MULTISIM DEMO 9.5: 60 HZ ACTIVE NOTCH FILTER

A big problem sometimes encountered in audio equipment is the annoying 60 Hz buzz which is picked up because of our AC power grid. Improperly grounded equipment and poorly shielded cables often gives a distinct buzz in the vicinity of 60 Hz which comes out of the speakers and can become very annoying. Consequently, some audio circuits have specific filters which filter out 60 Hz in order to remove this problem. These filters need to be very selective and have a very narrow block-band so they affect as little of the audio spectrum outside of their selected frequency as possible. We usually call then Notch filters because they only block out a small "notch" in the AC spectrum.

An active filter version of a notch filter is shown already built in Multisim in Figure 9.5.2 below. It is composed of 5 op amps, with the top two forming a series of two low-pass filters and the bottom two forming a series of two high-pass filters. The fifth op amp on the right side is a summing amplifier which effectively combines each filter's behavior. Remember that you can make a notch filter out of a parallel set of high and low pass filters. This is what is going on in this circuit.

Each of the top two op amps makes up a low-pass filter with a corner frequency of 58.95 Hz. In a series combination, then at 58.95 Hz, the attenuation should be 3 dB + 3 dB = 6 dB. Each of the bottom two op amps makes up a high-pass filter with a corner frequency of 61.2 Hz. In a series combination, the attenuation at 61.2 Hz is therefore 6 dB as well.

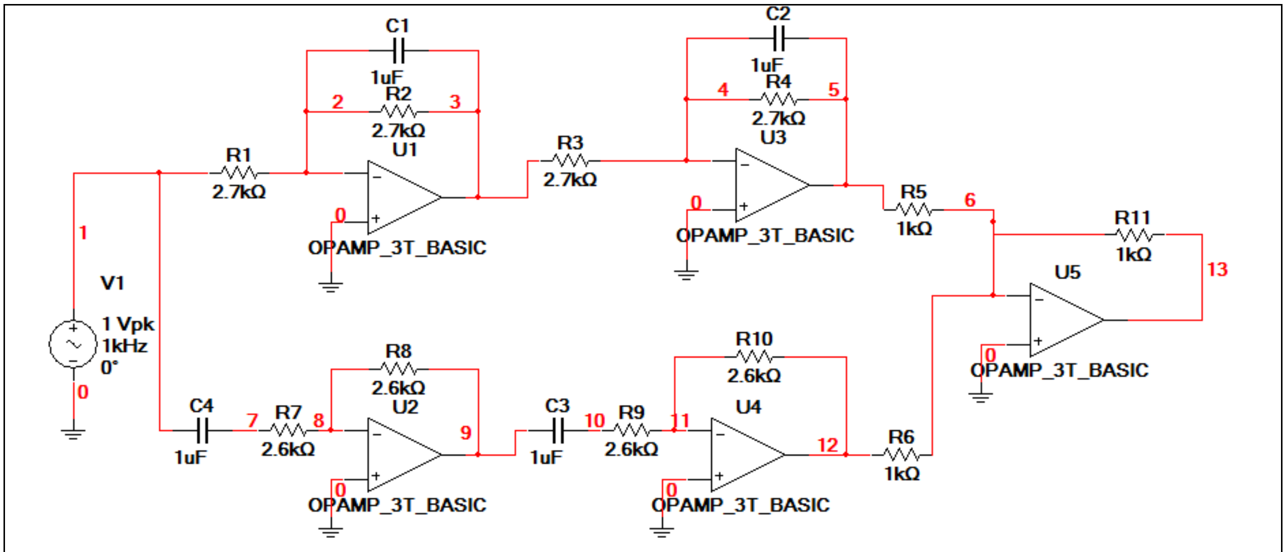

Figure 9.5.1 60 Hz notch filter implemented in Multisim. It's ready to be tested in an AC Analysis. Note that the op amps have been flipped across the horizontal using the Alt-y command.

Once the circuit is built, we need to do an AC analysis of it. We want to focus in right around 60 Hz, so set the sweep of the AC Analysis to be from 1 to 100 Hz. Also, set both the sweep type and the vertical scale to linear, and set the number of points to 100, as shown in Figure 9.5.2. This will give us a nice, clean-looking plot.

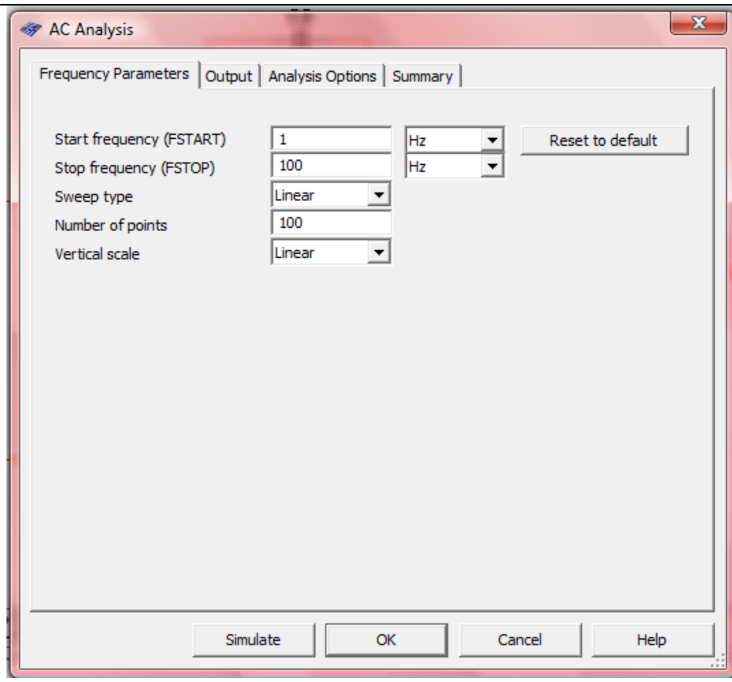

Figure 9.5.2 AC Analysis Frequency Parameters. Because we're looking at such a small frequency range, it makes sense to just view it over a linear frequency sweep.

Now before we plot the overall output of the filter, let's take a look at the behavior of each of the different stages. Let's first look at the low pass filters. Plot the signal taken at the output of each of the low-pass filter stages. In the schematic shown in Figure 9.5.2, that corresponds to V(3)/V(1) and V(5)/V(1). Make sure to set your vertical scale to Decibels! The result of this plot should look like what is shown in Figure 9.5.3.

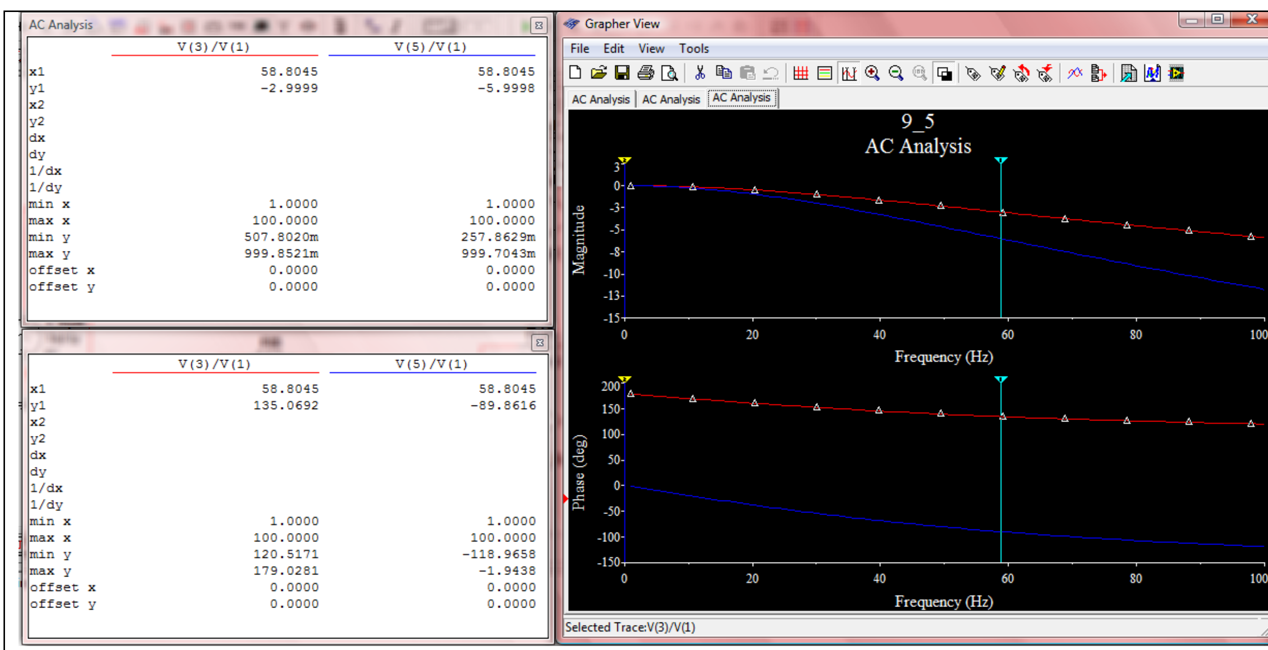

Figure 9.5.3 The transfer function plots of the two low-pass filters (Red is first stage, and blue is second stage).

As you can see, at 58.8045 Hz, the gain at the first stage is -2.9999 dB and the gain after the second stage is -5.9998 dB. This is exactly what we should expect because each stage has a gain of about -3 dB at that frequency, so when we add them in series the gain after both should be less than it is after just one stage.

Now let's do the same thing for the two high-pass filters. This corresponds to the ratios of V(9)/V(1) and V(12)/V(1) if you're going by the node numbering found in Figure 9.5.1. The result of this analysis can be seen in Figure 9.5.4 below.

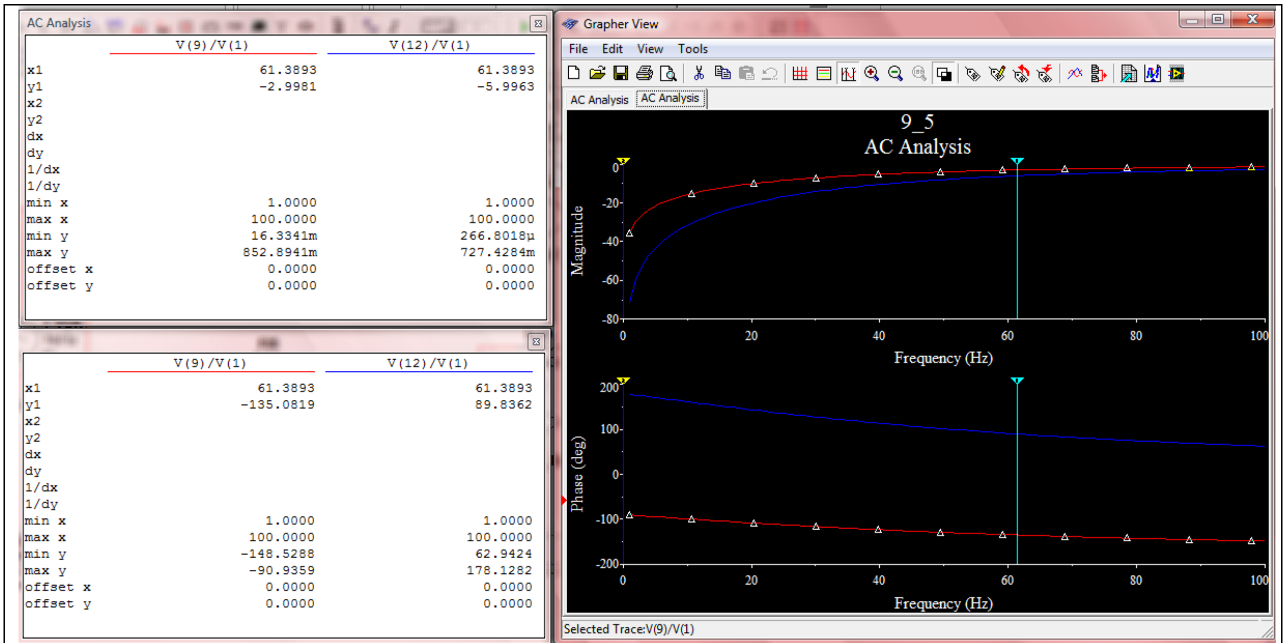

Figure 9.5.4 The transfer function plots of the two high-pass filters (Red is first stage, and blue is second stage).

As you can see, at 61.3893 Hz, the gain at the first stage is -2.9999 dB and the gain after the second stage is -5.9998 dB. This is exactly what we should expect because each stage has a gain of about -3 dB at that frequency, so when we add them in series the gain after both should be less than it is after just one stage.

Now let's plot the transfer function of the entire high-pass filter as well as the transfer function of the entire low-pass filter on the same plot. The result is shown in Fig. 9.5.5 on the next page.

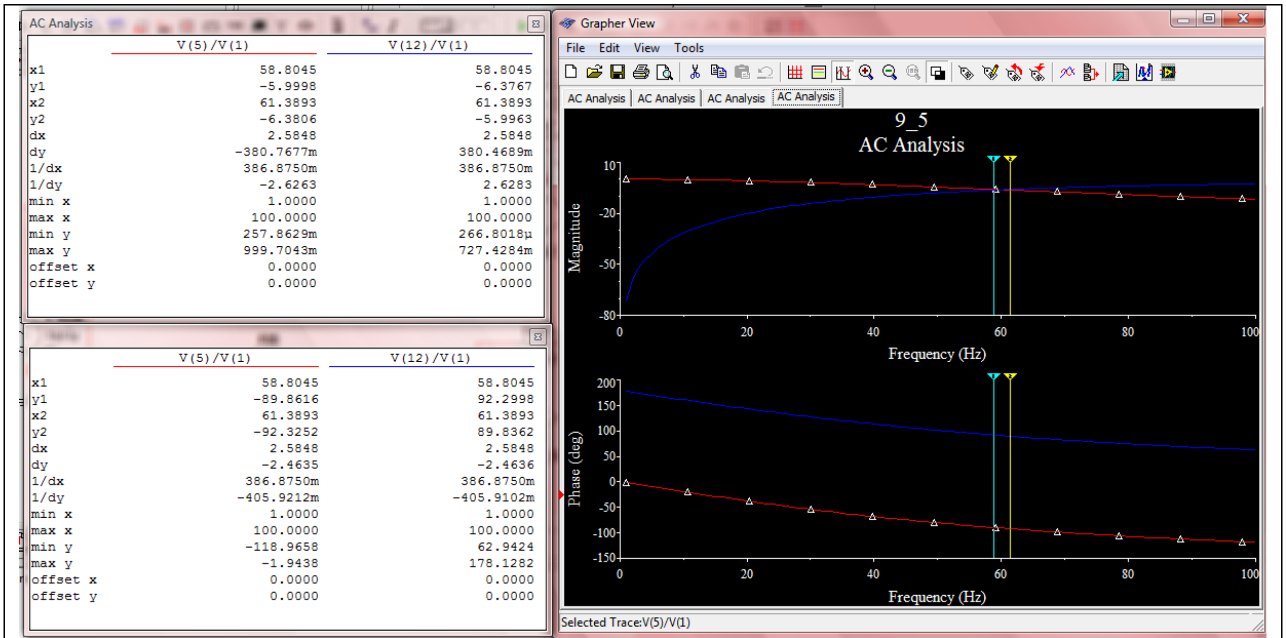

Figure 9.5.5 The transfer function plots of the entire low-pass filter (red) and the entire high-pass filter (blue).

As expected, the -6 dB points are 58.8045 Hz for the low-pass filter and 61.3893 Hz for the high-pass filter.

Now let's plot the overall transfer function. The output is shown in Fig. 9.5.6 below.

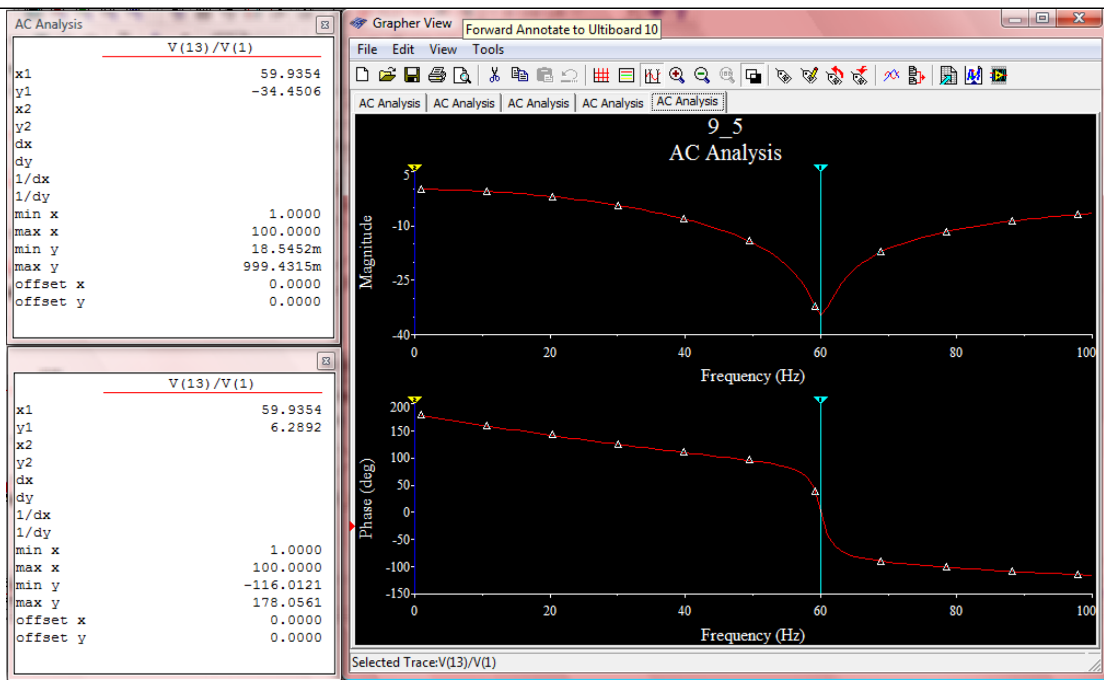

Figure 9.5.6 Transfer function of entire filter. Note the very distinct Notch in the AC spectrum right around 60 Hz.

This has good response, and has a rejection of -34.4506 dB at about 60 Hz.

But what exactly does that mean? Let's simulate the circuit by feeding in a set of two frequencies. Alter the circuit by replacing the AC_VOLTAGE source with an ABM_VOLTAGE source as shown below in Fig. 9.5.7.

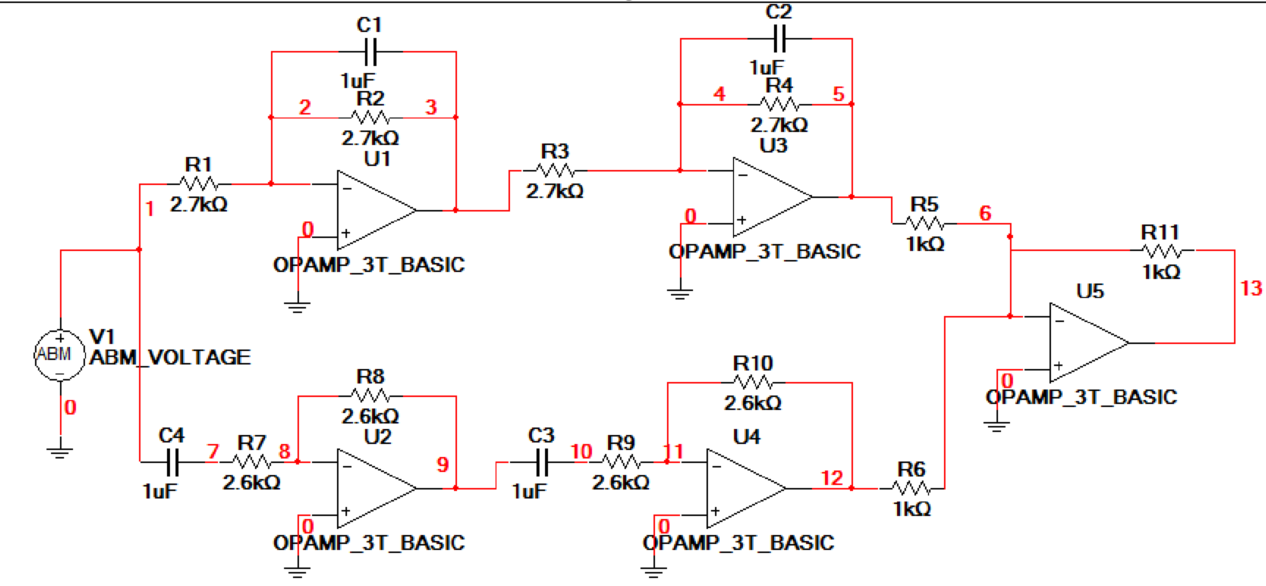

Figure 9.5.7 Multisim schematic of the notch filter with ABM_VOLTAGE source attached.

For the ABM source, set the voltage value to 2*sin(2*PI*1000*TIME)+1*sin(2*PI*60*TIME) as shown in Fig. 9.5.8. This corresponds to the signal: $v_s(t) = 2\sin(2\pi \cdot 1000\,t) + \sin(2\pi \cdot 60t)\,\text{V}$, which is a signal of 1 kHz with a noise signal of 60 Hz.

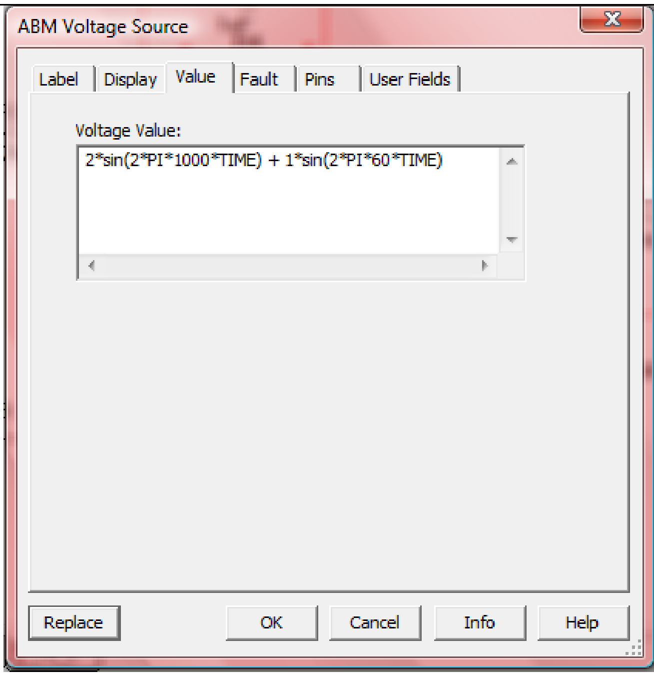

Figure 9.5.8 Voltage value for the ABM_VOLTAGE source. A combination of a 1 kHz sine wave and a 60 Hz sine wave noise signal presumably from nearby power lines.

Run a Transient Analysis from 50 ms to 100 ms, and plot both the input and output signals. Your result should look like Fig. 9.5.9.

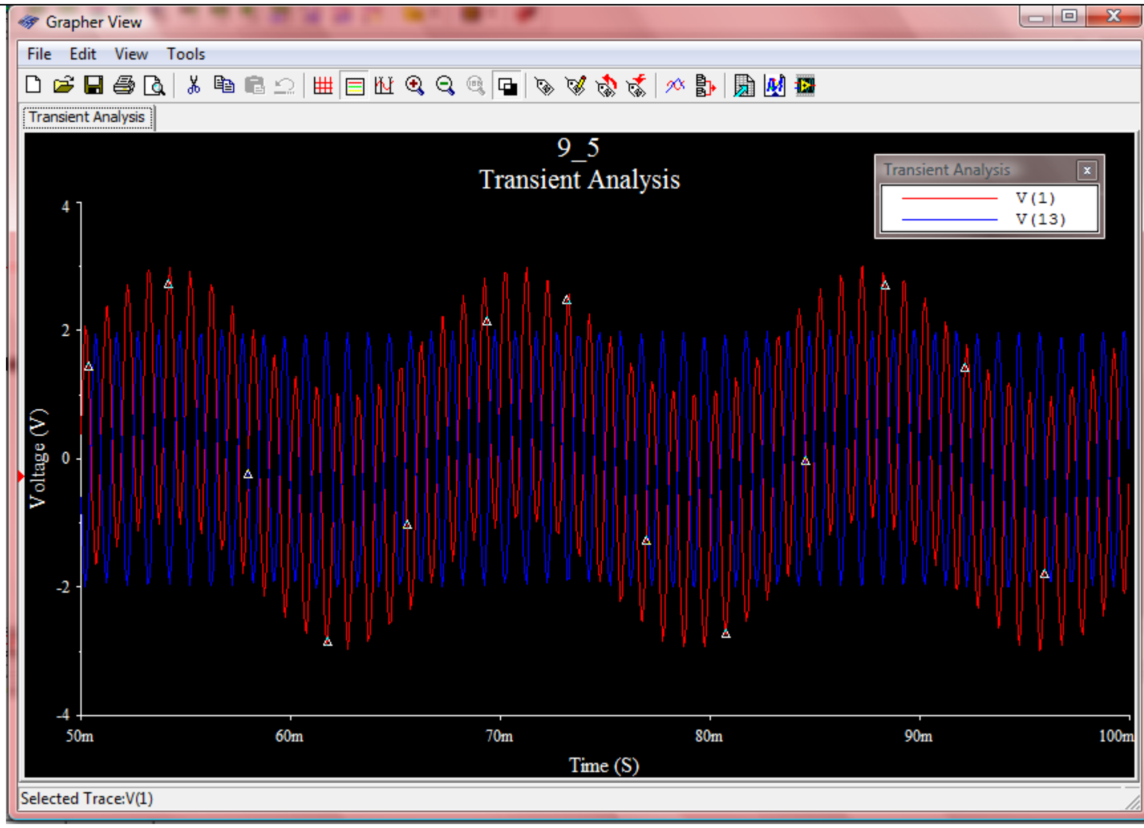

Figure 9.5.9 The input signal in red is composed of a pure 1 kHz tone and 60 Hz noise. The signal is fed into the notch filter and the output is almost purely the 1 kHz tone.

So what's going on? Pretend that we want to send a 1 kHz audio signal, but during the process of sending it, some poorly shielded cable allows 60 Hz from the nearby AC wall line to get picked up. The result is a messy combination of the 1 kHz tone that we want and a 60 Hz noise tone. This noisy signal is the red plot shown above. When we run it through the filter, however, the 60 Hz gets filtered out, and the result is the blue signal in Fig. 9.5.9, which is pretty much just the 1 kHz signal free of the 60 Hz tone. The notch filter works!