Project 7: Sensor Amplifier and Geophone damping

This project is similar to the geophone amplifier except that its bandwidth extends from DC to about 20Hz. Seismic sensors for earthquake detection are expensive. They can typically detect very low frequency (millihertz) vibrations (referred to as "long period"). Geophone frequency response is typically between 1Hz and 200Hz (referred to as "short period"). The second part of this project extends the low frequency response of the geophone for inexpensive earthquake detection.

Figure 6-5 below shows the circuit diagram of the amplifier. It is also a 4-pole low-pass filter with a cutoff frequency of 20Hz. A 60Hz notch filter is included to minimize 60Hz line interference (U2B).

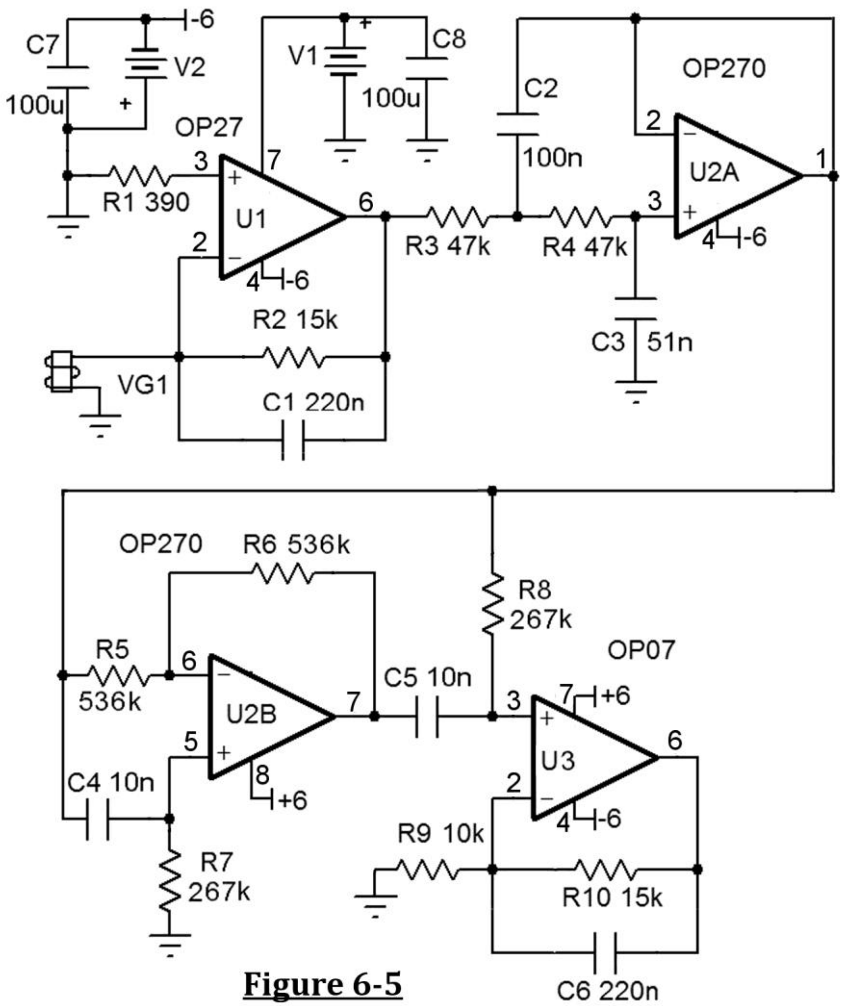


Figure 6-5

Simulation

Figure 6-6 below shows the *LTspice* circuit of the amplifier. V1's internal resistance was set to 380 ohms to represent the winding resistance of the sensor. U2A is a 2-pole low-pass Butterworth filter. U2B is a 60Hz notch filter. U3 serves as a buffer for the notch filter and provides additional voltage gain.

The notch filter's notch frequency could be changed to 50Hz for locations with 50Hz line interference but the amplifier's bandwidth would be reduced. Notch filters tend to have a relatively wide -3dB bandwidth.

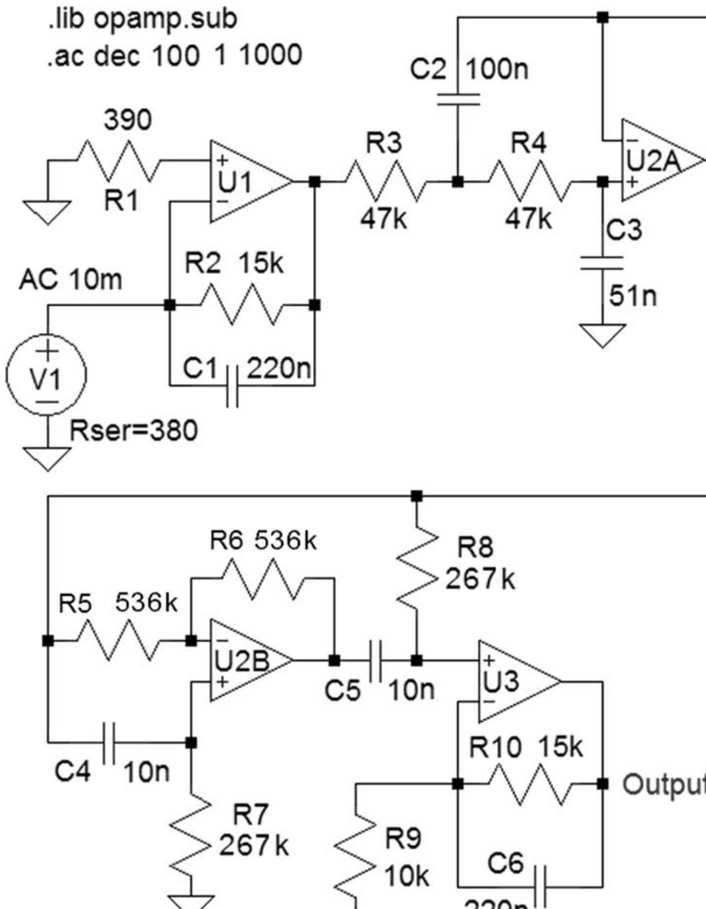
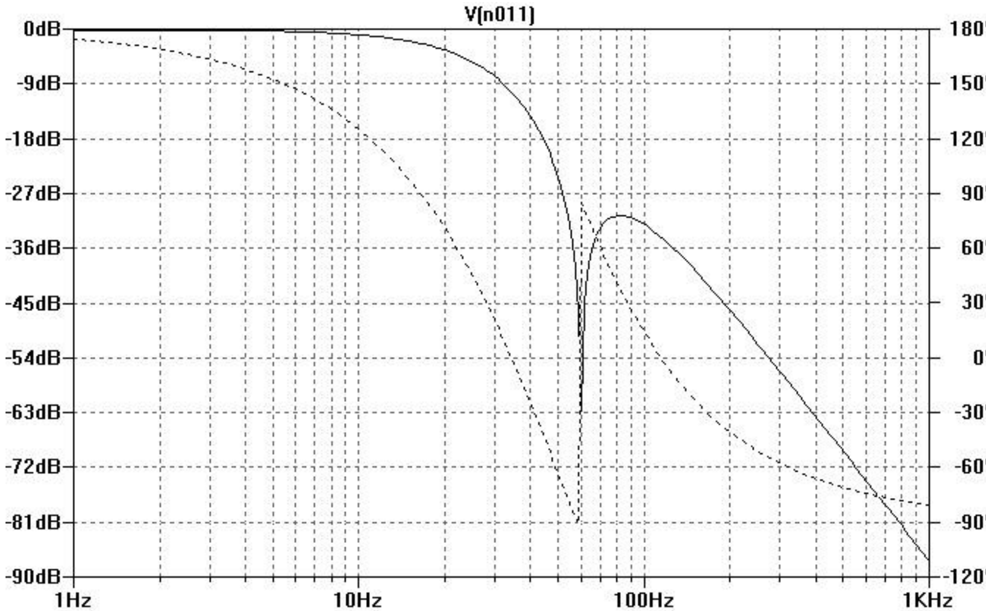


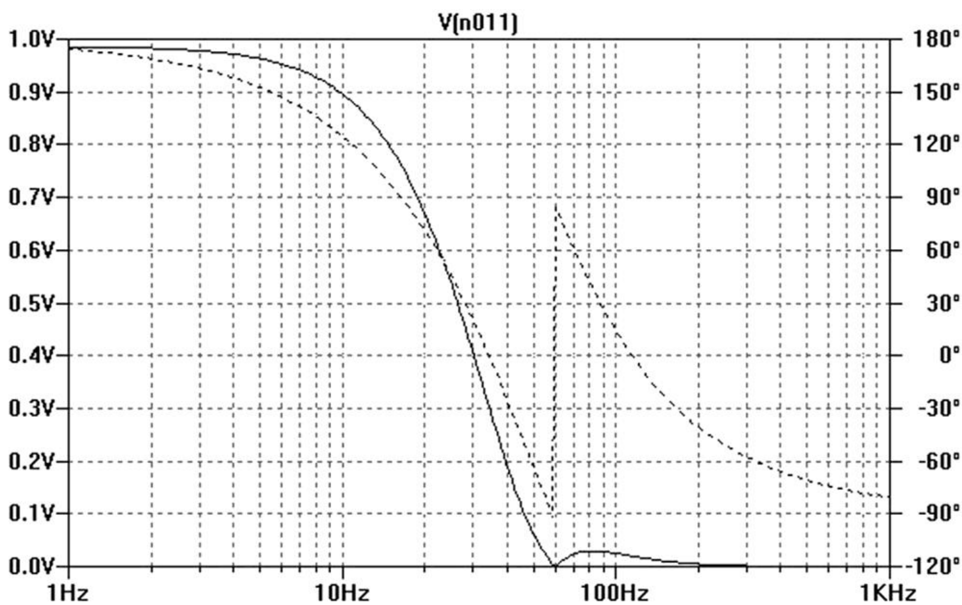
Figure 6-6

V1's AC amplitude was set to 10mV. Be sure that its internal resistance is set to 380 ohms. AC analysis was used to sweep the frequency from 1Hz to 1kHz.

The result below shows that the cutoff frequency is about 20Hz and that the attenuation at the notch frequency is 65dB.



Change the vertical scale to linear to get the result below. The attenuation at the notch frequency and beyond appears more dramatic.



Experiment

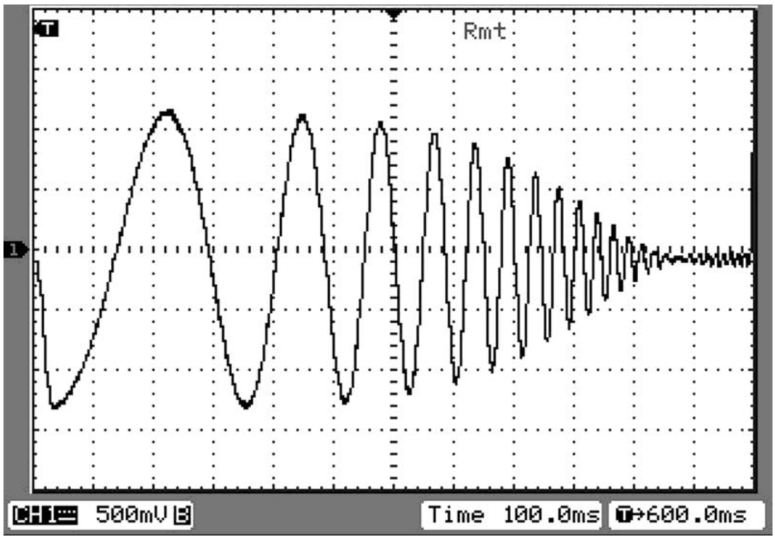
Parts

U1: OP27, U2: OP270, U3: OP07. Observe pin numbers.
R1: 390, R2: 15k, R3, R4: 7.5k, R9: 10k, R10: 15k, all ¼ watt, 5%.
R5, R6: 536k, ¼ watt, 1%. R7, R8: 267k, ¼ watt, 1%.
C1, C6: 220nF, 5%. C2: 100nF, 5%, C3: 51nF, 5%.
C4, C5: 10nF, 1% (Mouser part # 80-C330C103F1G).
C7, C8: 100uF, 16VDC electrolytic.
VG1: magnetic sensor. (Function generator with 330 series resistor for testing).

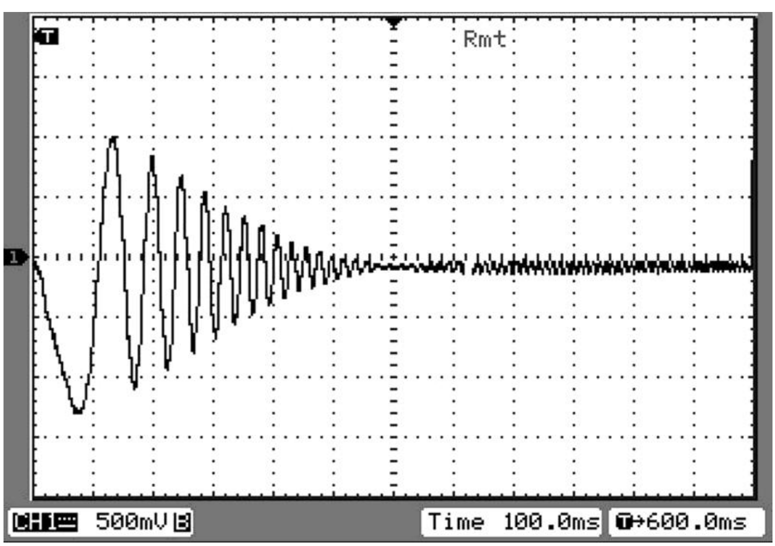
Construction and testing

1. Build the circuit in figure 6-5 on a breadboard using the part values given above. Wire and component leads should be kept short.
2. Connect a function generator in series with a 390Ω resistor to the input. It will be used for G1 to test and analyze the circuit.
3. Apply power to the circuit and set the function generator to output a 40Hz, 30mV peak-to-peak, sine wave.
4. Connect an oscilloscope to the output. You should observe a 40Hz sine wave with an amplitude of about 3 volts peak-to-peak.
5. Vary the function generator frequency to find the amplifier's corner frequencies (-3dB – where the signal amplitude is 0.707 of maximum).
6. Vary the function generator frequency to find the amplifier's notch frequency and notch attenuation.
7. Calculate the expected gain and bandwidth of the amplifier. Compare your results to the simulated results.
8. Calculate the worst case output noise over the bandwidth of the amplifier based on the op-amp specifications. Measurements may also show environmental noise.
9. Measure the amplifier's DC output voltage (offset voltage). Calculate the worst case output offset voltage of the amplifier based on the op-amp specifications.
10. U1 and U3 have offset compensation pins. Look up the required offset compensation circuits in the op-amp's data sheet. Apply offset compensation to U1.

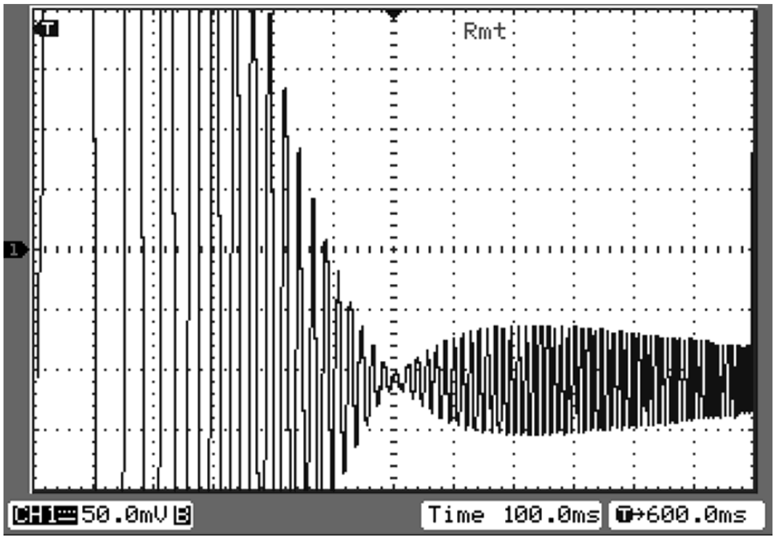
The oscillograph below shows amplifier response for a 2 decade sweep of the input frequency. The function generator was set to sweep the frequency from 1Hz to 100Hz in 1.2 seconds. The oscilloscope was triggered by the function generator and set to sweep at 100ms per division (there are 12 horizontal divisions). The 60Hz notch is apparent on the right side of the display.



The display below shows the response for a linear frequency sweep from 0.1Hz to 120Hz. The 60Hz notch is at the center of the screen.



The oscilloscope's vertical sensitivity is changed to 50mV per division in the display below. Note that there is a -110mV DC offset. Input offset compensation should be applied to U1. If this amplifier's gain is increased to 1000, its output offset voltage would become -1,1V.



Extending the Geophone's Low-frequency Response

There is considerable interest in extending the low frequency response of geophones for earthquake detection because geophones are simpler and much less expensive than seismograph instruments[1]. Over-damping is a common approach which can be done by connecting a resistance to the geophone. However, this requires a negative resistance. According to Ulman[2] this typically requires a negative resistance: $R_d = -0.8R_c$. R_c is the coil resistance odf the geophone.

Refer to "VNIC – Negative Impedance Converter" on page 52 of this book. The impedance for the circuit of figure 3-17 is given below. A suggested circuit to replace the U1 circuit in figure 5-14 is given on the next page.

$$Zin = \frac{Vin}{Iin} = -\frac{R1}{R2} Zx.$$

1. Novel Tools for Research and Education in Seismology, by Mikhail E. Boulaenko. Master of Science Thesis, Institute of Earth Physics, University of Bergen, December 2002
2. Over-damping geophones using negative impedances, Bernd Ulman, 2005

Example

This example is intended to show a possible design approach for a VNIC with a voltage amplification of 40 and given that a 4.5Hz, 395Ω, geophone requires an input impedance of - 316Ω (Zin = -.8R_d = -.8(395) = -316Ω. The calculation for a real application would require more information than just the geophone coil resistance. Specifications for the RTC-4.5-395 are given n the appendix.

The objective is to design an amplifier with a gain of 40 with a negative resistance at the inverting input of about -316Ω. Begin with the equations for the input current and the voltage on the input terminals.

$$\text{Iin} = \frac{\text{Vin} - \text{Vo}}{\text{Rx}} = \frac{\text{V1} - \text{Vin}}{\text{Ri}} \quad \text{and} \quad \text{Vin} = \frac{R_1}{R_1 + R_2}\text{Vo}.$$

$$\text{VinRi} - \text{VoRi} = \text{V1Rx} - \text{VinRx} \;\Rightarrow\; \text{Vin}(\text{Ri} + \text{Rx}) = \text{V1Rx} + \text{VoRi}.$$

$$\frac{R_1}{R_1 + R_2}\text{Vo}(\text{Ri} + \text{Rx}) - \text{VoRi} = \text{V1Rx}.$$

$$\frac{\text{Vo}}{\text{V1}} = \frac{\text{Rx}}{\frac{R_1}{R_1 + R_2}(\text{Ri} + \text{Rx}) - \text{Ri}}, \text{ If R2>>R1 and Rx>>Ri then } \frac{\text{Vo}}{\text{V1}} \approx \frac{\text{Rx}}{-\text{Zin} - \text{Ri}}.$$

$$\text{Design: } R_d = 395, \quad \text{Zin} = -0.8R_d = -316.$$

$$\text{For a gain of 40: } \frac{\text{Vo}}{\text{V1}} \approx \frac{\text{Rx}}{-\text{Zin} - \text{Ri}} = -40 \approx \frac{\text{Rx}}{316 - 400} \;\Rightarrow\; \text{Rx} = 40(84) = 3360.$$

let R2 = 10k, calculate R1:

$$\text{Zin} = -\frac{\text{R1}}{\text{R2}}\text{Rx} = -\frac{\text{R1}}{10000}3360 = -316 \;\Rightarrow\; \text{R1} = \frac{3160000}{3360} = 940.$$

The input impedance and voltage gain is sensitive to the values of R1, R2, and Rx. Therefore standard value 1% resistors are chosen for the design.

The circuit in figure 6-7 was fine tuned with *LTspice*. Rx = 3240. R1 = 953, R2=10000 (all 1%).

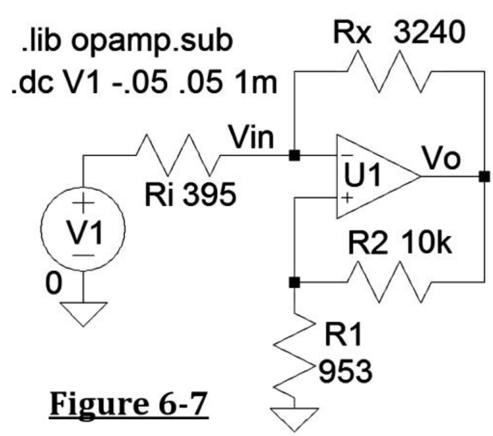
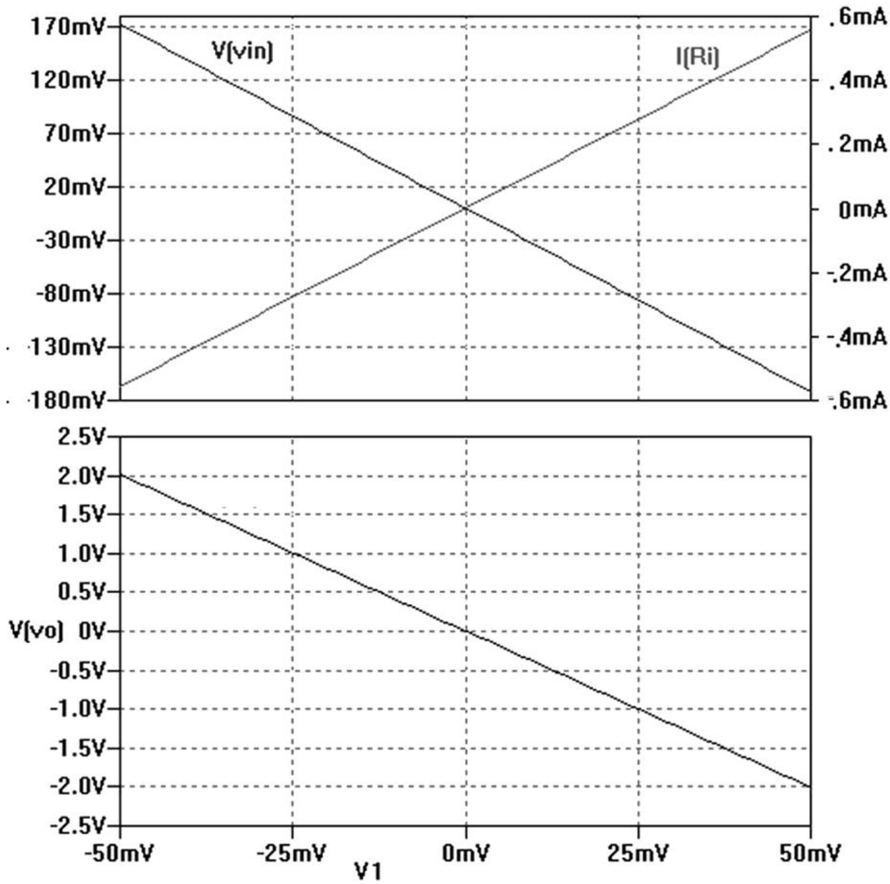


Figure 6-7

Simulation Results



The top graph shows the input voltage at the negative input of the op-amp and the current flowing into it. The total change in the input voltage is -340mV. The total change in the input current is 1.12mA. This shows an input resistance of -304Ω.

The bottom graph shows that the total change in the output voltage is 4 volts. The corresponding change in the input voltage, V1, is 100mV. This corresponds to a voltage gain of 40.

This VNIC could be the first amplifier, U1, of the geophone circuit figure 5-14. It would connect directly to the Butterworth filter. Theoretically it should extend the low frequency response of the RTC 4.5 to about 0.5 Hz. However, the negative impedance here was calculated based only on the sensor's coil resistance. There are other factors, such as the sensor's coil mass, that need to be considered to calculate a more accurate value of negative resistance.