EE 210 Lab Exercise #4: Voltage Dividers & D/A Converters

ITEMS REQUIRED	EE210 crate, EE210 parts kit, DMM, T-connector, 50Ω terminator, Breadboard
ASSIGNMENT	Lab report due at the beginning of the next lab period
Data and results from all of the numbered, bolded material in the procedure sections must be included and clearly numbered in the data section of the lab report.	

Introduction

This lab deals with simple resistive circuits. In the first exercise, the properties the voltage divider circuit will be examined. In the second exercise, an extension of the voltage divider used for digital to analog conversion will be explored.

Exercise 1: The Voltage Divider

One very useful, simple circuit consisting of resistors in series is the voltage divider. The voltage divider is commonly used to attenuate voltage, or produce multiple voltage levels from a single voltage supply. This characteristic should be evident due to the voltage drops incurred by series resistances.

Using Ohm's Law, Vout in Figure 1 can be expressed in terms of Vin as follows:

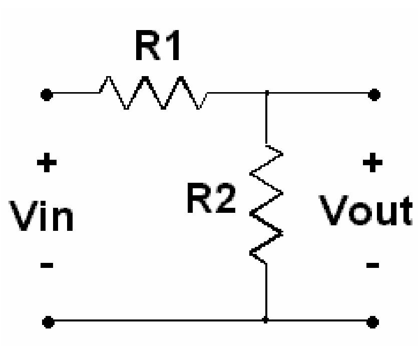


Figure 1: The voltage divider

$$Vin = i(R1 + R2)$$

$$i = \frac{Vin}{R1 + R2}$$

$$Vout = iR2 \longrightarrow \boxed{Vout = Vin\frac{R2}{R1 + R2}}$$

Notice that Vout will always be less that Vin, by a proportion that is dependent on R1 and R2.

Exercise 1: Procedure

1. Adjust the waveform generator to output a 6Vp-p, 100Hz sinusoid.

2. Using the waveform generator as Vin and a 10kΩ potentiometer (variable resistor) from the parts kit as R2, design a voltage divider circuit having a Vout of 2Vp-p when the potentiometer is set to 5kΩ. **(1) Sketch the voltage divider and include the resistor value calculations.**

3. Using the DMM, adjust the potentiometer to 5kΩ between pins B and either A or C – it doesn't matter (see Figure 2 below). These will be the pins used in the circuit. Construct the voltage divider circuit.

4. Monitor the input and output of the circuit simultaneously using the oscilloscope. **(2) Make a printout of these waveforms including Vp-p measurements. (3) Vary the potentiometer and record the range of the output.**

5. Exchange the resistors and **(4) vary the potentiometer and record the range of the output.**

6. With the potentiometer set at 5kΩ, adjust the waveform generator to have a dc offset of -1V. **(5) Make a printout of these waveforms including both Vavg measurements and Vp-p of Vout. (6) Vary the potentiometer and record the effect on the amplitude and dc offset of the output voltage.**

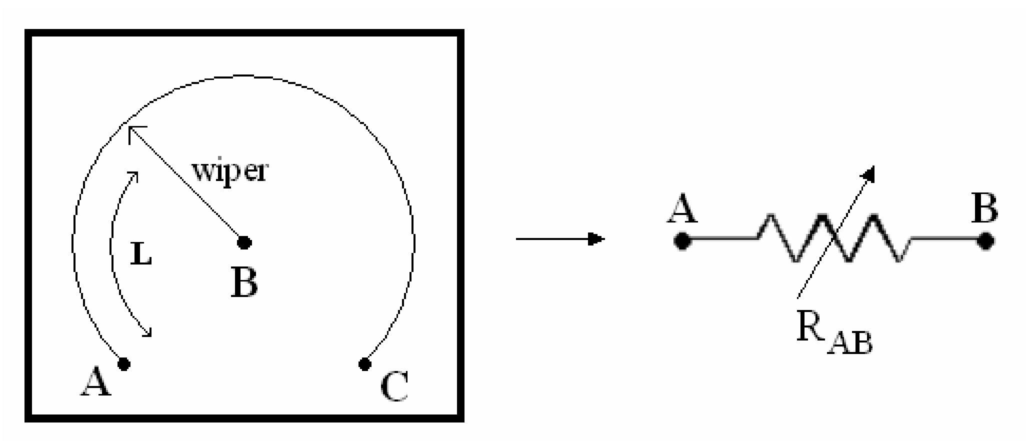


Figure 2. Potentiometer and circuit symbol

$R_{AB}=(\rho L)/A$

where ρ (resistivity) and A (area) are constant

and L (length) can be varied with the wiper arm

Exercise 2: The D/A Converter

Preliminary Definitions

Analog signal: May assume a continuous range of values for both for both time and amplitude. Most "real world" signals are analog. Examples include: Audio emanating from a loudspeaker and photographs taken with a film exposure camera.

Digital signal: Is characterized by discrete, uniform time steps and is quantized to discrete values in amplitude. Typically, an analog signal is sampled and quantized to create a digital signal. Examples include: Information stored on a Compact Disc and computer images.

Binary representations: Digital information is encoded into binary symbols before it can be processed and stored in computers and other digital electronic devices. These symbols consist of a series of 0's and 1's (bits) representing binary low and high (or off and on) respectively. Binary numbers are used in computers and other electronic devices because electronic "switches" (commonly transistors) can be easily used to produce the binary on/off states. Common base 10 or decimal numbers, such as voltage magnitudes for instance, are represented by one of the 10 digits (0-9) separated by placeholders in powers of 10. These numbers can also be represented in binary, using only 2 digits (0-1), by using placeholders in powers of two.

Example: **1932** decimal and binary representations

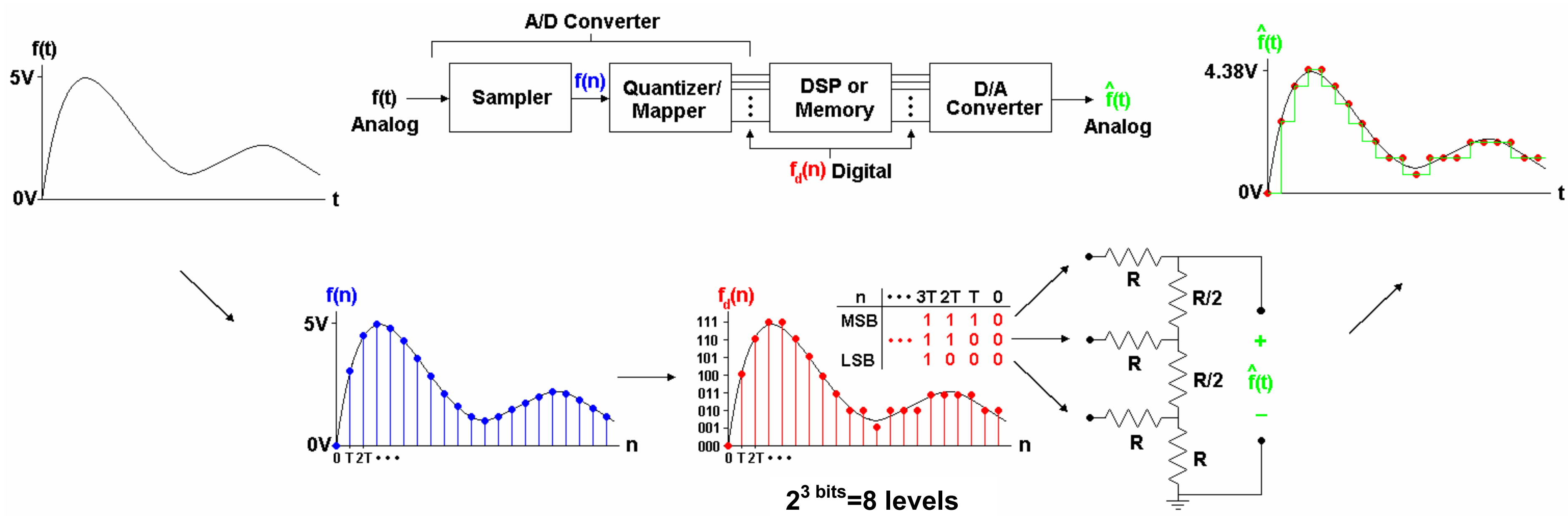
Decimal (base 10) = **1932** >>
$(1x10^3)+(9x10^2)+(3x10^1)+(2x10^0)$ =**1932**

Binary (base 2) = **11110001100** >>
$(1x2^{10})+(1x2^9)+ (1x2^8)+(1x2^7)+(0x2^6)+(0x2^5)+(0x2^4)+(1x2^3)+(1x2^2)+(0x2^1) +(0x2^0)$=**1932**

In binary, the digit to the left is called the most significant bit (MSB) because it represents the largest placeholder. The digit to the right is called the least significant bit (LSB) because it represents the smallest placeholder. It can be seen that more bits are needed in the binary representation, as the values grow larger.

Digital-to-analog (D/A) converters: A device used in many control and signal-processing applications for converting digital information (binary) used in electronic devices into usable "real world" analog information. For example, CD players use D/A converters to convert digital audio information that is read from the CD into an analog audio signal. Typically, the inputs to the D/A converter are digital logic signals, 0V and 5V for binary "low" and "high" respectively.

3-bit D/A Conversion Example



3-bit
D/A Converter

Sampler – Samples the continuous-time analog signal at uniform time instants T, creating a discrete-time signal with continuous amplitude.

Quantizer/Mapper – Assigns the samples of the discrete-time signal a binary value based on the desired number of levels, creating a digital signal that is both discrete in time and amplitude.

Digital signal Processing (DSP) or Memory – Manipulates or stores the digital signal. The signal is not altered by this block in the example.

D/A Converter – Converts the digital signal back into an analog signal that is both continuous in time and amplitude. The resulting signal in the example is an approximation of the original analog input signal f(t).

Part 1: 4-bit Ladder Resistive Summing Network

In this exercise, a digital (binary) output will be converted to an equivalent analog voltage using a 4-bit R–R/2 D/A converter shown in Figure 1. For a 4-bit digital input, the analog output should have 2^4 or 16 possible values since there are 16 combinations of digital input voltages. Each of the 16 combinations is shown in Table 1. Therefore, the analog output will not be smooth, but instead will be discretized into 16 steps. The discretization can be reduced by increasing the number of binary input bits, since the number of discrete steps goes as 2^n, where n is the number of bits.

Basic circuit theory (nodal analysis) can be used to analyze the circuit. However, the Superposition Theorem simplifies the circuit analysis. To use superposition, an input signal (+ 5 V) is applied to only one input at a time with all of the other inputs at 0 V (ground). The output voltage resulting from each input combination is determined and is labeled $V_{out,A}$, $V_{out,B}$, $V_{out,C}$, and $V_{out,,D}$. To find the total output voltage, the output voltage due to each of the input combinations are added. For example, for this 4-bit R–R/2 D/A converter, the total output voltage $V_{out,total}$ is given by:

$$V_{out,total} = V_{out,A} + V_{out,B} + V_{out,C} + V_{out,D}.$$

This procedure can also be used to determine a general expression for $V_{out,total}$ in terms of the input voltages V_A, V_B,V_C, and V_D. In this case, the total output voltage $V_{out,total}$ is given by:

$$V_{out,total} = (V_A + 2V_B + 4V_C + 8V_D) / 2^4$$

Decimal	Binary DCBA
0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111
8	1000
9	1001
10	1010
11	1011
12	1100
13	1101
14	1110
15	1111

Table 1. Analog equivalent of four-bit, digital number.

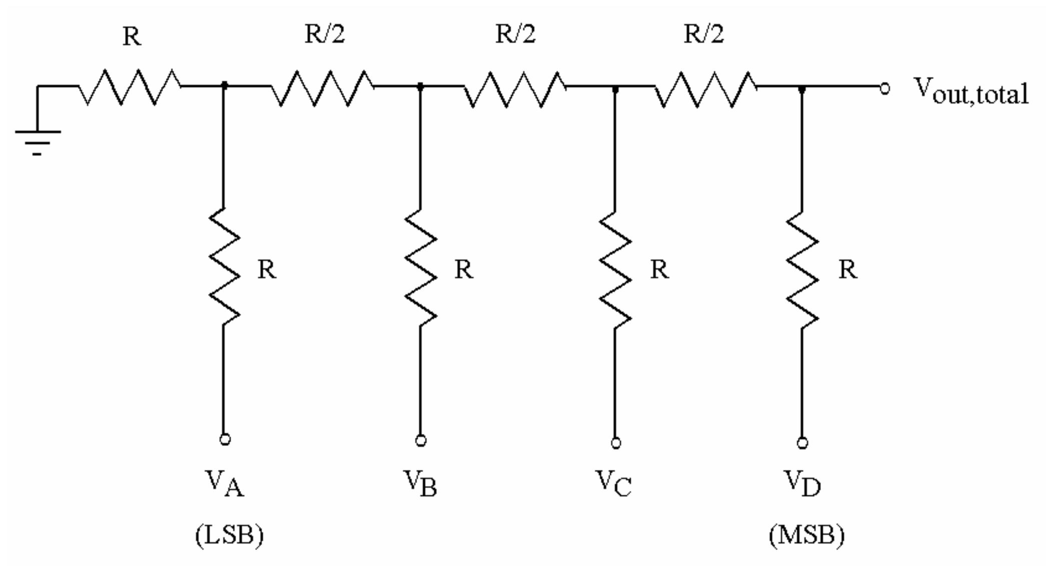


Figure 3. 4-bit R–R/2 D/A converter showing the most significant bit (MSB) and the least significant bit (LSB).

Part 1: Procedure

1. Build the 4-bit R–R/2 D/A converter shown in Figure 3. Let R=20 kΩ – *choose resistors with the same tolerances for consistency*. Place the LSB towards the top of the breadboard for expansion capability.

2. Generate one of the binary inputs from question 3 of the *pre-lab* exercise using the dc power supply and **(7) measure the open-circuit output voltage relative to ground of the D/A converter. Repeat the measurement for the other binary input from the *pre-lab*.**
   Note: 0V indicates that the input <u>*must*</u> *be grounded.*

3. Insert one of the R_{load} load resistors (see Appendix) from the *pre-lab* exercise between the output of the D/A converter and ground, as shown in the *pre-lab* circuit. **(8) Measure the output voltage of the D/A converter using the DMM for each of the input combinations from step 3. Repeat using the other value of R_{load} from the pre-lab exercise.**

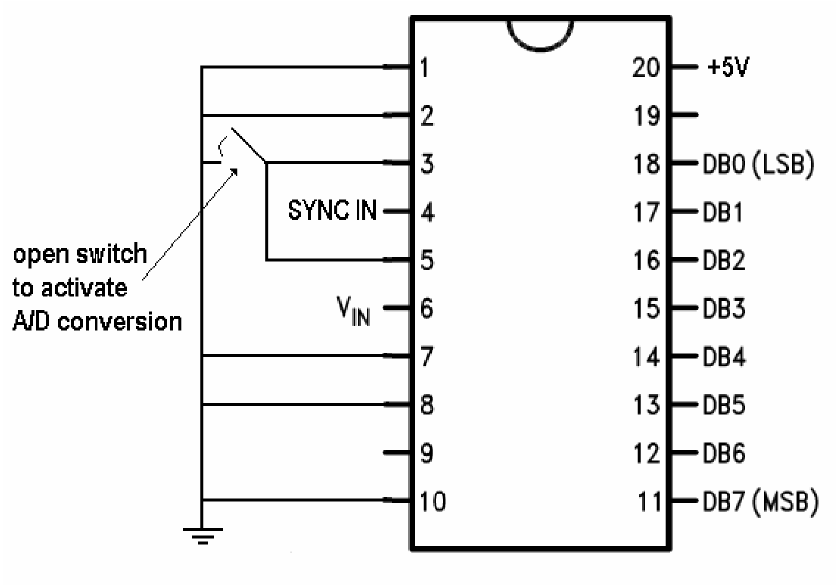


Figure 4. ADC0804LCN A/D converter connection diagram

Part 2: Using time varying input to the D/A Converter

In this exercise, an analog-to-digital converter integrated circuit (ADC0804LCN) is used to generate digital data from the waveform generator. This data is used as the input to the R–R/2 D/A converter. Here, rather than considering only one input combination at a time, the digital input waveforms vary as function of time leading to time varying analog output waveforms. The computer outputs 8-bits, therefore, for this part of the lab the four most significant bits should be used as inputs to the D/A converter.

Part 2: Procedure

1. Disconnect the input voltages and the load resistor from your 4-bit D/A converter.

2. Insert the ADC0804LCN A/D converter chip (from the parts kit) into the breadboard, straddling the gap meant for dual-in-line (DIP) integrated circuit chips.

3. Referring to Figure 4, ground the appropriate pins as shown, creating a wire switch for pins 3 & 5. Using the DC power supply, connect +5V to pin 20. Connect the four most significant bits from the ADC0804LCN A/D converter to the input of the R–R/2 D/A converter.

4. Set the frequency of the waveform generator to 500kHz. Connect the SYNC terminal (without the T-connector and terminator!) of the waveform generator to pin 4 of the A/D converter – this produces the 0-5V square-wave clock signal.

5. Configure another waveform generator for a 5Vp-p 20Hz sinusoid with a DC offset of 2.5V. Connect the OUTPUT terminal of the waveform generator to pin 6 of the A/D converter– this is the waveform that will be converted to an 8-bit digital signal.

6. Using the wire switch, simultaneously disconnect pins 3 & 5 of the A/D converter from ground - this activates the A/D conversion.

7. Using the oscilloscope, simultaneously monitor the sinusoidal output of the waveform generator and the output of the D/A converter. **(9) Make a printout of these waveforms including Vp-p measurements. (10) Determine the number of discrete voltage steps that are displayed between the minimum and the maximum voltage.**

8. Insert one of the load resistors from the *pre-lab* exercise between the output and ground and again monitor the output voltage of the D/A converter. **(11) Make a printout of the waveform including Vp-p measurements. Repeat using the other value of R_{load} from the pre-lab exercise.**

Part 3: 8-bit Ladder Resistive Summing Network

In this exercise, four bits are added to the D/A converter to determine the effect of the number of digital output bits on the analog output waveform.

Part 3: Procedure

1. Disconnect the load resistor from the 4-bit R–R/2 D/A converter.

2. Add the resistors required to make an 8-bit D/A converter and connect the eight MSBs of the A/D converter chip output to the input of the R–R/2 D/A converter chip.

3. Activate the A/D conversion as in Part 2.

4. Using the oscilloscope, simultaneously monitor the sinusoidal waveform generator output and open-circuit output voltage of the D/A converter. **(12) Make a printout of these waveforms including Vp-p measurements. (13) Determine the number of discrete voltage steps that are displayed between the minimum and the maximum voltage.**

Appendix: Circuit Loads

A circuit load is any device that is connected to the output of a circuit that draws current. The larger the load (the smaller the effective/equivalent resistance of the load), the more current that is drawn from the circuit. Loading generally generates an undesirable effect because of finite source resistances (see Lab 5) and must be considered in design situations. For instance, consider the common 60Hz AC power outlet. When an item that draws a large amount of current (such as a large appliance or power tool) is plugged in, it loads the circuit, dimming the lights. This occurs because the inherent resistance of the wiring acts as a voltage divider with any device on the circuit. When a large load is added or more devices are placed in parallel, the value of R2 in the voltage divider equation in Exercise 1 decreases. This effectively decreases the output voltage, leaving less power for the other devices on the circuit. Since source resistances are usually small, it generally takes a large load for these effects to be noticeable or significant, but they should be accounted for in most cases. A load can typically be modeled with a resistor. (see Figure 4 below)

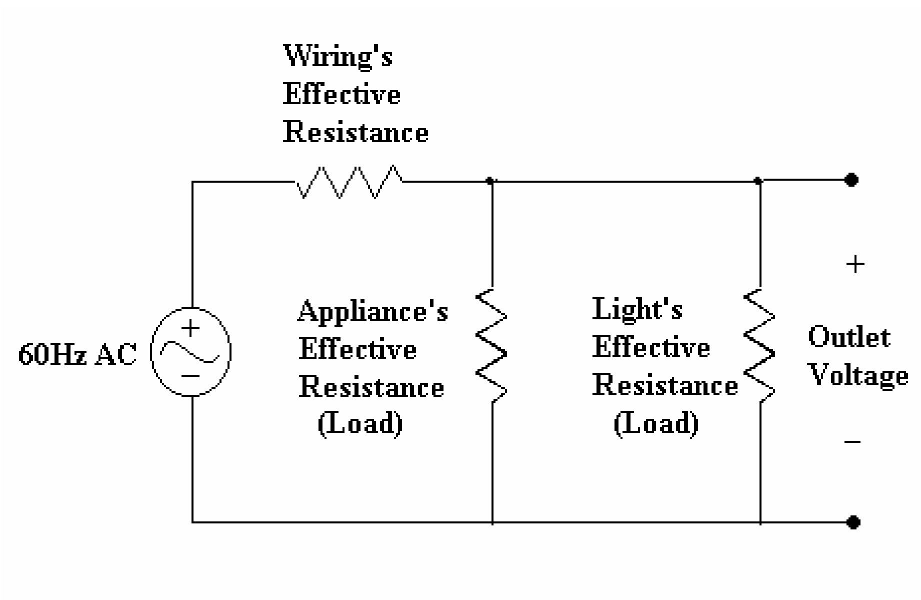


Figure 4: Practical example of circuit loading.

Discussion Questions

Discuss and thoroughly explain each of numbered the concepts below, listed by exercise. When applicable, consider the following items when formulating your responses:

- A comparison of theoretical and experimental results.
- An identification and description of the likely sources of error.
- A description of the purpose and function of each circuit and possible applications.
- A comparison of similar circuits in the lab and the respective functions.
- A discussion of relevant observations, results, and deductions.

<u>Exercise 1</u>

1. What is the relationship between the amplitude of the input and output of the voltage divider? What is the relationship between the DC offset of the input and output of the voltage divider?
2. Discuss the effect of potentiometer placement when its resistance is varied.

<u>Exercise 2</u>

Part 1

3. Comment on the pattern of voltages determined in the *pre-lab* exercise from Table 1.
4. Discuss the purpose of binary representations and the respective effects of the MSB and LSB on the output of the D/A converter.
5. Compare the experimental loading results to the *pre-lab* exercise.

Part 2

6. Describe the time-varying input to the resistive ladder network, considering the form of the output. What does each input bit's signal look like and how do they differ?
7. Explain the loading effect and why it is a concern, commenting on the time-varying results from both load resistor combinations.
8. State significance of a load resistor and what it represents in the real world. Give an example of a device that can be modeled using a load resistor other than the one given in the appendix.

Part 3

9. Discuss the effect on the output of adding more bits to a D/A converter.
10. Compare the theoretical values of Vmin and Vmax for the 4-bit and 8-bit converters and explain how and why they differ.