# *University of Portland*
# *School of Engineering*

# EE 271–Electrical Circuits Laboratory
# Fall 2016

# Lab Experiment #5: DAC *R-2R* Ladder Network

# Digital-to-Analog Converter (DAC) *R-2R* Ladder Network

## I. Objective

In this experiment, the students will analyze, construct and test a Digital-to-Analog Converter (DAC) *R*-2*R* Ladder Network to gain further insight and experience on electrical circuits and to verify some of the circuit theorems they learn in class such as the ***Superposition Principle*** and ***Source Transformations***.

## II. Introduction

A **D**igital-to-**A**nalog **C**onverter (DAC or D/A Converter) is an electronic circuit or a chip that is used to convert digital (usually binary) information or code (for example, from a CD or CD-ROM) into analog (usually a current or a voltage) information (such as sound or audio signals). DAC chips are currently being used in many applications involving modern communication and instrumentation systems. For example, all digital synthesizers, samplers and effect devices have DAC chips at their outputs to create audio signals. Some of the new DAC chips available in the high-tech market are designed in terms of highly complicated and sophisticated electronic circuits to be able to provide high speed and high resolution to the high performance communication/instrumentation systems.

A simple passive DAC circuit can be constructed with a network of resistors, usually a ladder consisting of two sizes of resistors, one twice the other, as shown in Fig. 1. The *R*-2*R* ladder network seen in Fig. 1 is an elegant implementation of a DAC. In this experiment, the students will construct this 3-bit DAC circuit consisting of only resistors, switches, and a single power supply.

## III. Procedure

For the *R*-2*R* ladder network shown in Fig. 1, the switch positions $S_3$, $S_2$, and $S_1$ together represent a 3-digit binary number $N$ given by $N=(S_3S_2S_1)_2$. Note that each switch can either be in position 0 (when connected to ground) or 1 (when connected to the power supply voltage $V_S$). Since there are $2^3=8$ different combinations, the 3-bit binary number $N$ can take any value between $N=(000)_2=(0)_{10}$ to $N=(111)_2=(7)_{10}$. The *R*-2*R* ladder network shown in Fig. 1 is designed to convert the 3-bit binary (digital) number $N=(S_3S_2S_1)_2$ into its equivalent decimal (analog) number $N=(\bullet)_{10}$. The output voltage $V_{out}=(\bullet)_{10}$ measured between terminals A and B is in fact the decimal equivalent of the binary number $N=(S_3S_2S_1)_2$ set by the positions of the three switches. For example, if the switch positions are $S_3=1$, $S_2=0$, and $S_1=1$ which represents the binary number $N=(101)_2$, then, the decimal equivalent of this number should come out to be $V_{out}=5$.

**Pre-lab Assignment 1:** For the circuit shown in Fig. 1, find $V_{out}$ in terms of $V_S$ and $R$ for each combination of the three switches. You will find 8 different expressions for $V_{out}$. Based on these expressions, you will be able to determine the appropriate value of the power supply voltage $V_S$ needed to realize the goal of this design. (<u>Hint:</u> Transform the $R$-$2R$ ladder network shown in Fig. 1 to the equivalent circuit shown in Fig. 2. Note that the power supply voltages $V_{s1}$, $V_{s2}$, and $V_{s3}$ can each take a value equal to $V_S$ or 0 depending on the position of the switches $S_1$, $S_2$, and $S_3$ in Fig. 1. Using this equivalent circuit and source transformation (or superposition principle), find the general expression for the output voltage $V_{out}$ in terms of $V_{S1}$, $V_{S2}$, $V_{S3}$, and $R$. Then, use the general $V_{out}$ expression to find the output voltage for each case.)
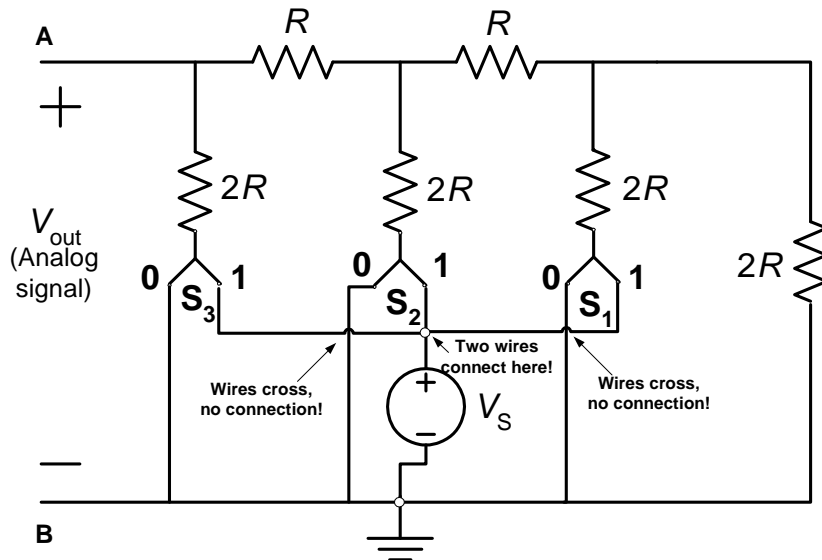


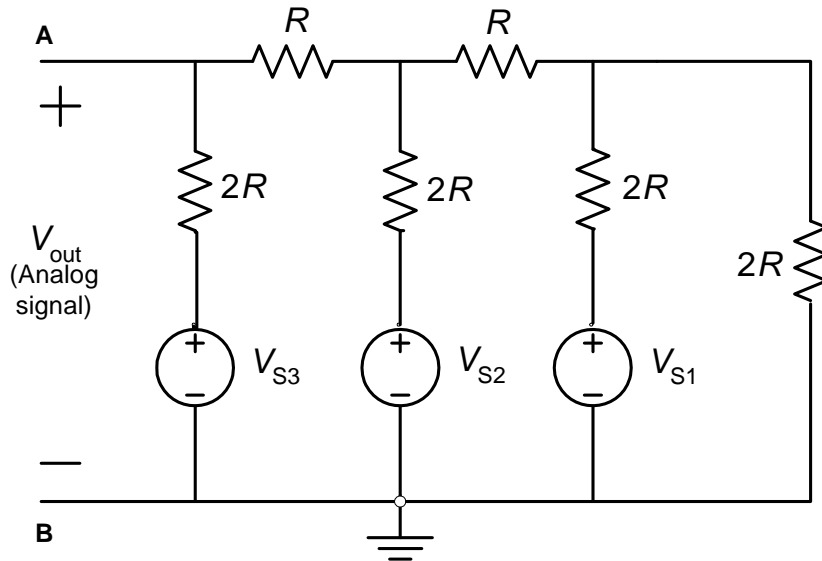Figure 1. 3-bit binary to decimal $R$-$2R$ ladder network.



Figure 2. Equivalent circuit for the $R$-$2R$ ladder network shown in Figure 1.

**Pre-lab Assignment 2:** Can you redesign the circuit shown in Fig. 1 to be able to convert any 4-bit binary number into its decimal equivalent? If so, how many additional elements would you need and what will be the new value of the power supply voltage $V_S$? Draw the complete circuit for the 4-bit binary to decimal $R$-$2R$ ladder network you designed similar to the 3-bit one shown in Fig. 1.

**Lab Experiment:** Select a value for the resistor $R$ and construct the DAC circuit shown in Fig. 1. Set the power supply voltage $V_S$ to the value you calculated in your pre-lab work. Measure and record the actual values of the resistors used in your circuit. Measure and record the value of the output voltage $V_{out}$ in each one of the eight different switch combinations. Present your values in a table similar to Table 1 shown below.

Table 1. Predicted and measured output voltage values.

| $S_3$ | $S_2$ | $S_1$ | $V_{out}$ (predicted) (V) | $V_{out}$ (measured) (V) | Error (%) |
|-------|-------|-------|---------------------------|--------------------------|-----------|
| 0 | 0 | 0 | | | |
| 0 | 0 | 1 | | | |
| 0 | 1 | 0 | | | |
| 0 | 1 | 1 | | | |
| 1 | 0 | 0 | | | |
| 1 | 0 | 1 | | | |
| 1 | 1 | 0 | | | |
| 1 | 1 | 1 | | | |

## IV. Discussions & Conclusion

In this section, discuss the various aspects of Experiment #5 and make some conclusions. In your write-up, you should at least address the following questions:

1. What was the objective of this experiment and was the objective achieved?
2. Did any of your measurements have more than 5% error? What was your maximum % error?
3. What sources of error may have contributed to the differences between the theoretical values and the measured values?
4. Other comments relevant to this experiment.