Project 2 – Diode Circuits (One Week)

BACKGROUND

Diode Current-Voltage Equation

As discussed in lecture, the complete current-voltage characteristic of the *pn*-junction diode is represented by the monotonically increasing function

$$i_D = I_S(e^{v_D/\eta V_T} - 1)$$

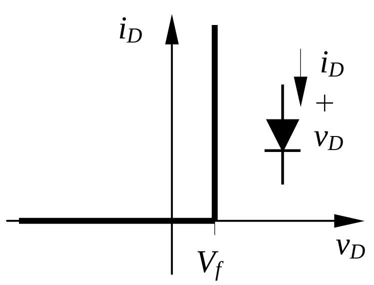
In situations where the precise value of v_D is important, this formula is the one to use. Examples of such situations include the design of integrated circuits at the chip level, voltage references, temperature sensors, and quasi-linear, analog signal processing circuits. In many other applications, however, the precise value of v_D is *not* important. Rather, it's simply sufficient to know whether the diode is operating in its *forward biased* or *reverse biased* state. In these situations, it's sufficient to use the so-called *large signal* model for the diode.

Large Signal Diode Model

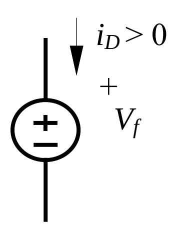
When use of the large signal model is justified, we approximate the voltage across a forward-biased diode as being constant. This voltage value will be on the order 0.5 to 0.8 V, depending on the diode and the general level of current expected. The current will be determined by the rest of the circuit to which the diode is connected. Note that the exact value we assume for the diode's forward voltage V_f is not critical when the large signal model is appropriate, because V_f will be much smaller than other voltages of interest in the circuit.

Conversely, when the diode is reverse biased, we approximate its current as zero. The diode's reverse voltage will be determined by the rest of the circuit. This condition is synonymous with an open circuit, and a reverse-biased diode is often represented as such.

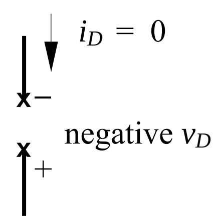
As discussed in lecture, The large signal model can be represented in a number of ways that may include any or all of the following:



Piecewise-linear i-v curve



Forward biased model



Reverse biased model

Laboratory Goal:	To design several useful circuits based on the large-signal model of the *pn*-junction diode.
Learning Objectives:	Diode signal-processing circuits.
Suggested Tools:	Variable voltage source, waveform or function generator, multimeter, light-emitting diodes (LED), oscilloscope, op-amps.

ASSIGNMENT

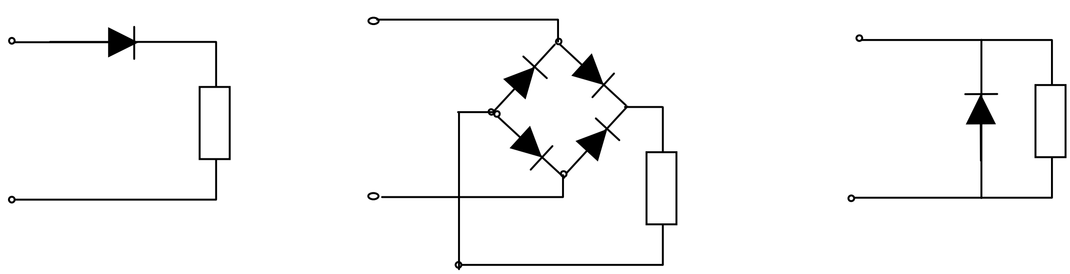
Level 1:
Design a diode circuit that can serve as a polarity protection device for an electronic instrument, such as a car GPS or two-way radio. Assume that the protected equipment operates from either 12-V dc (e.g., a car battery) or 9-V dc (e.g., a rectangular "transistor radio" battery). Your circuit should prevent the equipment from damage should the battery be connected backwards. Alternatively, your circuit could allow the equipment to function regardless of how the battery is connected. For this task, you should devise, simulate, or otherwise choose an appropriate piece of equipment for testing.

Level 2:
Design a diode circuit that functions as a voltage-level indicator. Your circuit should contain some number of light-emitting diodes (LED's) that form a digital bar graph wherein the number of lights is indicative of the voltage level applied to the circuit's input terminals. You may use op-amps as part of your design, but their use is not a requirement.

Level 3:
Design a triangle- to sine-wave converter that can operate over the frequency range from 1 kHz to 100 kHz. The input to your circuit should be a triangular voltage waveform provided by the function generator on your lab bench. (Choose an appropriate magnitude for this input signal). The output of your circuit should be a synthesized, approximate sinusoidal voltage waveform. Test for the sinusoidal purity of your output signal using the spectrum analyzer (Fast Fourier Transform) capability of the LeCroy oscilloscope.

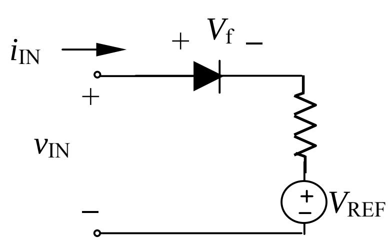
SOME HELPFUL TOOLS

Diode Rectifier Circuits: A polarity protector can take the form of a) half-wave rectifier, b) a full wave rectifier, or c) clamping circuit:



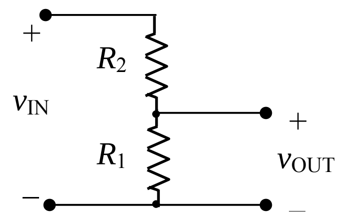
(a) (b) (c)

Diode Logic Circuit: The following circuit will allow current to flow only when v_{IN} exceeds V_{REF} by a diode forward drop. In other words, i_{IN} will flow when $v_{IN} > V_{REF} + V_f$:



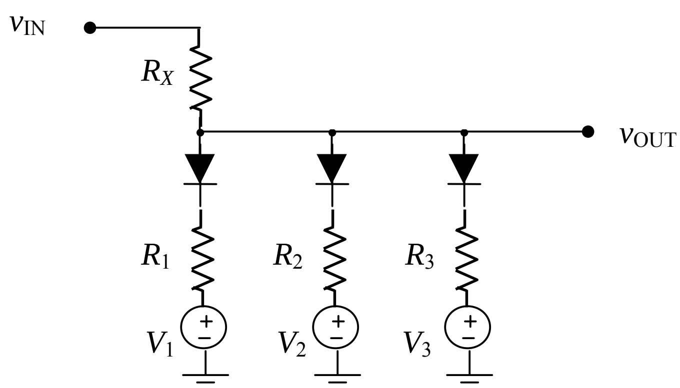
Voltage-Divider Tree Circuit: Recall the properties of the resistive voltage-divider circuit:

$$v_{OUT} = a_1 v_{IN} = \frac{R_1}{R_1 + R_2} v_{IN}$$



where $a_1 = \dfrac{dv_{OUT}}{dv_{IN}}$ is the *incremental voltage divider ratio* (a constant in this case). Note that a_1 is always less than unity for a resistive divider. If the diode logic circuit shown above is constructed with multiple voltage references, as shown below, then the incremental voltage divider ratio will change as the magnitude of v_{IN} increases. For example, for the circuit shown below, assuming that $0 < V_1 < V_2 < V_3$ and that V_f is small enough to be assumed zero, the following values of a_1 will apply:

a_1	$\dfrac{dv_{OUT}}{dv_{IN}} = 1$	$\dfrac{dv_{OUT}}{dv_{IN}} = \dfrac{R_1}{R_X + R_1}$	$\dfrac{dv_{OUT}}{dv_{IN}} = \dfrac{R_1 \Vert R_2}{R_X + R_1 \Vert R_2}$	$\dfrac{dv_{OUT}}{dv_{IN}} = \dfrac{R_1 \Vert R_2 \Vert R_3}{R_X + R_1 \Vert R_2 \Vert R_3}$
For Range:	$0 < v_{IN} < V_1$	$V_1 < v_{IN} < V_2$	$V_2 < v_{IN} < V_3$	$v_{IN} > V_3$



Spectral Content of Triangle Wave: In your EC/BE 401 class, you will learn (have learned) about the concept of Fourier Series. Stated briefly, any periodic waveform can be represented as the sum of an infinite number of sinusoids, where the period of each sinusoid is some integral multiple of the base, or fundamental frequency. For a square wave of magnitude V_o and frequency ω, the Fourier series can be expressed as:

$$v(t) = \frac{4Vo}{\pi}\left(\sin\omega t + \frac{\sin 3\omega t}{3} + \frac{\sin 5\omega t}{5} + \frac{\sin 7\omega t}{7} + ... \right)$$

For a triangle wave of magnitude V_o, the series becomes:

$$v(t) = \frac{8Vo}{\pi^2}\left(\sin\omega t - \frac{\sin 3\omega t}{3^2} + \frac{\sin 5\omega t}{5^2} - \frac{\sin 7\omega t}{7^2} + ... \right)$$

One performance measure of a triangle-to-sine converter is the magnitude of the higher harmonics in the output waveform (e.g.,the *harmonic distortion*). Ideally, the upper level harmonics should be zero if the the output is a truly pure sine wave.