BE 209 – Group BEW6
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The LM741C Integrated Circuit As An Oscillator
Building The Signal Generator

INTRODUCTION:

The purpose of this lab is to observe the frequency of an oscillating signal produced by a signal generator made from a LM741 operational amplifier. Additionally, attempts are also made in this lab to study low and high pass filters by using a commercial signal generator to generate the signals and an oscilloscope to measure the signal attenuation of the filters. Ideally, a low pass filter should block all frequencies lower than a certain “cutoff frequency”. The circuit is constructed so that high frequencies would go through a capacitor and become grounded, while the low frequencies would be detected. In contrast, a high pass filter would block all frequencies higher than a certain “cutoff frequency” – in this case, a resistor is grounded, lower frequencies cannot go past the capacitor, and the high frequencies are detected. However, because filters cannot be “ideal”, there exists always a slightly decline of the detection of frequencies past the “cutoff frequency”, as opposed to the total immediate blocking of all undesirable frequencies past the cutoff. A bode plot, demonstrating the attenuation in dB versus frequency, is constructed to verify the validity of the filters.

Studying of signals is of crucial importance in the biomedical fields. Human beings constantly emit signals, such as the beating of the heart. The filters in our experiment can be used to filter out unnecessary “noise” signals that might obstruct the measurement of the desired signals by eliminating the signals of incorrect frequencies.

METHODS & MATERIALS:

- Solderless Breadboard
- Wire, wire strippers
- LM741C Operational Amplifier
- Oscilloscope
- Signal Generator
- Voltmeters
- Resistors, Capacitors
- DC Power Source

The oscillator circuit was built according to Figure 1 below:

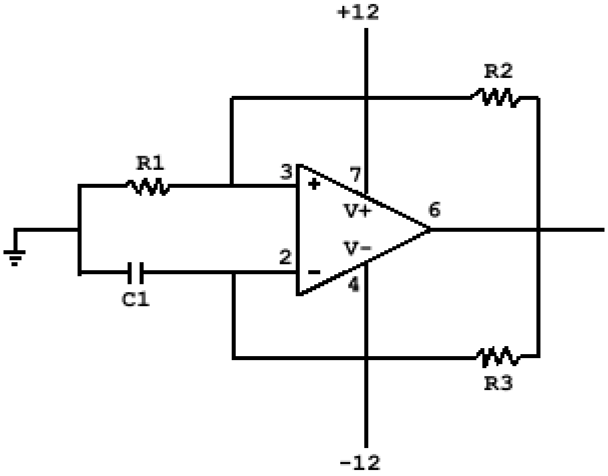

Figure 1: Oscillator circuit schematic

In the circuit, R_1=33KΩ (initially), R_2=R_3=100KΩ, and C_1=0.01μF. The oscilloscope was connected in line with pin 6. The oscilloscope was set to produce a square wave function. The divisions of one period were counted manually and this value was multiplied by the time setting of the oscilloscope. This calculation produced the period of the function from which the frequency was calculated. R_1 was varied for each subsequent trial and the divisions for one period were counted. The six values of R_1 that were used ranged from 10KΩ to 470KΩat irregular intervals. The data used in this section was used to create a plot of $1/(R_1C_1)$ versus frequency. This plot produced a straight line for which a best-fit line was constructed and a corresponding equation determined. To test the accuracy of the equation obtained, a resistor not used in the six trials was used as R_1. The frequency was manually determined and a comparison was made with the frequency obtained from the equation. This will be discussed further in "Results." The resistor used for the test was 15KΩ.

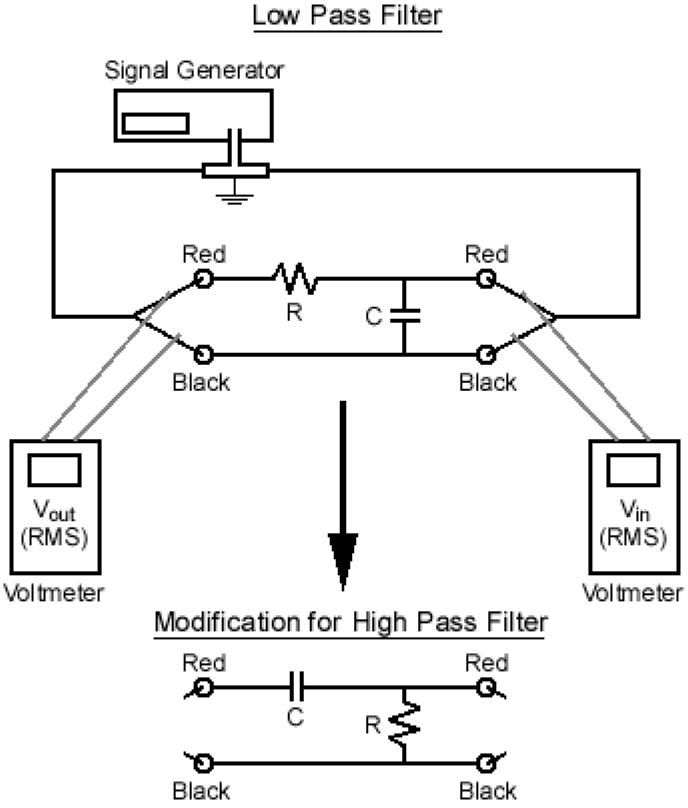

Figure 2: Low Pass and High Pass filter schematic

For the second part of the lab, low pass and high pass filters were made according the Figure 2 above and the input voltages and output voltages, that resulted as the frequency was manually adjusted on the signal generator, were recorded. The cutoff frequency used was approximately 1000Hz. This value was obtained using R = 15KΩ and C=0.01μF which were substituted into equation 1 below:

$$\text{Cutoff frequency of a filter} = 1/(2\pi RC) \tag{1}$$

The frequencies were adjusted above and below the cutoff frequency from 100Hz to 2000Hz at 100Hz intervals.

<u>RESULTS</u>:

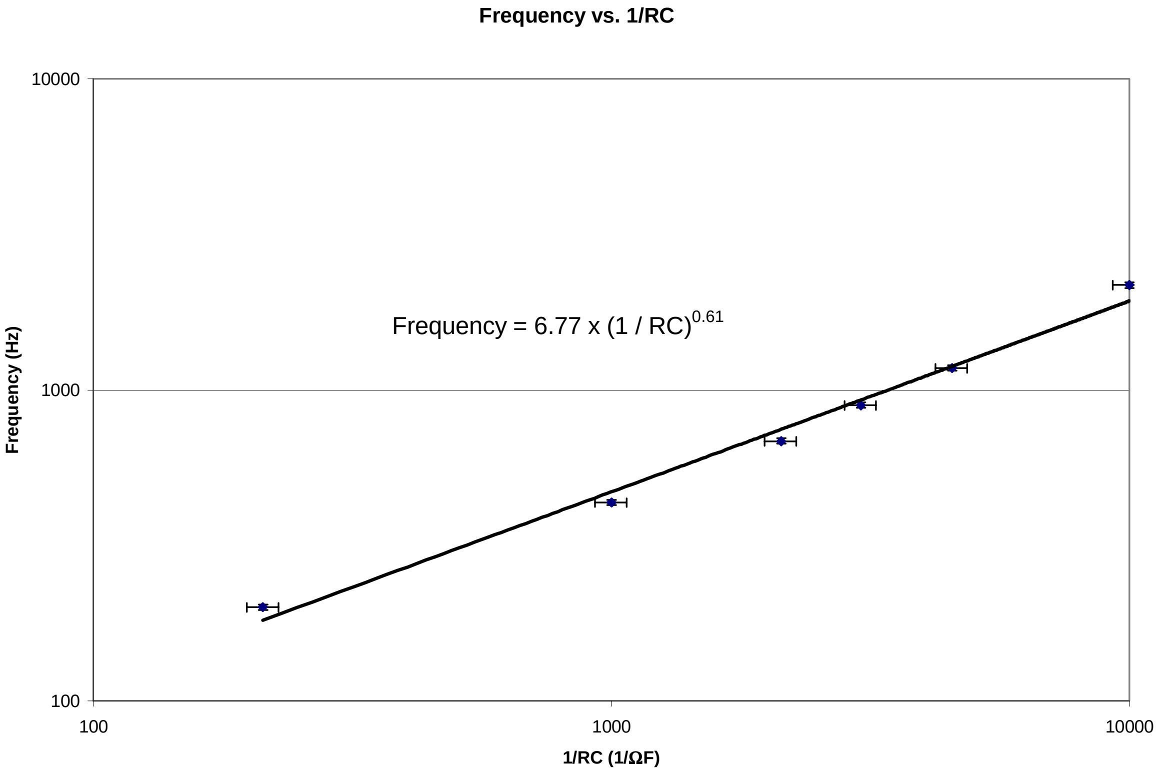

Figure 3: Frequency versus 1/RC graph for the oscillator circuit

Measured frequency values for the oscillator circuit were plotted against the calculated 1/RC values on a logarithmic scale, as shown in Figure 3 above. The value R represents the varied resistance of resistor R1, and C represents the capacitance of the capacitor used (0.01 μF). All the resistors and capacitor used have a 5% error in their value. Therefore, by using equation (2) below, the percent error for 1/RC is calculated to be ±7%. The percent error for frequency is directly related to the percent error of the counted divisions on the oscilloscope display grid. Errors for frequency ranged from ±1%-2%. These errors are represented on the graph with the error bars.

$$\%e_{1/RC} = \sqrt{\%e_R^2 + \%e_C^2} \tag{2}$$

A power series curve was determined for the frequency versus 1/RC graph in Figure 3 to best represent the trend. Equation (3) below is formula for this curve:

$$\text{Frequency} = 6.77 \times \left(\frac{1}{\text{Resistance} * \text{Capacitance}} \right)^{0.61} \tag{3}$$

Based on this equation, a circuit with R1 = 15 kΩ should produce a frequency of 1456 Hz. In actuality, the output frequency was measured to be 1555 Hz. For this specific case, the generated equation has a percent error of 6.4%, as shown in equation (4).

$$\%error = \frac{|actual - \exp erimental|}{actual} \times 100\% = \frac{|1555Hz - 1456Hz|}{1555Hz} \times 100\% = 6.4\% \tag{4}$$

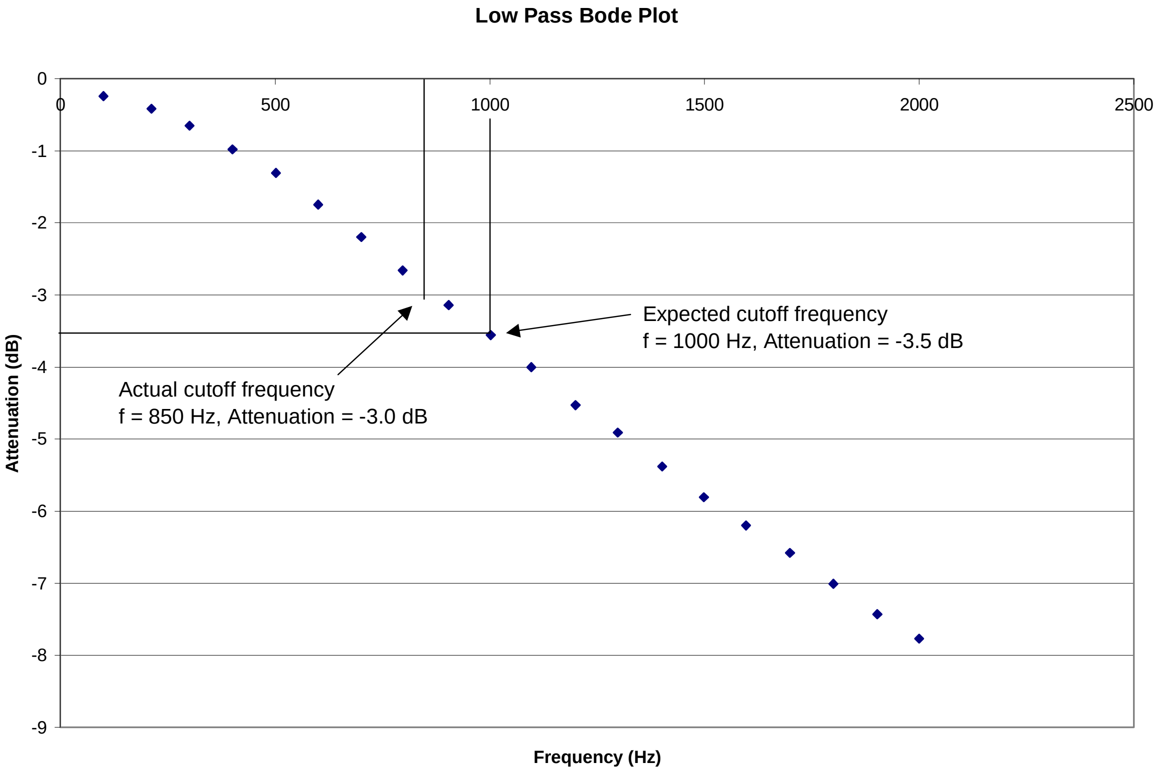

Figure 4: Bode Plot for the Low Pass filter

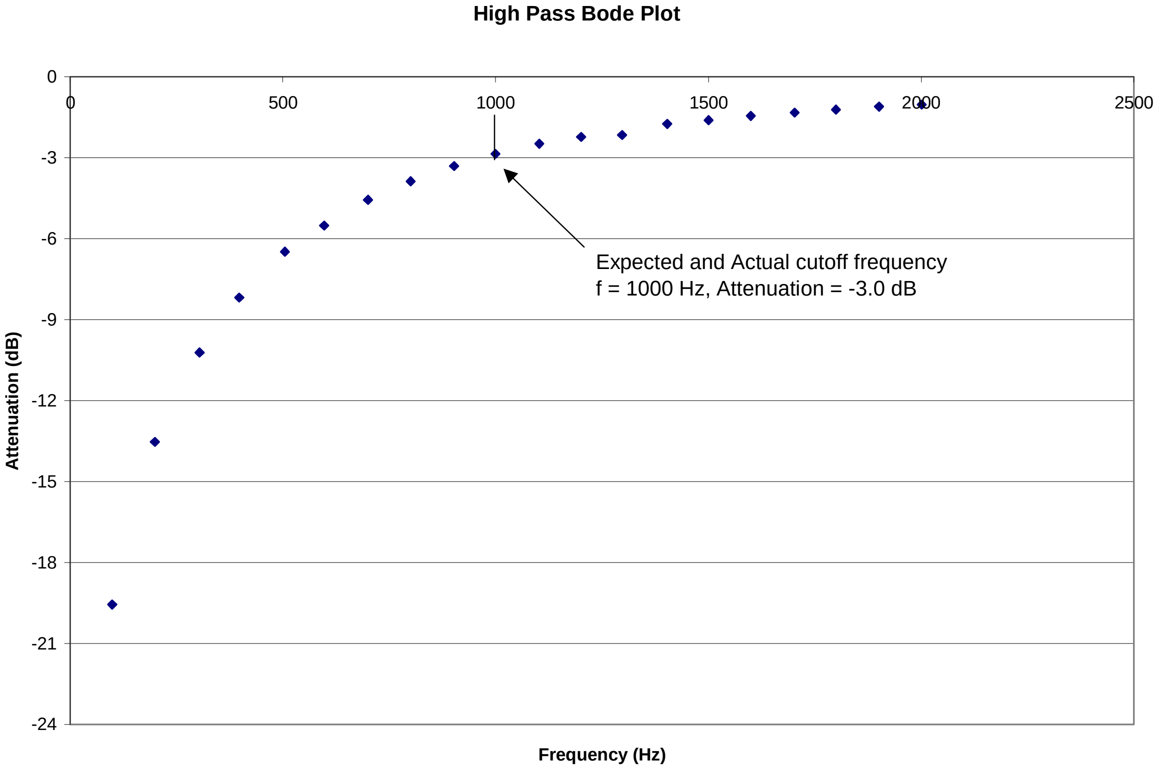

Figure 5: Bode Plot for the High Pass filter

Figures 4 and 5 above are Bode Plots for the constructed low pass filter and high pass filter respectively. The attenuation values were calculated by equation (5) below, where V_{out} is the output voltage and V_{in} is the input voltage:

$$Attenuation\ of\ Filter = 20 \times \mathrm{Log}\left(\frac{V_{out}}{V_{in}}\right) \tag{5}$$

The expected cutoff frequency for the filters is 1000 Hz. However, the cutoff frequency is also defined as the frequency at which attenuation is –3.0dB. In the case of the Low Pass filter, inconsistencies are evident. Table 1 on the following page summarizes these expected and actual values for cutoff frequency and attenuation.

Table 1: Summary of attenuation and cutoff frequency values		
	Attenuation based on expected cutoff frequency (1000 Hz)	*Cutoff frequency based on actual attenuation (-3bD)*
Low Pass Filter	-3.5 ± 0.1 dB	850 ± 10 Hz
High Pass Filter	-3.0 ± 0.1 dB	1000 ± 10 Hz

DISCUSSION:

An analysis of the data obtained for the signal generator (See Figure3) shows a logarithmically increasing trend in the plot of frequency versus 1/(RC). A power series function was generated to represent the increasing trend (See Equation 3). In order to test the consistency of this equation, a different resistor (i.e. a resistor that was not in the six trials) was used as R1 and the frequency was determined manually. This frequency value was compared to the frequency value of 15KΩ obtained using the power series function. The calculated value was lower (by about 100 Hz). This discrepancy accounts for the error between the frequencies measured manually and those obtained using the power series representation. The error was 6.4%. Taking more measurements and thus increasing the sample size of the plotted data would reduce the error in the power series equation.

The data obtained for the high-pass and low-pass filters produced showed varying results from the expected outcomes. The results were slightly different from the expected cutoff frequency of 1000 Hz and the expected decibel value of 3 dB at the cutoff frequency. Furthermore, the Bode graph generated showed a deviation from what is expected. For a plot of dB vs. f for a low pass filter, the expected graph would plateau at frequency values less than the cutoff frequency, then decreases linearly as the frequency increases after the cutoff frequency has been reached. Instead, the data obtained for the low-pass filter shows a decibel value of approximately 3.5dB at the expected cutoff frequency but no distinct plateau exists for frequencies less than the cutoff frequency. The plot begins with a slight plateau and the decreases linearly at a point before the cutoff frequency. This suggests that although the constructed low-pass filter was able to remove frequencies higher than the cutoff frequency as expected, it also removed frequencies that were lower than the cutoff frequency. An error in the filter setup could account for this apparent contradiction in the function of a low-pass filter.

For a plot of dB vs. f for a high-pass filter, the graph shows an increasing trend for frequencies less than the cutoff frequency and a decibel value of 3dB at the expected cutoff frequency [of 1000 Hz)]. For frequencies greater than the cutoff frequency, the graph plateaus, as expected. This behavior shows that the high-pass filter removes frequencies lower than the cutoff frequency (indicated by the sloped region of the graph), which correlates exactly with our understanding of the filter.

As a biomedical application, high-pass and low-pass filters can be used in the filtering of signals from a source that emits many different signals, from which a certain type of signal is the target of inspection. For example, different parts of the brain emit different signals when stimulated. The examination of a particular region of the brain can be facilitated through the use of a filter to block out other unnecessary signals. Since different signals have varying frequencies, the filter can be constructed so that the undesirable electrical current, indicated by a frequency that deviates from the desired signal, can be suppressed. Using such a method, a patient's electroencephalogram (EEG for short), which indicates electrical activity in the brain, would then report only the electrical activity of the desired region of the brain for study. Similar uses for such a device can be found in electrocardiogram (EKG) studies.

Signal generators could be used as a major component of pacemakers. Certain types of heart disease cause irregularities in patients' heartbeats, either mistimed pumps or complete inability to generate heartbeat. A pacemaker produces electrical signals that supercede the patients' own electrical signals and take over the regulation of the heartbeat. Signal generators can be used in these pacemakers to generate such electrical currents to stimulate the heartbeat.

Despite their efficiency, however, electronic filters such as those utilized within EEG and EKG machines are by no means perfect. In fact, disregarding the severity of the error, electronic devices in general produce an inherently greater quantity of sources of error than those exhibited within mechanical devices. Perhaps the most prevalent of which is the accumulation of the imperfection of the cables, voltmeter, oscilloscope, and LM741C Integrated Circuit Chip. The wires (utilized to construct the apparatus), circuit chip, and oscilloscope are not ideal and therefore carry a small amount of resistance; once combined, these individually insignificant resistances form a considerable aggregate resistance throughout the system. Furthermore, the lack of perfection of the voltmeter facilitates a small absorption of current, where an ideal voltmeter has infinite resistance and therefore absorbs no current. This small loss of current, combined with the resistance throughout the adjoining wires, creates added error within the system. This error is reasoned to be even larger, due to the minute values of current collected by the apparatus; the smaller the current value the larger effect such imperfections have throughout the system. Although this error is assuredly present, it exists only as a diminutive source of deviation.

Unquestionably the most definite source of error was due to the imperfection of the high-pass and low-pass filters. The ideal notion of a filter is one that possesses the ability to facilitate the entry of acceptable frequencies into the system while preventing the entry of any other frequency. Unfortunately, such systems are impossible to create in tangible form.

Consider the low-pass filter utilized throughout the lab. An ideal low-pass filter would allow frequencies below the designated cutoff frequency to pass and attenuate frequencies above the cutoff to zero dB. Low-pass filters similar to the one constructed within the lab do not exhibit ideal behavior. The filter exhibits greater increases in attenuation corresponding to increased frequency beginning at zero frequency. Prior to the cutoff point, the filter exhibits filtering of values below the ideal value. Subsequent to the cutoff point, the filter fails to attenuate to zero, allowing values outside of the ideal filter to remain present within the system. Please consult Figure 6 below for the graphical “Bode Plot” representation of the above explanation.

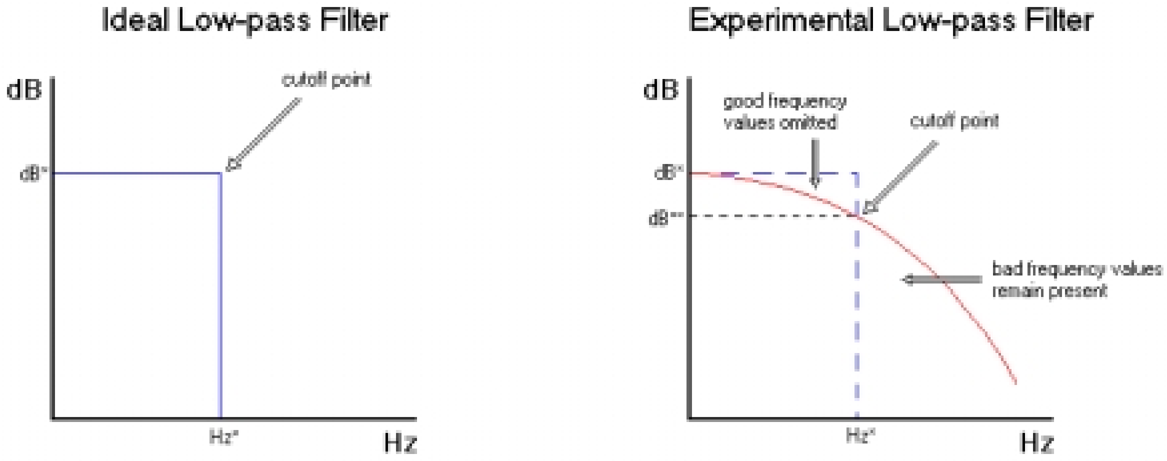

Figure 6: Bode Plots for the Ideal and experimental Low Pass filter

Although experimental filters are inherently erroneous, they can be improved to nearly mimic ideal behavior. The most accurate filters are ones that exhibit a power function that bends to nearly 90^o at the cutoff frequency, thus deviating only slightly near the threshold of the cutoff while minimizing the unwanted frequency within the system.

CONCLUSION:

Construction of a signal generator with the use of a specific calculated resistance allows for the output of a desired frequency. Usage of a low-pass or high-pass filter allows for the gradual blocking of frequencies lower or higher than a certain “cutoff frequency”, respectively. Using a bold plot, the data showed roughly the expected trend of the block in blocking of lower / higher frequencies, suggesting that the filters were indeed functional. The data did show, however, that the filters did not function entirely as expected. There was evidence that the low-pass filter blocked some frequency lower than the cutoff frequency. In addition, on the bode plot for the high-pass filter, the part of the graph that increases with frequency was not linear as expected. Suggestions were made to improve the function of the filters. The construction of the signal generator and filters allowed for extended applications in the biomedical field, such as the application of signal generators in pacemakers, and that of filters in EEG.