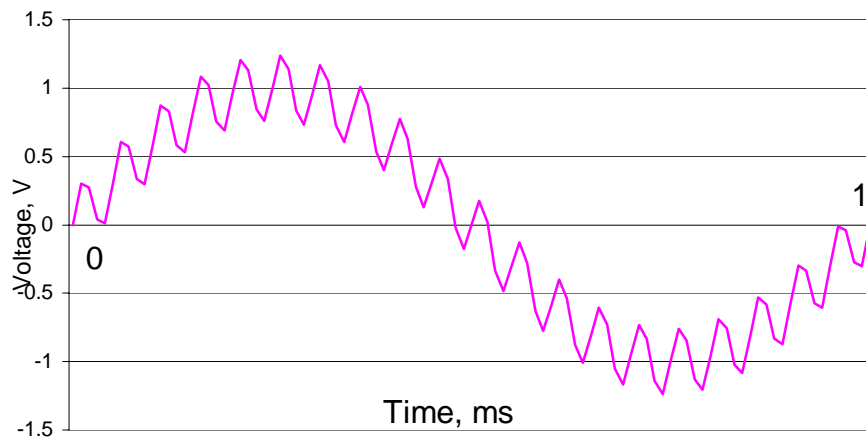


RC Filters

Pre-lab Questions

1. What are some typical uses of RC filter circuits?
2. Given a low-pass filter with a 2 K Ω resistor and a 0.2 μ F 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 OOPic microcontroller and its capability to output tones

Components

Qty.	Item
1	Oricom Technologies OOBOT 40-II robot controller board
1 ea.	1 k Ω and 10 k Ω resistors
1	0.1 μ F capacitor
1	10 μ F capacitor
1	30 Ω resistor
1	piezo speaker (Murata PKM17EPP-2002-130 (Mouser 81-PKM17EPP-2002))

Introduction

Resistor-Capacitor Filter Circuit

Consider the circuit shown in Figure 1. 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. Equation 1 is derived using the voltage divider relationship. Equation 2 solves equation 1 for the ratio of V_o to V_i , which is called the ‘transfer function’ of the filter.

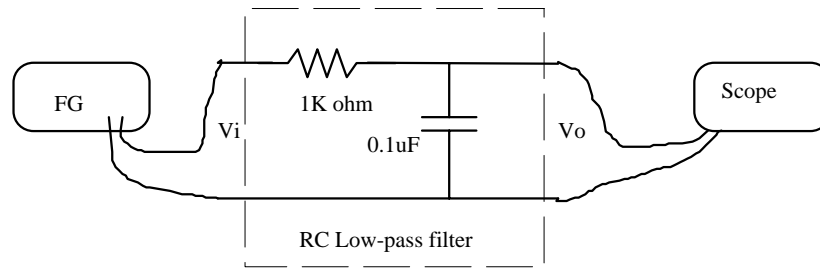


Figure 1 RC low-pass filter. The resistor and capacitor together function as a frequency-dependent voltage divider.

$$V_o = \frac{1/(j\omega C)}{R + 1/(j\omega C)} V_i \quad (1)$$

$$\frac{V_o}{V_i} = \frac{1}{1 + j\omega RC} \quad (2)$$

The transfer function tells how much of the input voltage is ‘transferred’ to the output. What happens to the value of the transfer function as the frequency of the input voltage increases? Does it increase or decrease? For a given sinusoidal input voltage V_i , the magnitude of the output voltage V_o is given by the product of V_i and the magnitude of the Transfer Function (evaluated at the frequency of V_i).

We will verify equation 2 by the following experiment.

Procedure

1. Construct the single-stage RC Low-pass filter circuit shown in Figure 1.
2. Set V_i to 5 volts peak-to-peak (V_{pp}) at 500 Hz and record the amplitude of V_o . Repeat this measurement with the frequency of V_i set to 1.6 kHz and 10 kHz. Compare the ratio of the input voltage and the output voltage (i.e., V_o/V_i) 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 V_i and V_o 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 $V_i=1.6$ kHz. **Does the theoretical value match the observed value?**

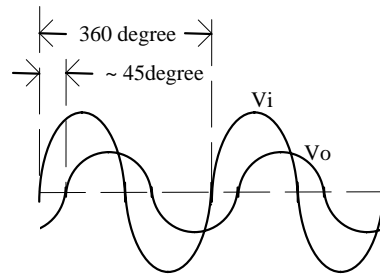


Figure 2 Phase lag of V_o .

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

$$V_o = \frac{R}{R + 1/(j\omega C)} V_i \quad (3)$$

$$\frac{V_o}{V_i} = \frac{j\omega RC}{1 + j\omega RC} \quad (4)$$

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

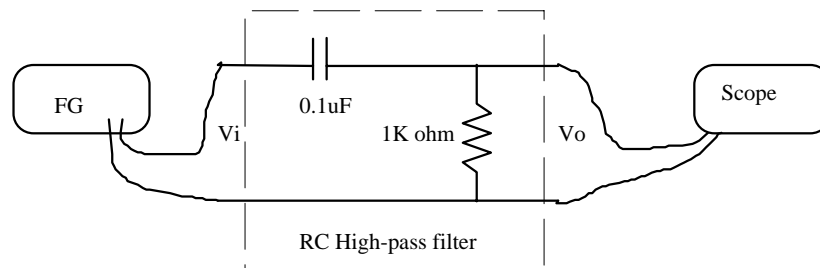


Figure 3 High-pass filter

6. Add a DC offset (any value) to the function generator output. **Does this DC offset affect the output (V_o) 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.”

OOPic Primer

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

7. Remove the OOPic 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). Orient the OOPic as shown in Figure 4.

8. Locate the power cable, a red-green twisted pair with stripped leads on one end, and a connector on the other. Make sure that the power supply is turned OFF, then connect the stripped end of the red lead to the +12 V terminal of the power supply, and the stripped end of the green lead to the COMMON of the power supply. The connector at the other end of the twisted pair plugs into the power input terminal and can do so in only one orientation so as to avoid switching + and -.

The OOPic has a voltage regulator chip that will power the components on the board with a steady 5 V when the power input connector is supplied with a DC voltage in the range of about 6 to 15 V. This makes it convenient to power the OOPic using a battery pack, such as that for an RC car, camcorder, even just a 9 V alkaline cell.

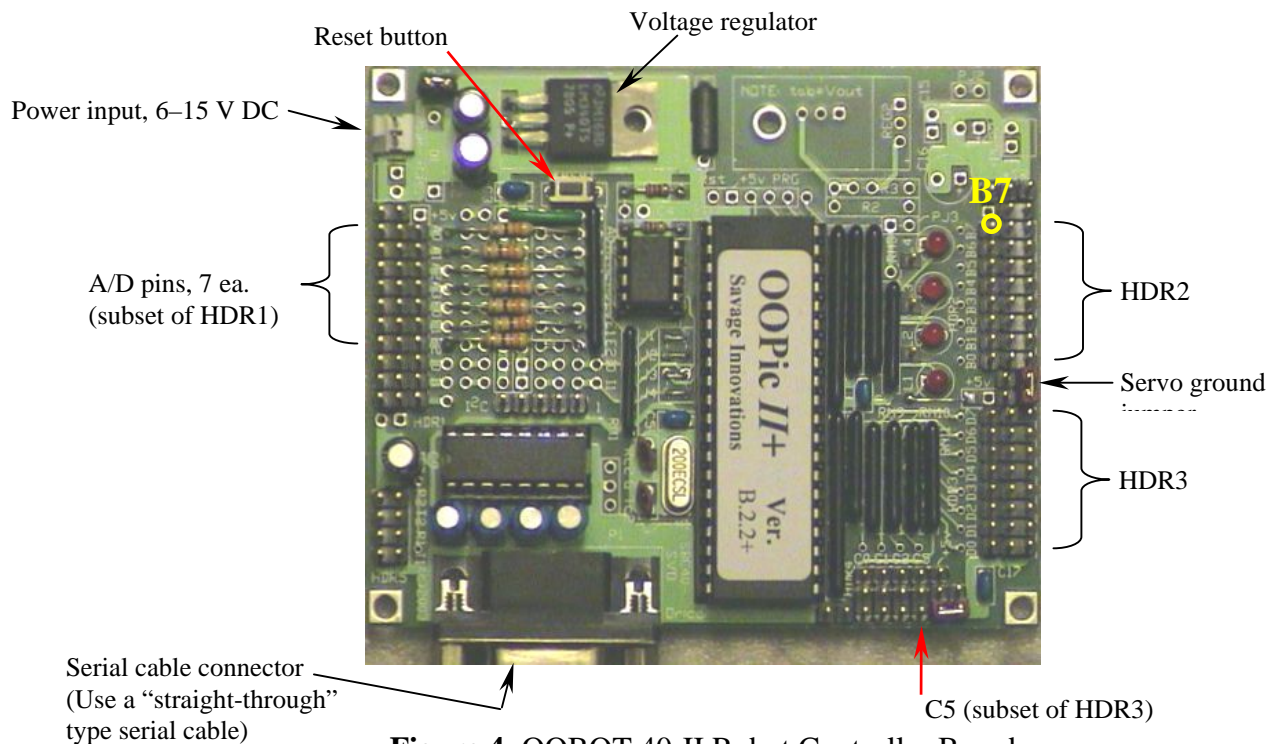


Figure 4 OOBOT 40-II Robot Controller Board

9. Turn on the power supply, and verify that the ‘power on’ LED (L1) lights up. If the light does not come on, see the TA for help. Do not proceed if the board does not power up!
10. After you are successful with step 9, turn off the power supply, and connect the piezo speaker to the three pins in the vertical row at C5 in HDR 4 (see Figure 4), so that the black wire connects to the pin closest to the lower edge of the board. The outermost pins along the edges of the board in each HDR block are all ‘ground’.
11. Turn on the power supply. You should hear a tune being played by the OOPic. (Turn the power supply off if you don’t want to listen to the tune play forever!) If you don’t hear the tune, the speaker is probably not connected properly.
12. Connect the serial cable to the OOPic connector and to the COM 1 serial port on the PC. Open the OOPic software from the Start → Programs menu. Verify the cable and software configuration under the Tools menu in the OOPic software (‘Cable Configuration’ and ‘Target Device’ respectively). If the power supply is on, the software can determine which

COM port is being used by clicking on the 'Find Serial Cable' button on the Cable Configuration dialog box. The 'Target Device' should be, 'OOPic Firmware ver B.2.x+.

13. Try downloading a few of the example programs that play tunes (File → Samples). Look for Sample-B-hd-oFreq-X.osc, where X=1 to 4). Note that these samples are written in Visual Basic. You can choose to write your program using Visual Basic, C, or Java syntax from the main toolbar. After selecting the sample program, click on the ▷ button on the main tool bar to download the program to the OOPic.
14. **NOTE OF CAUTION:** the OOPic integrated development environment (IDE) is quirky in that if you modify a program, and then download it to run, the source file is *overwritten* and saved automatically according to your changes. Thus, it is highly recommended that you make program changes to a *copy* of your original source using Save As, so that you will have a backup of your original source in case your programming modifications leave you in a bad spot. So, use Save As to save a copy to the Desktop of one of the sample programs. Modify this copy by removing the DO and LOOP statements. This will cause the tune to play only once: at power up, or when the Reset button is pressed. Look at the OOPic manual for the oFreq object, and **explain how it works**. (Note: the OOPic manual is available online. Go to Help → Manual; click on OOPic Objects, B.2.x+)
15. Build the circuit shown below in Figure 5 on the solderless breadboard. Use a jumper wire (female socket on one end, stripped wire at the other end) to connect the OOBOT pin B7 (see Figure 4) to the solderless breadboard. Note that the 10 μF capacitor is 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.

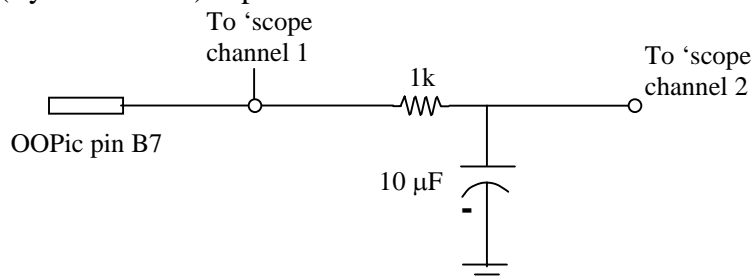


Figure 5 OOPic circuit with RC Filter. The 'scope is used to display the output from the OOPic before and after the filter. Note that the ground shown is the common ground of the power supply. One of the ground clips from the 'scope probes must be connected to the power supply common ground.

16. Make sure that the C syntax in the OOPic IDE is selected, and enter and download the following program:

```
// Pulse Width Modulation (PWM) program
// causes the duty cycle of the output on line 15 (pin B7)
// to continuously vary
```

```

oPWMx pwm_out = new oPWMx;    // declare PWMx object
oSerial PCterm = new oSerial; // declare Serial object

sub void main(void)
{
  pwm_out.IOLine = 15;    // I/O line 15 selected
  pwm_out.Operate = cvTrue; // PWM object is enabled

  PCterm.Baud=cv9600;    // Set serial communication baud rate to 9600
  PCterm.Mode=0;        // Asynchronous serial communication
  PCterm.Operate=cvTrue; // Serial object is enabled

  While (1)              // Continuous loop
  {
    if (PCterm.Received == cvTrue) // True when OOPic gets data from PC (note ==)
    {
      switch (PCterm.Value)
      {
        Case 93:          // ASCII code for ']' → increase duty cycle
          pwm_out++;      // Increment PWMx value by 1
          break;
        Case 91:          // ASCII code for '[' → decrease duty cycle
          pwm_out--;      // Decrement PWMx value by 1
          break;
      }

      // Tell the user what the PWM value is

      PCterm.string="PWM=";
      PCterm.string=str$(pwm_out); //Send PWM value
      PCterm.value=13;            // Carriage return character
      PCterm.value=10;           // Line feed character
    }
  }
}

```

17. Open the OOPic Communication window (View → Comm Control).
18. Look at the signal on channels 1 and 2 using the oscilloscope. Grab the 'scope trace showing both waveforms using Benchlink.
- 19. Describe what is happening to the signals on channel 1 and 2 when you press the '[' or '[' keys and why. (Note: in order to change the duty cycle with the '[' and '[' keys, you must have the Comm Control window selected.) What is the RC filter doing? What could you do with this?**

Questions

Questions are in bold letters in Procedures.