EE 230
Experiment 9
Fall 2006

Nonlinear Circuit Applications – Diodes, Rectifiers and Comparator Arrays

Components:

741 Operational Amplifier
1N4006 Diode
LM 339 Comparator Array
4116 Resistor Array
Assorted resistors

Objectives: The objective of this experiment is to develop familiarity with diodes and diode applications. The relationship between the actual diode and the ideal diode will also be investigated. A second objective is investigate some basic data converter circuits built from the basic linear and nonlinear components that have been used in earlier laboratory experiments.

Diodes and Rectifiers: There are several types of diodes that are widely used in the industry today. When diodes are initially introduced, they are generally in the context of a nonlinear device that ideally passes current in one direction and blocks current in the opposite direction. The I-V characteristics of such a device are shown in Fig. 1.

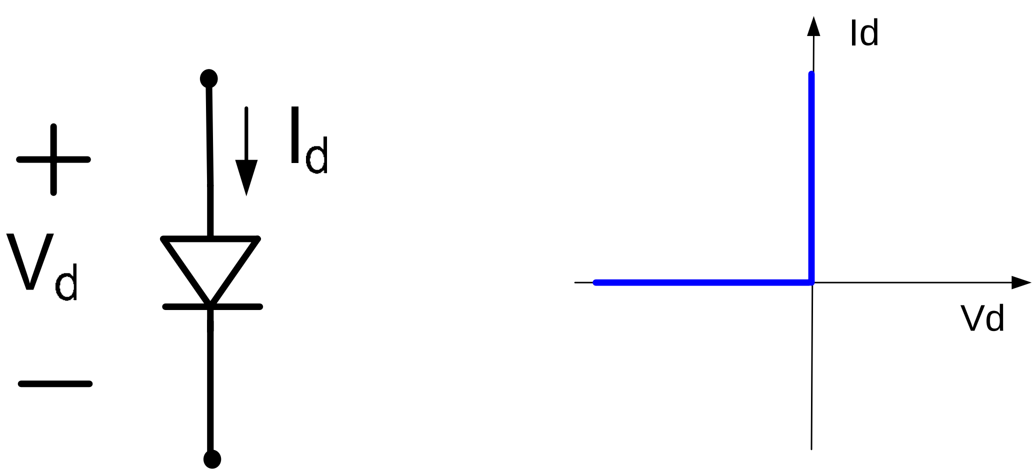


Fig. 1 I-V Characteristics of an Ideal Diode

Diodes that are fabricated with an intended use that takes advantage of these nonlinear characteristics are often termed signal diodes or rectifier diodes.

Other types of diode exist that have some properties that are similar to those shown in Fig. 1 but other properties that are significantly different. Five of the more popular alternative diodes are zener diodes, light emitting diodes, photo diodes, Schottky Diodes, and Varactor Diodes. The property of passing a current in one direction and blocking it in another direction are seldom of interest in zener diodes, light emitting diodes, photo diodes, and Varactor Diodes. The use of Schottky diodes is similar to that of signal diodes.

In this experiment we will be focusing on junction and rectifier diodes. In what follows we will not distinguish between junction and rectifier diodes.

The characteristics of a typical junction diode are shown in Fig. 2. It can be seen that this diode conducts little current for Vd < 0.5 V and the current gets very large for Vd>.65 V. The I-V characteristics of the diode can be modeled by the diode equation

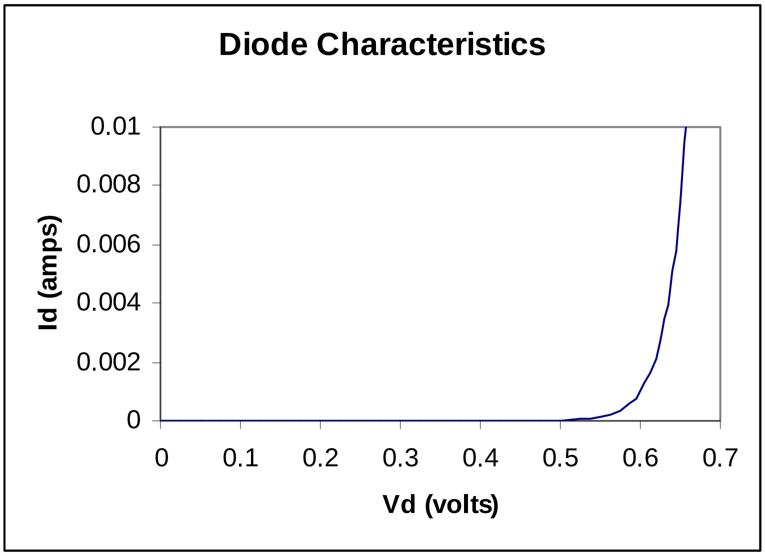


Fig. 2 I-V Characteristics of Typical Junction Diode

$$I_D = I_S \left(e^{\frac{V_d}{nV_t}} - 1 \right) \qquad (1)$$

where I_S is a constant characteristic of the diode, Vt=kT/q where k is Boltzman's constant, T is temperature in Kelvin, n is a constant that depends upon how the diode is made, q is the charge of an electron. k/q= 8.63E-5V/°K and at room temperature Vt is approximately 25mV. The constant I_S is often in the range of 10fA to 100fA. The parameter n is typically 1 for integrated diodes and varies between 1 and 2 for many discrete diodes. In the lecture portion of the course we assumed that n=1 but since we will be using discrete diodes in this experiment it is necessary to introduce the slightly more complicated model of (1) for this experiment.

The diode equation is quite unwieldly and in many applications, particularly applications where the voltages in the circuit around the diode are in the 10V range or larger, the ideal diode model of Fig. 1 is adequate. If lower voltages are used, a piecewise linear model of the diode is often used. This is shown with the thick blue curve in Fig. 3.

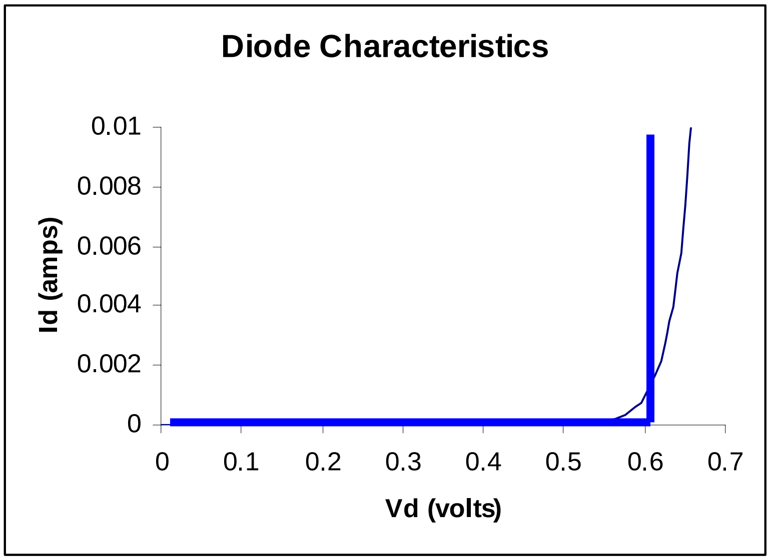


Fig. 3 Piecewise Linear Model of Diode

This model can be expressed mathematically as

$$\begin{aligned} I &= 0 \qquad V_d < 0.6V \\ V &= 0.6V \qquad I > 0 \end{aligned} \tag{2}$$

At lower voltages the shift in the breakpoint in the transfer characteristics from 0V for the ideal diode to around 0.6V for a physical device often causes problems. One circuit where this causes problems at lower input voltages is in the basic rectifier circuit shown in Fig. 4.

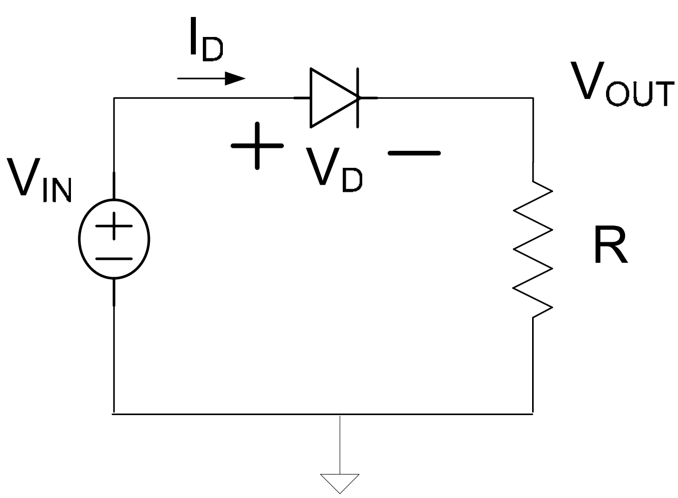


Fig. 4 Basic Rectifier Circuit

For instrumentation applications, when the frequency of operation is small, a precision rectifier circuit is often used. Two variants of a precision rectifier are shown in Fig. 5. The first is a precision rectifier and the second (with $R_1=R_2$) is a full-wave precision rectifier. Since the output voltage of the precision rectifier is across a resistor rather than at the low impedance output node of an operational amplifier, a buffer is generally required to avoid loading of the rectifier circuit itself.

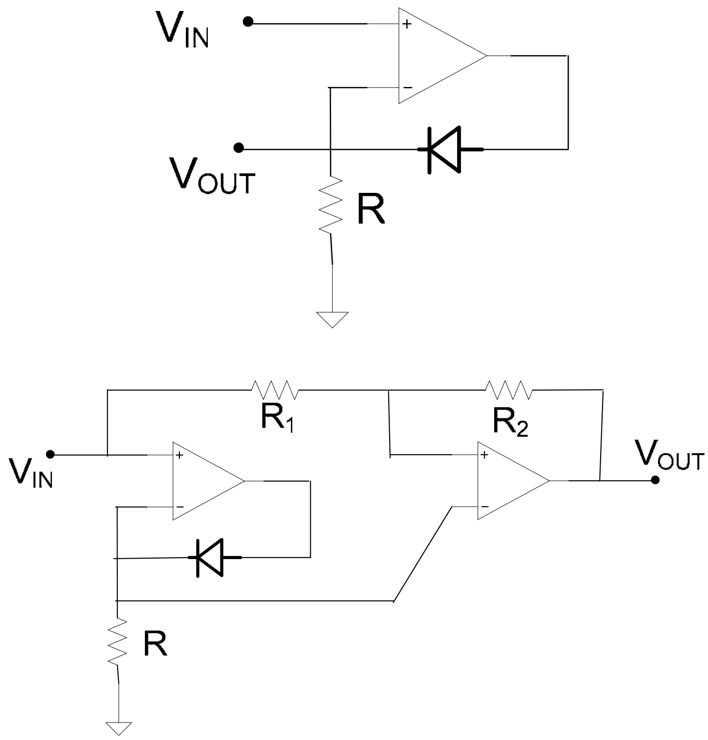


Fig. 5 Precision Rectifier Circuits

Data Conversion Circuits

Circuits that make a conversion of an analog signal to a digital signal are called Analog to Digital Converters (ADCs) and those that make a conversion from a Digital to Analog Signal are called Digital to Analog Converters (DACs). Data converters are extensively used in electronic systems today and serve as the interface between what is dominantly an analog environment and the digital computers or controllers that are integral to most electronic systems today. There are many different ways to make ADCs and DACs and almost all are made in integrated form. The concept of data conversion can, however, be investigated with discrete components. A basic DAC and a basic ADC that can be built with discrete components are shown in Fig. 6 and Fig. 7 respectively. The number of bits of resolution depends upon the number of Boolean input or output variables. An n-bit DAC will have $N=2^n$ distinct input states and an n-bit ADC will have 2^n distinct Boolean output states. In the DAC of Fig. 6, resistors R_1., .. R_{N-1} are all ideally the same. The Boolean inputs control the switches with the Boolean input being represented in thermometer coded form. Wires can be used in place of the switches. In the n-bit ADC of Fig. 7, the resistors R_1., .. R_N are all ideally the same. The digital binary output is obtained by converting the thermometer code that comes out of the comparators to binary format.

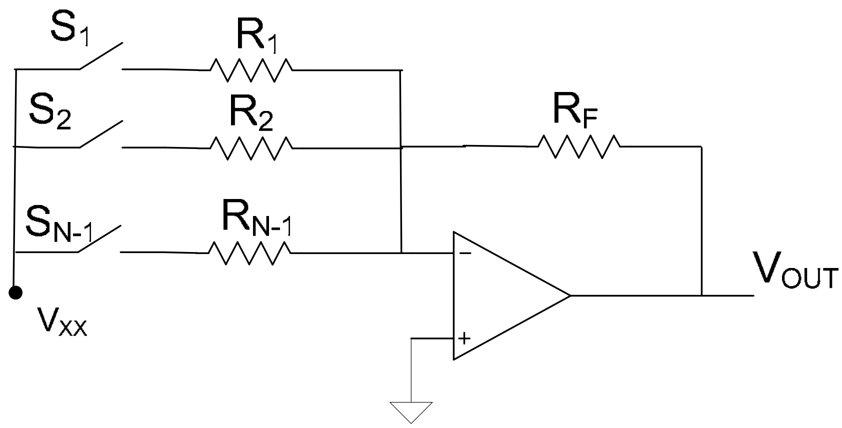


Fig. 5 Basic DAC

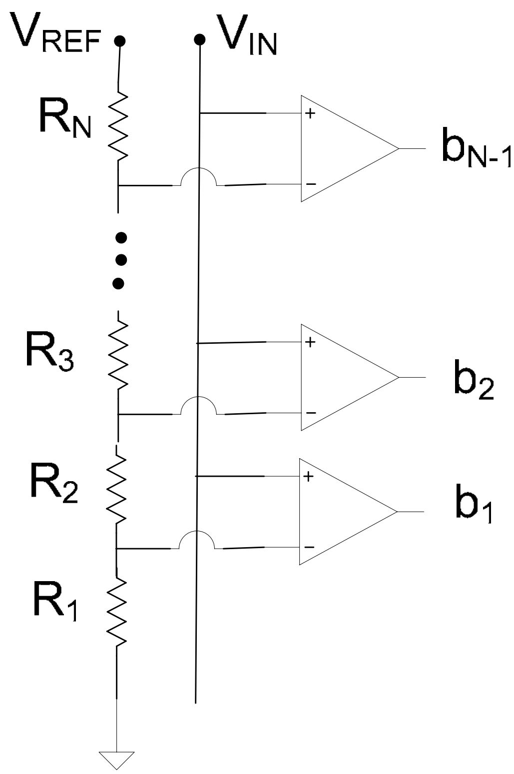


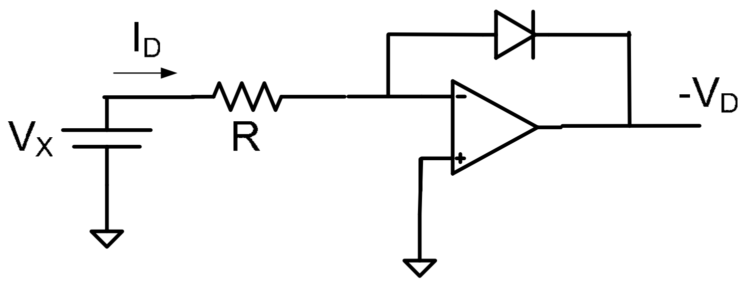
Fig. 7 Basic ADC

Part 1

Measure I_S and n for the 1N4006 diode and compare with the values predicted in the datasheet. A plot of the I-V characteristics for the 1N4006 diode obtained from the manufacturer's data sheet is shown below. Extract the parameters I_S and n at current levels between 2mA and 20mA. (The transfer characteristics in the attached datasheet do not extend below 10mA but the existing curves can be extended linearly from 10mA to 1mA and below.) In these measurements, it is not a good idea to put a dc voltage source across the diode because small changes in this voltage can cause large, possibly destructive changes in the diode current. Plot the I=V characteristics predicted by the diode model for currents between 1mA and 100mA and compare with those in the data sheet (the datasheet only provides data for currents above 10mA and the diode equation model is only good inside the region indicated with the red box in the figure. Your comparison will need to be restricted to the 1mA to 100mA range).

From the model you extracted, predict the current you expect to flow at a diode voltage of 0.6V and compare with what is measured.

Hint: The following circuit may prove useful for helping measure the relationship between I_D and V_D for a diode.



Hint: From the diode equation observe that if the current is measured at two voltage levels, then you can write the following two equations

$$I_{D1} = I_S\left(e^{\frac{V_{d1}}{nV_t}} - 1\right)$$

$$I_{D2} = I_S\left(e^{\frac{V_{d2}}{nV_t}} - 1\right)$$

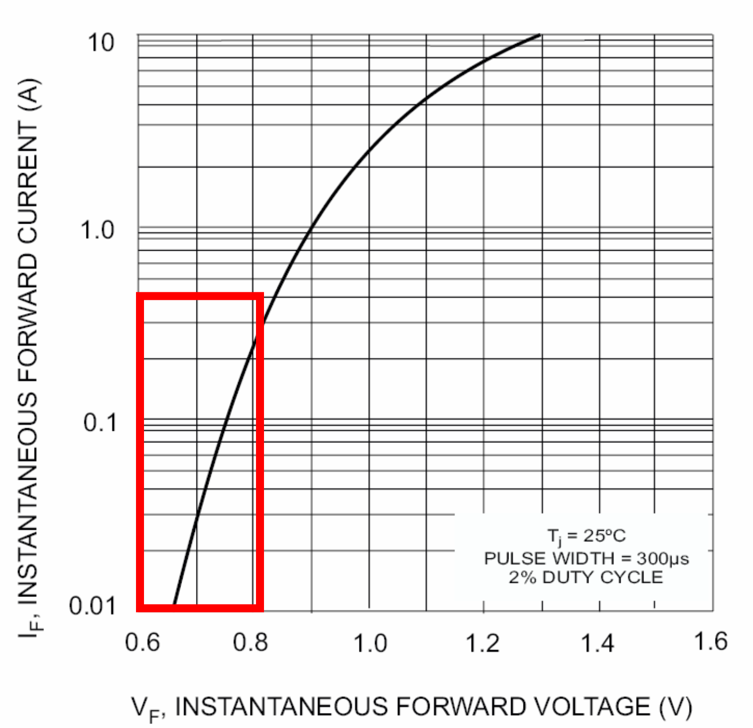


Fig. 2 Typical Forward Characteristics

Part 2
Design and test a simple diode rectifier circuit Test the circuit with a 100Hz sinusoidal signal with a zero-to-peak value of 1.5V and a zero-to-peak value of 10V. Compare theoretical and experimental results.

Part 3
Design and test a precision rectifier with the same test conditions that were considered in Part 2. Compare theoretical and experimental results and comment on how this circuit performs compared to the simple diode rectifier. If the frequency is increased (say to the 10KHz to 30KHz range), the precision rectifier no longer performs as desired if op amps such as the uA741 are used. Test the precision rectifier with a high frequency input and identify the reason it no longer performs as desired.

Part 4
Design and test a 3-bit DAC. First use resistors from your parts kit – share with a neighbor if you do not have enough of the same value. Use nominal resistors (i.e. do not put series and parallel combinations to get matched resistors). When testing the DAC, accurately measure the output for each of the 8 thermometer-coded Boolean inputs. Plot the output voltages versus the corresponding binary Boolean input variable. Ideally the voltage differences between all of the DAC outputs should be identical. What is the worst case deviation you observe? Repeat the test using the 4116 resistor array.

Part 5
Design and test a 3-bit ADC. Use the 4116 resistor array for designing the ADC. A transition voltage is that which causes a digital output to change. Accurately measure all

7 transition voltages. Plot the transition voltages versus the Boolean output variable. Ideally the voltage differences between transition voltages should be identical. What is the worst case deviation you observe?

Lab Upgrade Note: The 1N4006 should be replaced with a signal diode so that the current levels are easier to work with in this laboratory.