Lab 3

LTI Systems and Filters

3.1 Pre-Lab

1. Design a first-order lowpass RC filter with a cutoff frequency of 10 kHz. Show all values used in your design. What is the rolloff rate and pass-band gain of the filter?

2. Using Simulink, pass a square wave source of frequency 8 kHz through a first order lowpass filter with a bandwidth of 10 kHz. With MATLAB, calculate the spectrum and print it out.
   Now pass the same source through a fourth-order lowpass filter with a bandwidth of 10 kHz. Again calculate and print the spectrum. Discuss the difference.
   (Note: You can use any type of lowpass filters for your simulation such as Butterworth, Chebyshev I, Chebyshev II, or elliptic.)

3.2 Overview

Many communication systems operate on sinusoid signals and the sums of sinusoid signals. In theory, we know what behavior to expect from linear operations on sinusoids. In this experiment we will continue to study the behavior of linear time-invariant systems and compare it with the behavior of nonlinear systems. Particular emphasis is placed on the observations in the frequency domain.

We will also become familiar with some practical lowpass filters and their effects on signals with high frequency components. We know that an ideal lowpass filter is not causal; so we must work with non-ideal filters. We will consider some effects of using non-ideal filters and try to analyze tradeoffs of filter selections for a particular application. Some of the practical applications of filtering include:

- Integration of a signal

- Pulse shaping
- Operations on spectral components of a signal (i.e., correcting distortion, converting a square wave to a sine, etc.)

There are four basic types of filters: lowpass (LPF), highpass (HPF), bandpass (BPF), and bandreject (BRF). A general transfer function for each type of filter describes its frequency response that includes bandwidth, center frequency, cutoff frequency, rate of rolloff, and passband ripple.

In this lab we will work with first-order and fourth-order lowpass filters. We are interested in applying an LPF to isolate the first harmonic of a square wave (in other words, a square-to-sine conversion).

3.3 Procedure

3.3.1 Signal Superposition

In this part, we will look at the effects of superposition in our system.

1. On signal generator 1, create a sine wave of peak amplitude 1 Volt and frequency 1 kHz. On signal generator 2, create another sine wave with amplitude 0.1 Volt and frequency 10 kHz. Build a half-wave rectifier circuit as shown in Figure 3.1, and connect these signal generators to the circuit. Leave the spectrum analyzer disconnected in this step.

2. Observe the signal at both V_1 and V_2 on the oscilloscope. Adjust the attenuator to ensure a low voltage signal is input to the spectrum analyzer. Connect the spectrum analyzer. Record all your observations from both the oscilloscope and the spectrum analyzer.

3. Now adjust the frequencies of both sine waves (keeping the amplitudes the same as in step 1). Change the frequencies of signals 1 and 2 to 2 kHz and 5 kHz, respectively.
   Repeat step 2.

4. Now adjust the amplitudes of both sine waves (keeping the frequencies the same as in step 3). Make both amplitudes 1 Volt.
   Repeat step 2.

5. Now make both signals approximately identical: Amplitude 1 Volt and frequency 10 kHz.
   Repeat step 2.

3.3.2 Filter Building

In this part, we will build and implement our lowpass filters.

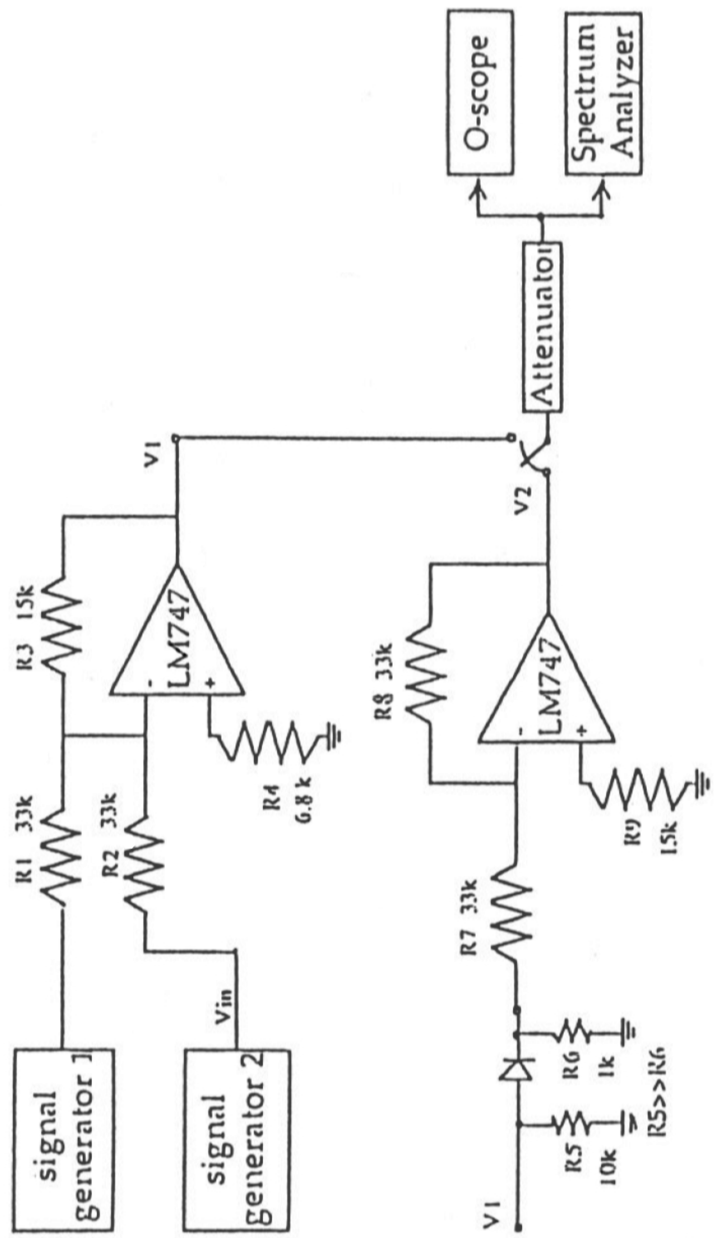


Figure 3.1: Equipment setup and circuit diagram for step 1 of Experiment 3

1. Build the lowpass filter shown in Figure 3.2a. On the oscilloscope, measure the filter parameters of this filter (cutoff frequency, passband gain, rate of rolloff). You may use the sinusoid wave as input while changing its frequency (keep the amplitude the same). Record the corresponding output amplitude.

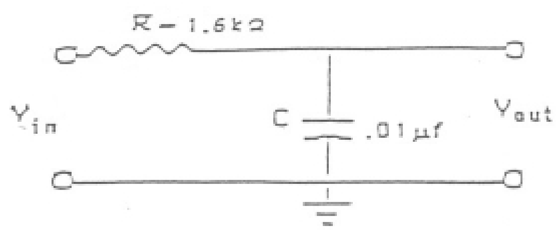
2. Use the signal generator to create a square wave with amplitude 0.2 Volts and frequency 1 kHz. Observe this signal both on the oscilloscope and the spectrum analyzer. Note in particular the frequency components of this signal.

3. Connect the output of the signal generator to the lowpass filter. Observe the filter output on both the oscilloscope and spectrum analyzer. Record all necessary data. Increase the frequency of the square wave and observe the change on both devices. Is there a difference in the spectrum of this output compared to the unfiltered signal?

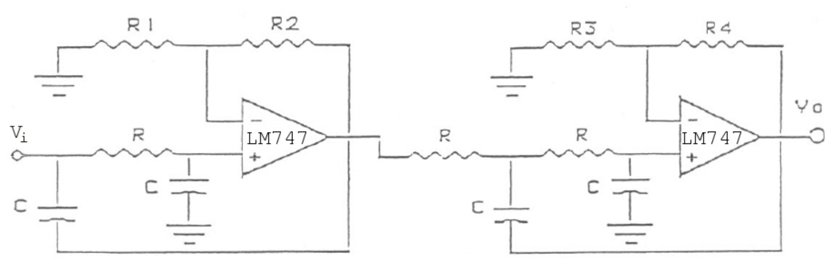
4. Build the lowpass filter shown in Figure 3.2b. On the oscilloscope, measure the filter parameters of this filter. Use a sine wave.

5. For the circuits shown in Figures 3.2, use the square wave described in step 2 as input and vary its frequency. Compare the output of the two filters with the unfiltered output. How well did you isolate the fundamental frequency component of the square wave?

6. Now generate a square wave with amplitude 5 Volts peak-to-peak and frequency $10f_c$, where f_c is the cutoff frequency. Apply this signal to the input of the filter of Figure 3.2b. Observe the output of the system on the oscilloscope and spectrum analyzer. Sketch the signal in the time domain and note the signal peak-to-peak amplitude.



(a) First-order lowpass filter



(b) Lowpass filter

Figure 3.2: Lowpass filters for Experiment 3. Component values are as follows: $R = 1.6$ kΩ, $C = 0.01\mu$F, $R_1 = 10$ kΩ, $R_2 = 12$ kΩ, $R_3 = 10$ kΩ, and $R_4 = 1.5$ kΩ.

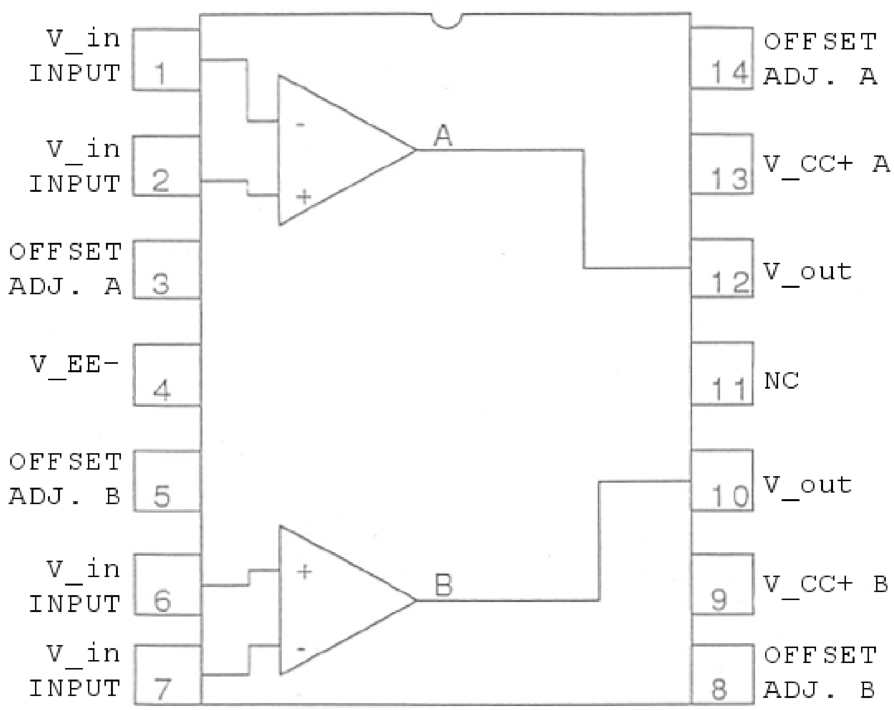


Figure 3.3: Dual OpAmp 747