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CECS 311 Section 01
Lab 1B
2020-01-28 to 2020-02-04

1 Introduction

In this lab, we were tasked with simulating using a rectifying diode with DC and AC voltage sources in the program LTspiceVI. DC voltage sources are straightforward, but AC voltage sources create a sine wave signal, meaning that they go up to a certain voltage and go down to the opposite voltage. This reverse polarity may be undesired for some devices, so it may be necessary to remove the negative portion of this sine wave. This is what a rectifying diode is meant to do.

For this lab, we modeled the diode 1N4001, which is made of silicon and has a typical forward voltage of $V_f = 0.7\,\mathrm{V}$.

2 DC Sources

2.1 Forward Biased

The first circuit that we tested was a DC voltage source set at 5 V with a 1N4001 diode and a 1 kΩ resistor connected in series. The circuit looks like this:

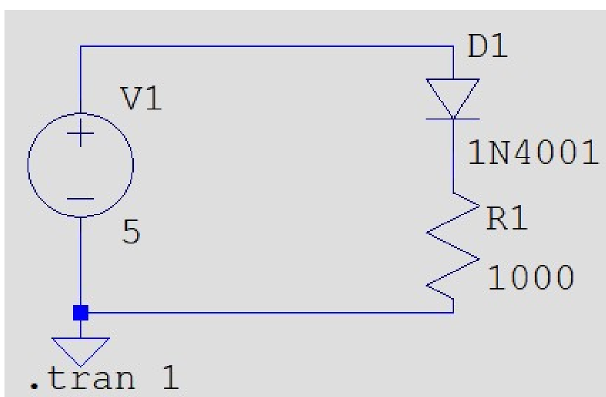

Figure 1: Forward Biased DC Circuit

This circuit is simple to analyze, because there are no moving parts. The voltage across the diode should be the same as its forward voltage, or $V_D = 0.7\,\mathrm{V}$. Due to KVL, the resistance across the resistor must be $V_R = 5\,\mathrm{V} - 0.7\,\mathrm{V} = 4.3\,\mathrm{V}$.

The output from the simulation is listed below.

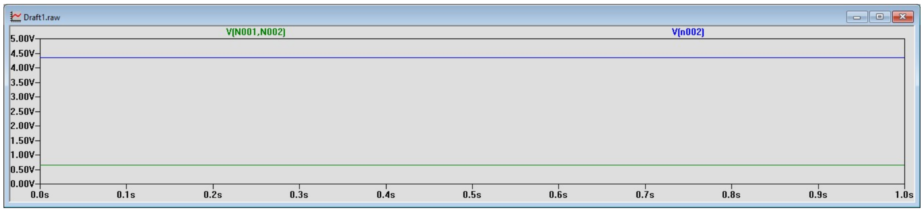

Figure 2: Graph of output

It may not be very visible on Figure 2, but V_D drops just a tiny bit (about $1\,\mu\mathrm{V}$) during the first $0.25\,\mathrm{s}$, but is otherwise constant at a measured $648.737\,\mathrm{mV}$, or $0.7\,\mathrm{V}$, just as calculated. V_R also rises by about $1\,\mu\mathrm{V}$ during the first quarter second of the simulation, but is otherwise constantly $4.351\,26\,\mathrm{V}$, which is close to the expected $4.3\,\mathrm{V}$.

2.2 Reversed Biased

The next circuit is identical to the last one minus the fact that the polarity of the diode has been switched:

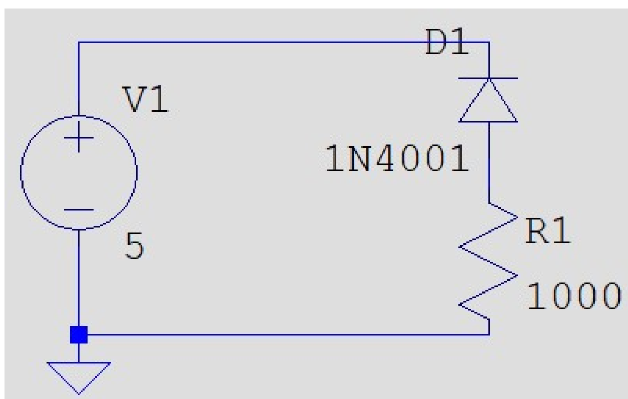

Figure 3: Reversed Biased DC Circuit

Because this diode is reverse biased, there is no current going through the circuit, and therefore by Ohm's Law there is no voltage drop across the resistor ($V_R = 0\,\mathrm{V}$). This means that the diode is dropping all $5\,\mathrm{V} = V_D$.

The output from the simulation of this circuit is shown below. As it is evident, this is exactly the result found when measuring the circuit.

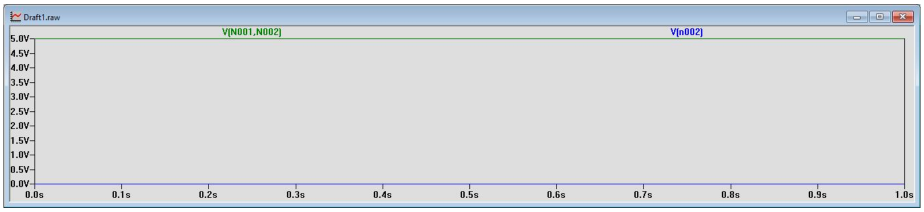

Figure 4: Graph of output

3 AC Circuits

When dealing with a diode and a resistor in series in an AC circuit, it matters whether you take the voltage across the resistor or the diode as V_{out}, because they behave differently.

3.1 Forward Biased

Note that "forward biased" is in reference to ground, which in this case is always placed on the bottom of the voltage source. The circuit we are testing is the following:

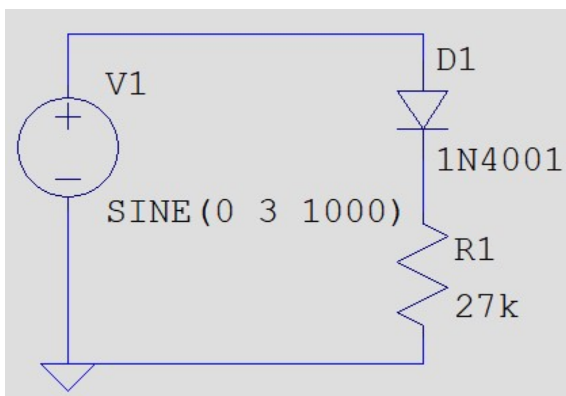

Figure 5: Forward biased diode in AC circuit

3.1.1 V_{out} across resistor

If V_{out} is taken to be the voltage across the resistor, this is called a series diode clipper, because it has a diode in series with the resistor, and it is said to "clip" the negative alternation of the sine wave that the VAC source outputs. It follows the following function:

$$V_{\text{out}} = \begin{cases} V_{\text{in}} - V_f & \text{if } V_{\text{in}} > V_f \\ 0 & \text{if } V_{\text{in}} \leq V_f \end{cases} \tag{1}$$

Note that in this lab, $V_{\text{in}} = 3\,\text{V} \cdot \sin(x)$ and $V_f = 0.7\,\text{V}$. V_{out} is zero until V_{in} hits V_f, and therefore will always be $0.7\,\text{V}$ below V_{in}. V_{out} will never be negative because a diode does not allow current to go through it if it is reverse biased.

3.1.2 V_{out} across diode

If V_{out} is taken to be the voltage across the diode instead of the resistor, it is considered to be a shunt diode clipper. The voltage output therefore follows the following function:

$$V_{\text{out}} = \begin{cases} V_{\text{in}} & \text{if } V_{\text{in}} < V_f \\ V_f & \text{if } V_{\text{in}} \geq V_f \end{cases} \tag{2}$$

This means that the output voltage will follow the input voltage until the forward voltage of the diode is reached: in that case, it will only output that voltage. For example, for the whole negative alternation and the beginning and end of the positive alternation (up to $0.7\,\text{V}$), V_{out} will equal V_{in}. However, when V_{in} hits $0.7\,\text{V}$ and above, V_{out} will be equal to a constant $0.7\,\text{V}$.

3.1.3 Results

Here is the graph output of both the series diode clipper and the shunt diode clipper. The sine wave is V_{in} (labeled `V[n001]` or Trace 3), or the output of the AC voltage source. The line that extends into the negative region (labeled as `V[N001, N002]`, or Trace 1) is the shunt diode clipper, and the line that does not (labeled as `V[n002]`, or Trace 2) is the series diode clipper.

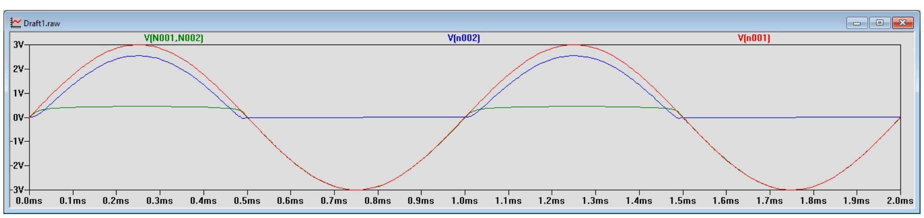

Figure 6: Output for both circuits

As it is evident, the graph of the output matches the description. Trace 2 stays under V_{in} and completely clips off the negative alternation of the sine wave, while Trace 1 only goes up to $0.7\,\text{V}$ and follows V_{in} for its negative alternation. V_{in} is $6\,\text{V}_{pp}$. $V_{\text{out},R}$ is $2.3\,\text{V}_{pp}$, and $V_{\text{out},D}$ is $3.7\,\text{V}_{pp}$.

3.2 Reverse biased

Again, "reverse bias" refers to the diode in reference to ground, which is placed on the bottom-right of the circuit. This is the circuit we will be testing:

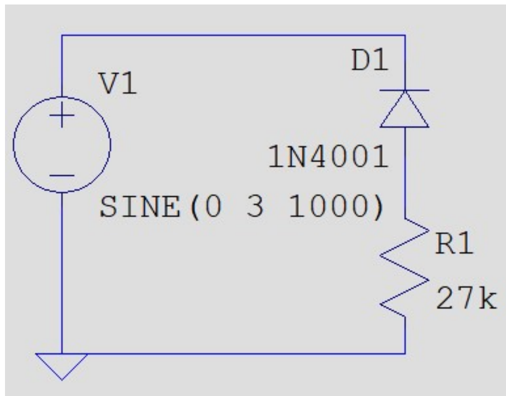

Figure 7: Reverse bias AC circuit

The difference between this circuit and the last is the direction of the diode.

3.2.1 V_{out} across resistor

This circuit is again called a series diode clipper like the last one, but the direction of the diode is switched, and will therefore clip the positive alternation of V_{in} instead of the negative alternation. Due to KVL, V_{out} will follow the following function:

$$V_{\text{out}} = \begin{cases} V_{\text{in}} + V_f & \text{if } V_{\text{in}} < -V_f \\ 0 & \text{if } V_{\text{in}} \geq -V_f \end{cases} \tag{3}$$

This piecewise function is more or less the opposite of the negative-clipping variant of this circuit. Instead of cutting off the negative portion of V_{in}, V_{out} is simply 0 V during the positive alternation, and just above V_f above V_{in} during the negative alternation. In both cases, $|V_{\text{in}} - V_{\text{out}}| = V_f$.

3.2.2 V_{out} across diode

Once again, if V_{out} is measured across the diode instead of the resistor, you get a shunt diode clipper; however, instead of clipping the positive alternation, this circuit clips the negative alternation. V_{out} will follow the following function:

$$V_{\text{out}} = \begin{cases} V_{\text{in}} & \text{if } V_{\text{in}} > -V_f \\ -V_f & \text{if } V_{\text{in}} \leq -V_f \end{cases} \tag{4}$$

Again, this function is almost the opposite of its negative-clipping counterpart. V_{out} follows V_{in} during its positive alternation, and is capped at $-V_f$ during its negative alternation.

3.2.3 Results

Below is the output of the simulation of this circuit for both outputs. The sine wave (labeled `V[n001]` or Trace 3) represents V_{in}. Trace 1, labeled `V[N001, N002]`, represents the shunt diode clipper; and Trace 2, labeled `V[n002]`, is the series diode clipper.

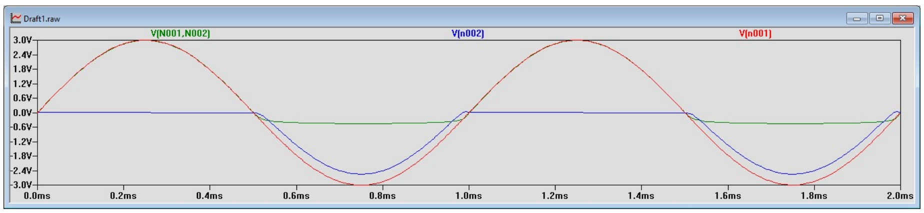

Figure 8: Output for both circuits

Both Trace 1 and Trace 2 are merely rigid transformations of their previous counterparts, being reflected over the time axis and shifted over one period. Once again, V_{in} is $6\,\text{V}_{pp}$. $V_{\text{out},R}$ is $2.3\,\text{V}_{pp}$, and $V_{\text{out},D}$ is $3.7\,\text{V}_{pp}$.