RC Filters

Pre-lab Questions

1. What are some typical uses of RC filter circuits?

2. Given a low-pass filter with a 2 KΩ resistor and a 0.2 µF capacitor, find the corner frequency.

3. Design an RC filter that removes the high frequency noise from the signal seen below.
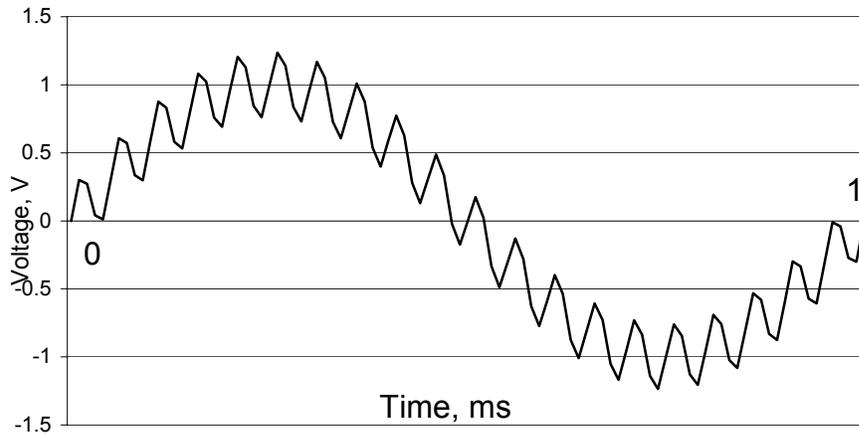
Purpose

*   To introduce resistors and capacitors

*   To introduce the concept, construction, and utility of low-pass and high-pass RC filters

*   To introduce the Basic Stamp microcontroller and its capability to output tones

Components

Qty.	Item
1	OEM Basic Stamp II microcontroller
1 ea.	1 kΩ and 10 kΩ resistors
1	0.1µF capacitor
2	10µF capacitor
1	30 ohm resistor
1	8 ohm speaker

Introduction

Resistor-Capacitor Filter Circuit:

The impedance of a capacitor is $1/(j\omega C)$, a complex quantity, where j is the square root of -1, ω is frequency in rad/sec (2π rad/sec = 1Hz), and C is capacitance in Farads. The following equation relating input voltage, V_i and output voltage, V_o for the circuit shown in Figure 1 is obtained by using the voltage division formula:

$$Vo = \frac{1/(jwC)}{R + 1/(jwC)} Vi \qquad or \qquad \frac{Vo}{Vi} = \frac{1}{1 + jwCR}$$

The frequency dependent term $1/(1+j\omega CR)$ is called the Transfer Function of the circuit. For a given sinusoidal input voltage Vi, the magnitude of the output voltage Vo is given by the product of Vi and the magnitude of the Transfer Function (evaluated at the frequency of Vi). We will verify this relation by the following experiment.
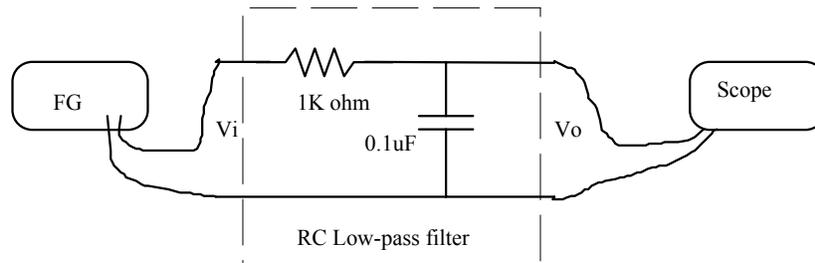
Figure 1 RC low-pass filter

Procedure

1. Construct the <u>single-stage RC Low-pass filter circuit</u> shown in Figure 1.

2. Set Vi to 5 volts p-p at 500Hz and record the amplitude of Vo. Repeat this measurement with the frequency of Vi set to 1.6 kHz and 10 kHz. Compare the ratio of the input voltage and the output voltage (i.e., Vo/Vi) with the magnitude of the Transfer Function evaluated at the corresponding frequency. **What can you conclude from this comparison about the relationship between the magnitude of the transfer function and the ratio of the input and output voltages? Explain. Why is this circuit called a "low-pass filter"?**

The phase lag of a circuit can be thought of as the amount of delay in the signal as it goes through the circuit. Phase lag is measured in degrees as shown in Figure 2. The phase lag of the circuit shown in Figure 2 is the angle of the transfer function, $1/(1+j\omega CR)$, evaluated at the frequency of the signal. We will verify this relation by the following experiment.

3. Set the scope to dual-trace mode. Display both Vi and Vo on the scope at the same time. (Ask the TA for help if needed). Measure the phase lag of this circuit as shown in Figure 2 at Vi=1.6 kHz. **Does the theoretical value match the observed value?**
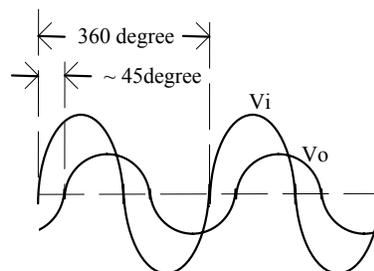
Figure 2 Phase lag of Vo.

4. Construct the <u>single-stage RC High-pass filter circuit</u> shown in Figure 3, and verify (using the voltage division formula) that Vo/Vi for this circuit is as follows:

$$Vo = \frac{R}{R + 1/(jwC)} Vi \qquad \text{or} \qquad \frac{Vo}{Vi} = \frac{jwCR}{1 + jwCR}$$

5. Repeat step (2) and (3) for this high-pass filter.
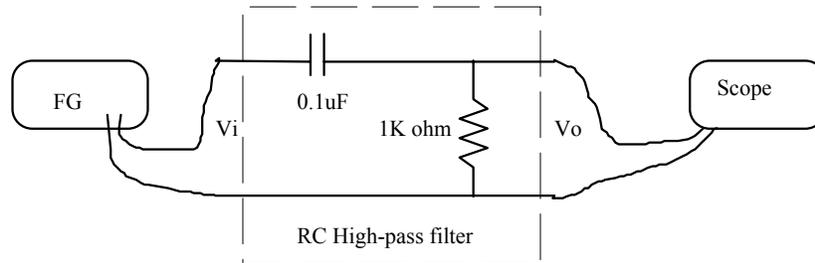
Figure 3 High-pass filter

6. Add a DC offset (any value) to the function generator output. **Does this DC offset affect the output (Vo) of the filter?** This is the reason that a capacitor can be thought of as a device that blocks a DC component, but allows the AC component to go through. This is called "AC coupling."

7. Now we want to use the Basic Stamp microcontroller to output a tone and see the effect of filtering a Pulse Width Modulated signal. First let's get familiar with the Basic Stamp hardware and its connections.

Remove the OEM Basic Stamp from its anti-static bag, being careful to avoid touching the exposed pins. It is always a good idea to hold a card like this by its edges, and avoid touching the pins or circuit traces unless you are properly grounded for electrostatic discharge (ESD). See Figure 4.

<u>Carefully</u> plug the OEM Basic Stamp into the lower right or left corner of the solderless breadboard with the solder pins facing away from the breadboard.

Looking at the Stamp, from the left side (the left side has the DB9 serial cable connector), the third pin marked V_{in} is the pin to which power must be connected in order to run the Stamp. The Stamp has a voltage regulator onboard that will accept 5.8 V to about 15 V comfortably and regulates that to 5 V, which is what the Stamp IC needs to run. It will be best to supply 9-12V to the V_{in} pin. Thinking ahead toward self-contained projects you might build, it will be easy to power the Basic Stamp using a 9 V battery. So keep life easy for yourself here in the lab, and use 12 V from the fixed supply to power V_{in}. (As recommended in the previous lab, <u>make sure the power supply is turned off when you are wiring or making any changes to the wiring</u>. Make connections from the power supply to the screw terminal posts on the solderless breadboard using the banana-to-banana test leads. Then, from the screw terminals, run short lengths of hookup wire to the bus strips that run the length of the breadboard. Finally, use short lengths of hookup wire to connect the appropriate pins to power or ground. This not only saves hookup wire, but it makes your circuits more robust, and less sensitive to noise.)

The common connection is marked V_{SS}. It is the second pin from the left side. This is the common ground connection for the Stamp. Make this connection to the common ground of the power supply (through the bus on the solderless breadboard)
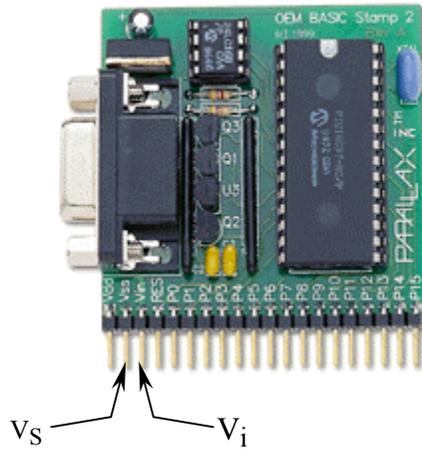
Figure 4 OEM Basic Stamp II

8. Build the circuit shown below in Figure 5. Note that the 10 μF capacitors are POLARIZED. If you look at the side of the capacitor body, you will see one leg marked with a minus sign. IT IS EXTREMELY IMPORTANT THAT THE MINUS LEG ALWAYS BE KEPT AT LOWER POTENTIAL THAN THE OTHER LEG! If you reverse the polarity, the capacitor can explode, so take extra precaution and double-check how you wire the capacitors before you apply power to your circuit. Not all capacitors are polarized, but electrolytic ('lytic for short) capacitors are.
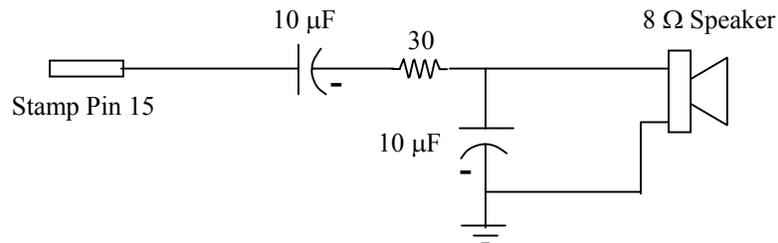
Figure 5 Basic Stamp circuit

9.   Attach the serial cable from the computer to the Basic Stamp.

10. Double click on the Basic Stamp Editor icon on the computer desktop. This brings up the Basic Stamp Windows Editor, which allows you to write, download, and debug programs for the Stamp. Enter the following program.

```
'Speaker test program
'Your name here  put the date here

'end 'this is a quick way to stop your program

loop1: freqout 15, 65000, 440
```

```
goto loop1

end
```

FREQOUT is a built-in function that allows you to output tones the syntax is:

FREQOUT pin, duration in msec, freq1 {, freq2}

where freq1 is the frequency in Hz of the tone to be output, and the optional freq2 is a second frequency that will be mixed with freq1.

loop1: is a label that allows the freqout command to be executed continually.

11. Turn on the power supply, and run your program (CNTRL-R, or Run from the menu bar, or click on the blue triangle icon). You should hear a tone coming from the speaker.

12. Look at the signal applied to the speaker using the oscilloscope. **Describe what it looks like. How is it generated? What does the capacitor connected the Stamp pin do?**

13. Remove the second capacitor connected between the speaker and common. **What happens to the sound and signal? What does this second capacitor do?**

14. Try changing the parameters in the FREQOUT function and see what happens.

Questions

Questions are in bold letters in Procedures.