation is to prepare you for the hands-on labs related to analog-to-digital /digital-to-analog converter. It introduces the operating characteristics typical of an analog-to-digital /digital-to-analog converter circuit.

Improvements in current day integrated circuit manufacturing technology have made the integration of AD and DA directly on chips, which have more complex functions. This is especially true of the sigma-delta converters. Studying the operation inside some of these fully integrated circuits helps our understanding of the internal operation of a more complex integrated circuit.

**Simulation Goal:** Observe the operation of a representative DA converter, an AD converter, and the demonstration of Nyquist Theorem utilizing the AD and DA converter circuits.

## Learning Objectives

1. Explain the input-output terminal relationships of AD and DA converters
2. Determine the binary input signal for a given analog output signal.
3. Determine the affect the reference voltage has on the DA converters output signal.
4. Determine the affect a failed binary bit has on the analog output signal.
5. Determine the required analog input signal for a binary output signal of an AD converter.
6. Determine the affect the reference voltage has on an AD converters output signal.
7. Determine the affect a failed binary output signal bit has on the ADC converter.
8. Measure the affect of varying the input analog signal frequency for an AD-DA converter circuit.
9. Demonstrate the Nyquist Theorem.

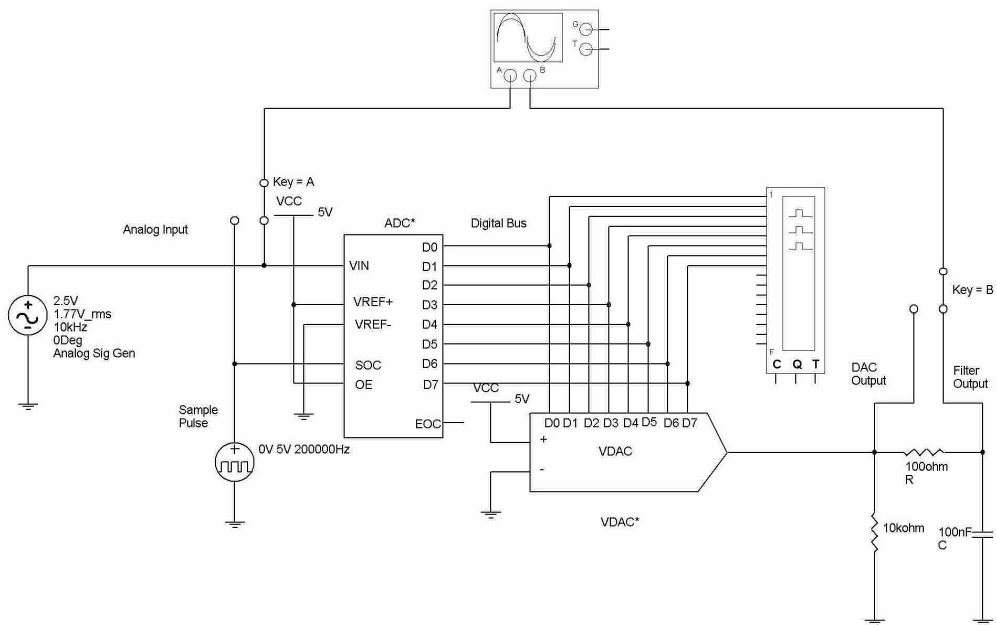
**Grading Criteria:** Your grade for this interactive simulation will be determined by your performance on the simulation, the simulation questions, and quality and content of your final written report.

## Simulation Preparation

1. Print a copy of the procedure to use as a reference, schematic, and workbook while completing the simulation.
2. Read the Introduction section.
3. Review the Simulation Procedures.

**Software Alert:** When performing circuit simulations, failing to read and follow directions exactly can result in incorrect circuit operation and data measurements. For instance, if you fail to stop or pause the circuit at the appropriate times and leave circuits running, functions within Multisim 7 may become inoperative.

## Introduction




Analog-to-Digital and Digital-to-Analog Circuit

In this circuit, the major components are the AD and the DA converters. This circuit is used to measure the affect of sampling frequency changes as related to an input signals frequency and to demonstrate the Nyquist theorem.

There are two signal sources in this circuit. One is the clock that is connected to the AD clock terminal, labeled SOC (for start of conversion). It is set at a 200 kHz square wave.

The other signal generator is a sine wave generator, which is initially set at 10 kHz. The output of the DA is connected to a filter which can be switched in or out. It is used to smooth the stair step output of the DA.

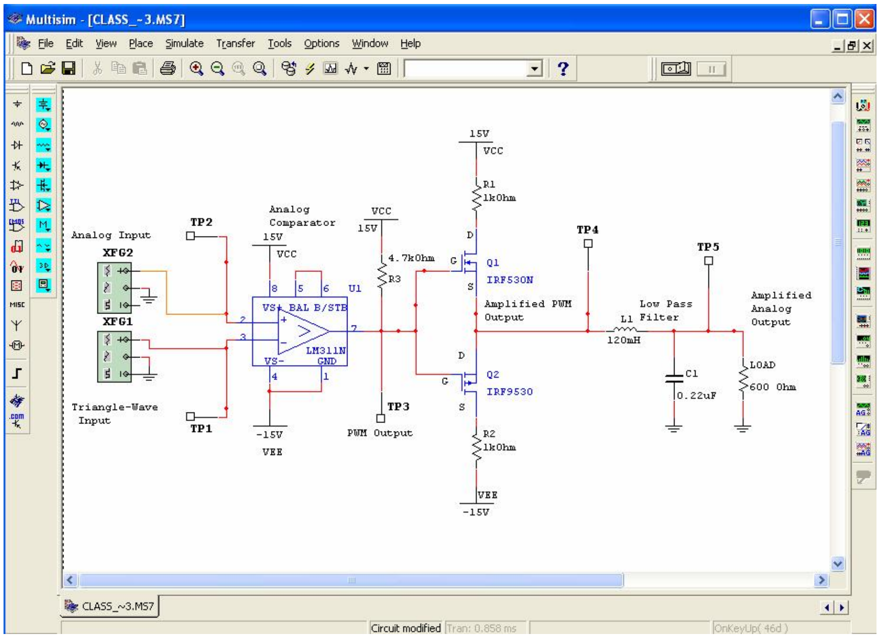
With the oscilloscope, both the input signal and output signal can be viewed at the same time. As you run the simulation of an input signal at 10 kHz being sampled at 200 kHz you will note the input and output signals appear to be relatively the same.

## Simulation Procedures

NOTE: The schematic, tables, and lab questions are at end of this section.

### Using Multisim

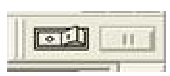
1. Open the simulation circuit AD-to-DA Simulation Lab 3.
2. If you have not used Multisim before, please review the following section.




a. The simulation circuit is in the center of the screen.

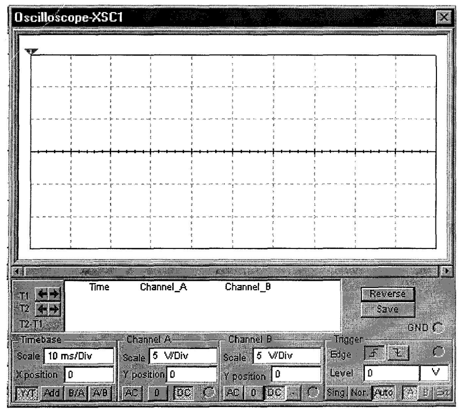
NOTE: This is an example only. The circuit you are using is at the end of this procedure.

b. The Run/Stop and Pause/Resume simulation buttons are on the tool bar near the Help (?) button. Run/Stop is on the left and Pause/Resume is on the right.



c. This simulation uses an oscilloscope. If you have not used an oscilloscope in Multisim, please review the following steps.

d. To use the oscilloscope, place your mouse over the instrument and double click.




e. The slide bar below the oscilloscope screen can be used to move and adjust the wave image in the screen when the simulation is paused.

f. To set or change values, positions, or other parameters, place your mouse over the entry you want to change. When the hand appears, click once and up/down arrows will appear to allow you to scroll through preset values. Be sure to note the measurement units.

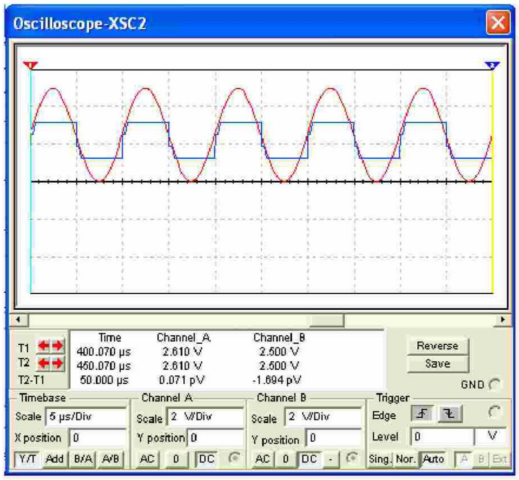
g. To get the most accurate reading, adjust the scale so the wave is as large as it can be without clipping.

h. The Reverse button the right side changes the changes the background of the scope screen to white from black.

**ADC to DAC Simulation**

2. Press Run/Stop to start the simulation.
3. Double click on the oscilloscope to view the input signal and output signal.
4. Press the B key on your keyboard and note the stair step output from the DA. Since the input binary values are discrete values, the analog output can only be values related to the input values. The filter is used to smooth out these steps at the lower input frequencies.
5. Press Run/Stop to stop the simulation.
6. Double-click on the input signal generator and locate the frequency setting.
7. Change the input frequency to 100 kHz and run the simulation again. Notice the output from the DA is now a rectangular wave that is of the same frequency as the input, but does not look like the input. This is because the DA output changes value at a frequency, which is the difference between the sampling frequency and the input signal frequency, and if you placed a dot at each of the points where the output wave changed value you would find only a 100 kHz sine wave would pass through all of the points you marked. Although the output from the DA is not sinusoidal, it does represent the required values to implement a sine wave from the output data.

8. Study the figure below which is the DA output signal for a 100 kHz sine wave input signal.




   a. The red trace is the input sine wave.

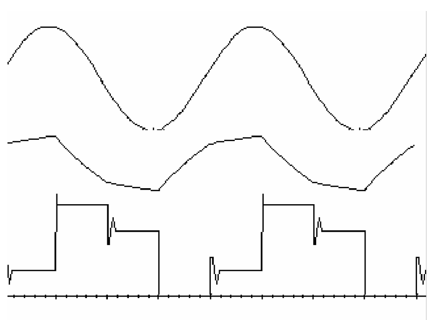
   b. The blue trace is the DA output signal.

   c. Note the frequency of the output is the same as the input. Also, note the output changes values twice for each sine wave cycle.

9. To experience the Nyquist theorem we must either increase the input signal frequency or reduce the sampling frequency of the circuit. For this portion of the simulation, we will increase the input signals frequency until it exceeds the Nyquist frequency for the circuit.

   a. First increase the input signals frequency to 150 kHz.

   b. Run the simulation and analyze the oscilloscope data. Notice the output is no longer at the same frequency as the input. If you study the output, you will find a relationship between the frequency of aliasing and the output wave shape. This can be seen in the figure below of a 50 kHz sine wave and the output from the DA with and without the output filter.



Relationship between Frequency of Aliasing and Output Wave Shape

   c. Increase the input signals frequency to 200 kHz.

   d. Run the simulation and analyze the oscilloscope data. Is the DA output signal what you expected? What is the frequency?

**Post Simulation Questions**

1. As you increase the frequency of the input signal what occurs to the output frequency of the DA?

2. If the input frequency was 66.67 kHz, how many level changes would the output of the DA make per cycle?

**Written Report:** Write a report that addresses your observations of the output waveform associated with the DA output changes as the AD signal input frequency changes.

Analog-to-Digital and Digital-to-Analog Converter Schematic