

Lab 9: Op Amps and the 555 Timer

OBJECTIVES

- Understand the following op amp circuits:
 - Voltage follower
 - Rectifier
 - Low pass filter
- Gain experience with the 555 timer.

MATERIALS

- The lab assignment (this document)
- Your lab parts
- Printouts (required) of the below documents:
 - Pre-lab analyses
 - Multisim screenshots e-mailed to course e-mail

INTRODUCTION

In this lab we explore some applications of op amps and introduce the 555 timer. First we introduce the voltage follower, which mitigates loading effects. Then we perform AC-DC conversion using the combination of an op amp rectifying amplifier and an active low pass filter. Finally, we work with the 555 timer, a widely used integrated circuit (IC).

Voltage Follower

Earlier in the semester we emphasized the significance of *loading effects*. We must make sure that connecting a load to a circuit does not drastically change the open circuit voltage. A voltage source is said to be “stiff” if it can supply a constant voltage to the load, regardless of the load resistance. We can model a voltage source by its Thévenin equivalent circuit, as in Fig. 1. The Thévenin resistance is called the *output resistance* of the source, R_{out} . This connects to a load with *input resistance* given by R_{load} .

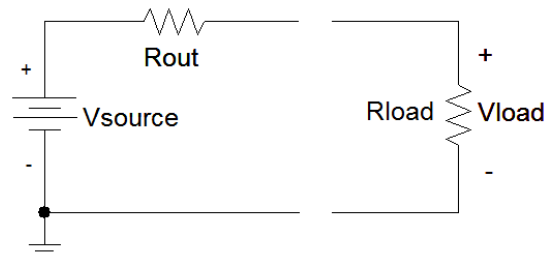


Figure 1 – Voltage source Thévenin equivalent and load resistor.

The circuit in Fig. 1 is simply voltage division. The voltage delivered to the load, V_{load} , is

$$V_{load} = V_{source} \left(\frac{R_{load}}{R_{out} + R_{load}} \right)$$

In the case that $R_{load} \gg R_{out}$, the source resistance becomes negligible and this equation reduces to $V_{load} = V_{source}$. Therefore, for optimum voltage transmission, we want sources with low output resistances and loads with high input resistances. This is not always the case. For example, voltage signals must drive audio speakers with R_{load} values as low as 4 Ω . A solution is to use the *voltage follower*.

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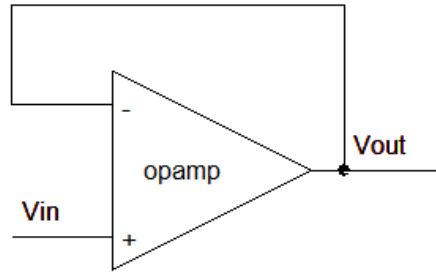


Figure 2 – The voltage follower.

When placed between the source and the load, the voltage follower, seen in Fig. 2, serves as a buffer that isolates the source from the load. Because of its high input resistance, the voltage follower is a good load for V_{source} , and the voltage at its input (the + terminal) is approximately equal to V_{source} . The voltage follower has unity gain, so at its output, the voltage is also approximately equal to V_{source} . The voltage follower acts a low output resistance source for R_{load} . The voltage source and the voltage follower function as a stiff voltage source. No matter what R_{load} we use, we will deliver the desired voltage to it.

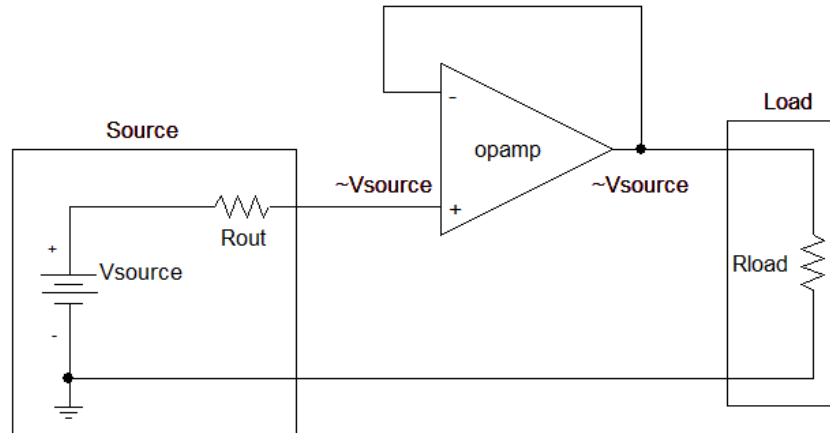


Figure 3 – Due to high input resistance, no current enters the op amp, therefore the voltage at the + terminal is approximately equal to V_{source} .

AC to DC Converter

To convert AC voltage to DC voltage, we will make use of two cascaded (series) op amp circuits. An AC voltage source is fed into a half-wave rectifier, which zeros the negative component and amplifies the voltage. The output of rectifier is sent to a low pass filter, which produces a nearly DC voltage. A filter implemented with op amps is known as an *active filter*, because it relies on active elements (active elements require power sources, unlike passive elements such as resistors and capacitors).

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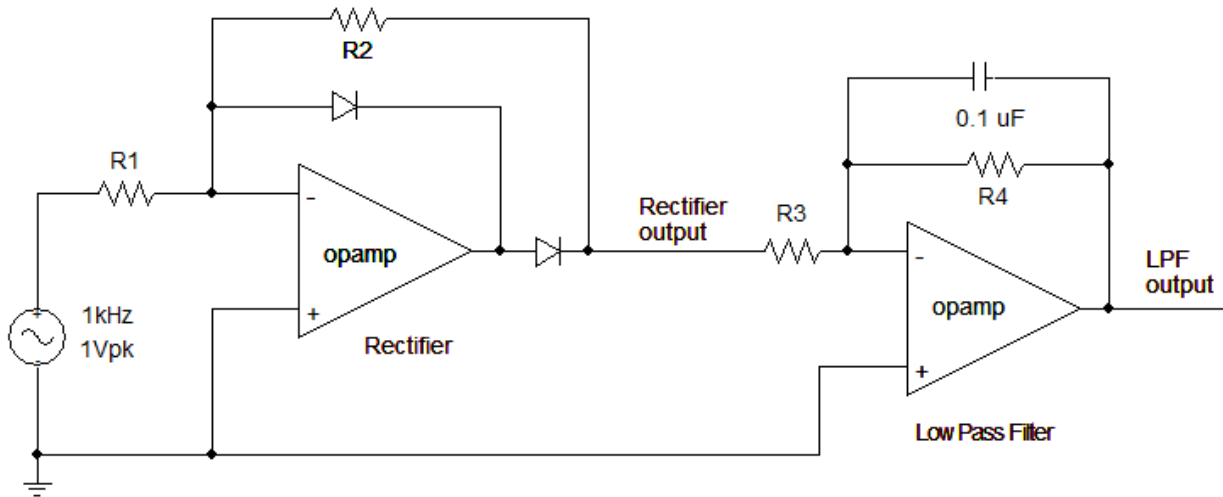


Figure 4 – A 1V, 1kHz AC voltage source is first rectified, then filtered to produce a negative DC voltage.

The rectifier has a gain $G_{rect} = \frac{R_2}{R_1}$ and the low pass filter has a gain $G_{LPF} = \frac{R_4}{R_3}$. The cut off frequency for the LPF is $f_o = \frac{1}{2\pi R_4 C}$. The LPF must have the cutoff frequency set very low for its output to approximate a constant. Note that it is an inverting amplifier.

The 555 Timer

The 555 timer is a popular IC often used as a timer, logic clock, or oscillator, with three modes of operation: monostable, bistable, and astable. The configuration for astable mode of the 555 timer is shown on the left in Fig. 5.

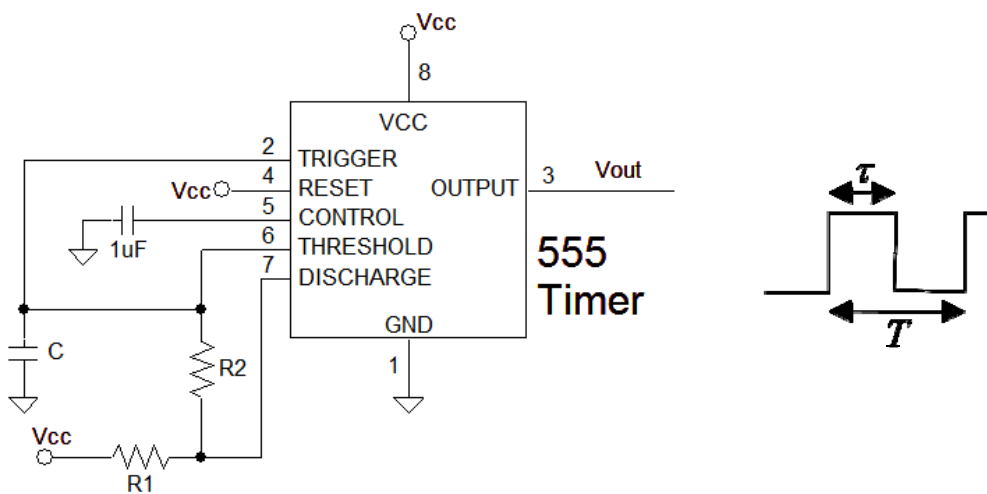


Figure 5 – Setup and output for the 555 timer in the astable mode (left) and definitions for duty cycle (right).

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The output is a pulse waveform and comes from pin 3. A characteristic of pulse waveforms is known as the *duty cycle*, defined as $D = \frac{\tau}{T}$, where τ is the duration of the “high” pulse and T is the period (as shown on the right in Fig. 5). Therefore $T - \tau$ is the duration of the “low” pulse. We design the timer to output a pulse waveform with a certain duty cycle and frequency, using the following two equations,

$$\tau = 0.693(R_1 + R_2)C \quad \text{and} \quad T - \tau = 0.693R_2C$$

(The number $0.693 = \ln(2)$.) If we choose R_2 large relative to R_1 , the “low” and “high” durations are the about the same and the duty cycle is 0.5. The value of R_1 should be greater than or equal to $1\text{k}\Omega$.

PRE-LAB AND QUESTIONS

1. A simple voltage divider is to be used as a voltage supply. Its Thévenin equivalent voltage is 10 V and resistance is $100\ \Omega$. In Multisim, construct this circuit as in Fig. 1 (with load resistor connected). Determine the load voltage for the case of $R_{load} = 10\text{ k}\Omega$, $1\text{ k}\Omega$, and $100\ \Omega$.
2. Now, in Multisim add the voltage follower to your circuit as in Fig. 3. Calculate the load voltages for each of the three load resistors in part 1. Email a screenshot of this circuit for the $100\ \Omega$ case, with the multimeter open.
3. For the AC-DC circuit in Fig. 4, design a rectifier with a gain of 3, and a low pass filter with a gain of 5 and a cutoff frequency of 10 Hz . Keep all resistors $> 1\text{ k}\Omega$. Show your work.
4. Build this circuit in Multisim and send a screenshot of the circuit and (well-scaled) oscilloscope output.
5. Design an astable 555 timer circuit as in Fig. 5 with duty cycle 0.6 and frequency 200. Show work.
6. Build your timer circuit in Multisim and send a screenshot of the circuit and oscilloscope output.

LAB PROCEDURE AND QUESTIONS

1. Let's test the results of pre-lab parts 1 and 2. Build the circuit described in part 1.
2. Find the load voltage when the load is: $10\text{ k}\Omega$, $1\text{ k}\Omega$, and $100\ \Omega$. Use a resistance box for efficiency.
3. Insert the voltage follower and measure the load voltages again for the three cases. Calculate percent error in these cases, comparing load voltage with voltage follower to load voltage without the follower.
4. Build the AC-DC converter of Fig. 4. Use the function generator to produce the sinusoidal voltage. Let $R_1 = 10\text{ k}\Omega$ and $R_2 = 33\text{ k}\Omega$. Use resistance boxes for R_3 and R_4 .
5. Measure and sketch the rectifier and LPF outputs in each of the oscilloscope channels, for the following three cases: $f_o = 10\text{ Hz}$, 100 Hz , and 300 Hz . (Determine the value of R_4 to achieve this cutoff frequency, and then calculate the corresponding R_3 to get a constant gain of 5.)
6. Explain the change in the LPF output.
7. Build the astable 555 timer circuit from Fig. 5, with $R_1 = 1\text{ k}\Omega$ and $C = 1\ \mu\text{F}$. Use a resistance box for R_2 . Put a clear LED in series with a $1\text{ k}\Omega$ resistor between the output (pin 3) and ground. (Note: the long leg of the LED is the positive terminal.) Set the box to $1\text{ M}\Omega$ and turn the power on.
8. Using the oscilloscope, measure the voltage from pin 3 to ground. Decrease the resistance box R_2 until you no longer can discern discrete light pulses from the LED. Note the frequency at which this occurs.