Nonlinear Circuits and Devices

Logarithmic Amplifier

<u>Milestone 0</u>

Schokley's first-order theory for a pn-junction gives the relationship between the voltage V_D across the diode and the current I as

$$I_D = I_S\left(\exp\left(\frac{eV_D}{k_B T}\right)-1\right) \quad (8.1)$$

where $e = 1.6\times10^{-19}$ C, $k_B = 1.38\times10^{-23}$ J K^{-1} and I_S is the **reverse saturation-current** of the diode, typically 25 nA at 25˚C but it doubles with every 10˚C increase in temperature.

Shockley's model can be improved with the addtion of a parameter $1<\lambda<2$ such that

$$I_D \approx I_S\exp\left(\frac{eV_D}{\lambda k_B T}\right) \quad \text{when} \quad V_D > 100 \text{ mV}. \quad (8.2)$$

Assuming that $|V_1/R_1| \ll |V_3/R_3|$, use this approximation to calculate V_4 as a function of V_1 for circuit 8.1 (below). What is (a) the lowest value of V_4, and (b) the largest value of input current (V_1/R_1), for which you would expect the circuit to work satisfactorily?

<u>Milestone 1</u>

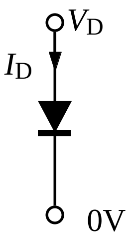
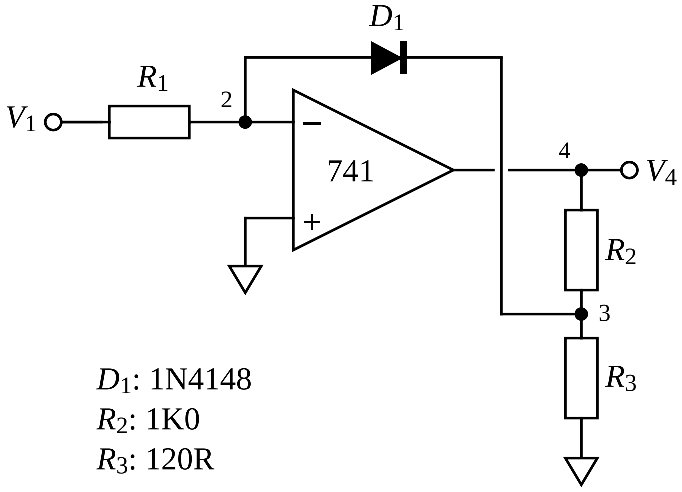
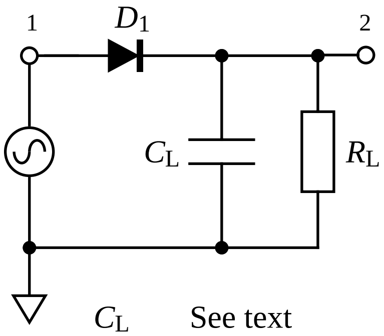


Figure 1. Sign convention.

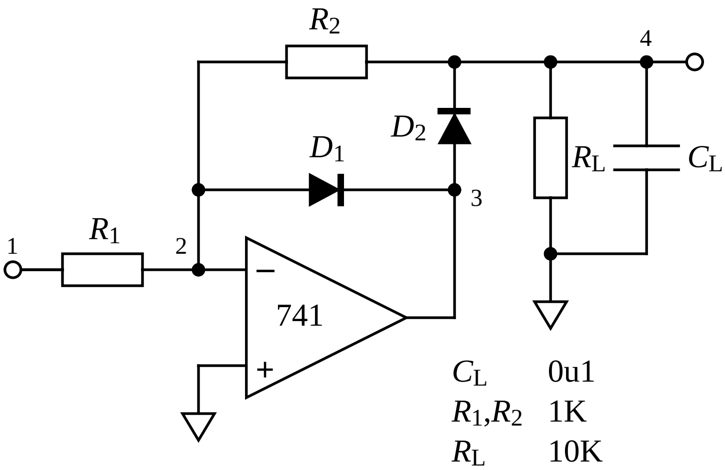


Circuit 8.1 Primitive logarithmic amplifier



C_L	See text
R_L	10K
D_1	1N4148

Circuit 8.2 Passive half-wave rectifier



C_L	0u1
R_1,R_2	1K
R_L	10K
D_1,D_1	1N4148

Circuit 8.3 Precision half-wave rectifier

Construct circuit 8.1. Adjust the op-amp offset-null with the diode temporarily bridged by a 1 kΩ resistor. Test your circuit by plotting a graph (on semi-log axes) of V_4 *vs* V_1/R_1 over a range from 0.1 μA to 1 mA (use values for R_1 of 1 kΩ, 33 kΩ and 1 MΩ to cover the range). Estimate the values of λ and I_S for the diode, and comment on the accuracy of the model.

Milestone 2

Half-Wave Rectifiers

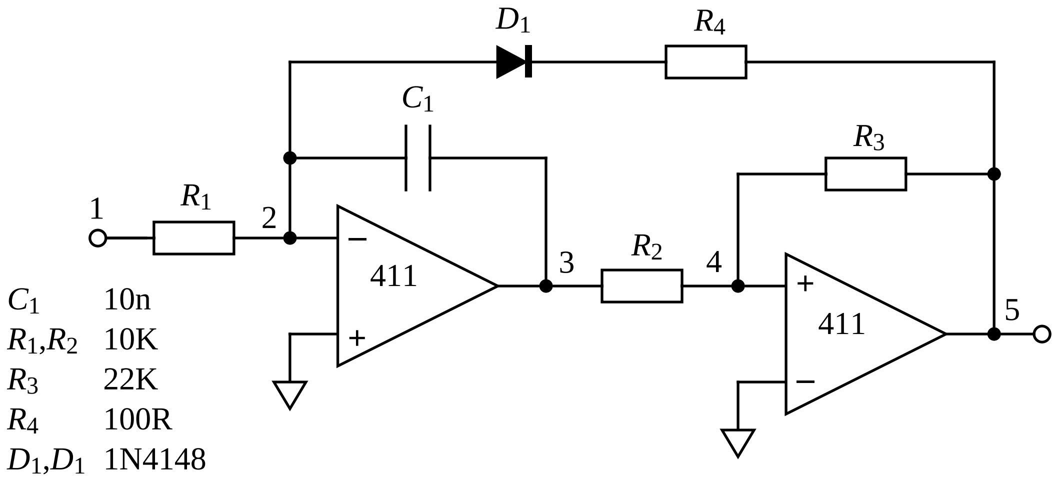
Circuit 8.2 is a so-called **half-wave rectifier**. Build it and, using a 5 V amplitude 2 kHz sine-wave input (node 1), carefully sketch the output (node 2) waveform when the smoothing capacitor C has each of the values: 0 pF (*i.e.* not present), 10 nF and 100 nF.

With $C = 100$ nF and a 2 kHz sine-wave input, measure the DC voltage (with a DMM) at the output as a function of the input amplitudes from 0 to 10 V and plot the results on a graph.

Milestone 3

Construct circuit 8.3 and, as before, with a 2 kHz sine-wave input, measure the DC voltage at the output (node 4) as a function of the input amplitudes. Add the results to your previous graph and comment on the accuracy of this circuit.

Milestone 4



Circuit 8.4 Simple voltage-to-frequency converter

Voltage-to-Frequency Converter

Circuit 8.4 is a simple **voltage-to-frequency converter**, the frequency f of its output depends on the (DC) voltage at the input V_{in}. Build this circuit and sketch the signals at nodes 3 and 5 when the input is 1 V. Briefly explain how the circuit works and obtain an expression relating f to V_1. Plot a graph of the measured f against V_1. and hence determine the linearity and range of this circuit. Ask a demonstrator to see whether a frequency counter is available for this part of the experiment as the circuit may well be more accurate than the oscilloscope timebase.

Note: Circuit 8.4 is abusing an *op-amp* by using one as a *comparator*. This is bad practice because op-amps are designed to work with $V_+ = V_-$ and have poor performance (they may even suffer latch-up, or become noisy) in circuits where this is not the case. Comparators are designed to operate with $V_+ \ll V_-$ or $V_+ \gg V_-$ and should be used for this purpose all ‘real’ applications.

Milestone 5