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Development and Characterization of First Order Wide Bandpass Active Filter (BPAF)

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***Abstract* - Unwanted signals in electrical systems frequently overpower the desired signal. In an attempt to increase the ratio, the desired signals are amplified proportionately to the undesired ones. Frequency selective circuits, often known as filters, can be used to separate desired signals from undesirable ones as signals can be identified by their frequency characteristics. Analog filters are available in both active and passive varieties, each having unique properties. A first order band pass active filter is developed and characterized in this study. The Operational Amplifier (OP AMP 741) is the active element in this case. With the Band Width (BW), Cut-off Frequencies (FL and FH), Center Frequency (FC), and Quality factor (Q) provided, the Transfer Function (TF) equation is generated and defined.**

Keywords: Active filter, Band-pass, Operational Amplifier, Transfer Function, Band Width, Center Frequency, Quality Factor.

I. INTRODUCTION

It is impossible to overstate the significance of filters in the realm of electronics and communications. While boosting desirable frequencies, filters block certain frequencies. According to Sanjay (2010), an electrical filter is a network that attenuates some frequencies while allowing others to pass through unaffected. Analog and digital filters are the two basic categories into which filters fall. Hughes (1995) categorized analog filters based on their frequency response: band-pass, band-stop, low-pass, high-pass, and all-pass. Additionally, passive and active filters can be used to group analog filters. Active filters have several benefits over passive filters, such as: pass band gain, flexibility in gain and frequency control, minimal insertion loss, easy tuning, and no isolation issue because of their high input impedance.

Figure 1 illustrates the properties and terminology of a band pass active filter. A Band-Pass Filter (BPF) prevents all frequencies that are outside of its frequency range while passing all signal frequencies between its two cut-off frequencies, which are the higher frequency (f_H) and the lower frequency (f_L), with little to no attenuation. The center frequency (f_C) in BPF is centered between f_L and f_H, and equation 1 establishes a mathematical relationship between it and F_L and f_H.

$$f_C = \sqrt{f_H f_L} \qquad (1)$$

The range of frequencies that the filter accepts to pass through to the output without any attenuation is known as the pass-band, while the range of frequencies that the filter prohibits from passing through to the output is known as the stop band. Two stop bands make up a band pass filter: one before and one after the pass band. The pass-band of a band-pass filter is located between the two cut-off frequencies, f_L and f_H. Broad band-pass filters and narrow band-pass filters are the two different forms of band-pass filters. A band-pass filter is considered narrow if the Quality factor (Q) is less than 10, and wide if it is larger than 10 (Sanjay, 2010).

It is important to note that in reality, the transition to stop bands is not as abrupt as it is in the ideal band-pass characteristics, as seen in figure 1. The filter's gain is reduced by 3dB at the two cut-off frequencies, f_L and f_H (George & Steve, 2010). The transition band is the middle band that forms between the stop and pass bands. Figures 2 and 3 below, respectively, depict the optimal and realistic band-pass filters. According to Ezema (1990), a low-pass filter may be connected in series with a high-pass filter to obtain first order broad band pass.

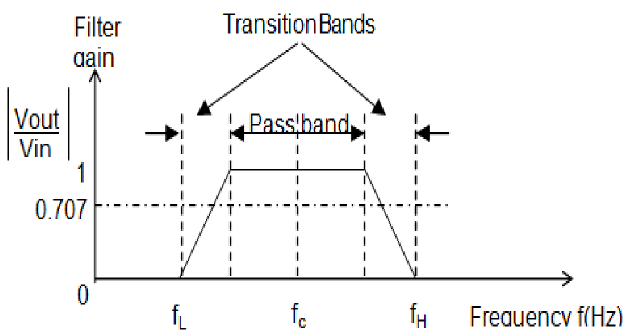

Figure 1: Practical Band-Pass Filter

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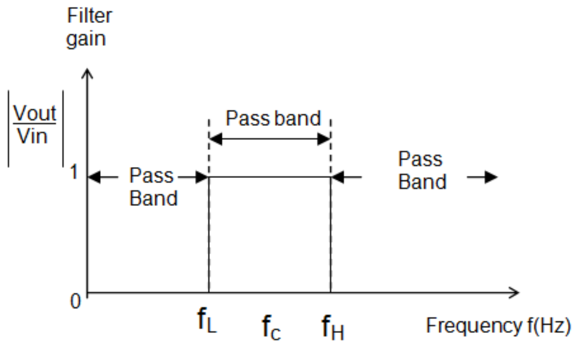

Figure 2: Ideal Band-Pass Filter

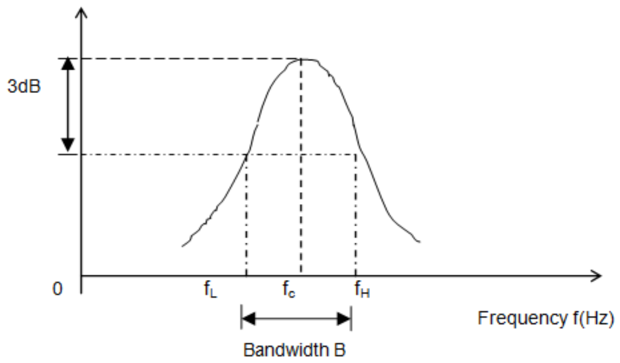

Figure 3: Frequency Response of Band-Pass Filter

II. MATERIALS AND METHOD

2.1 LC Filter Simulation

The foundation of any active filter design is an LC filter structure. This is accomplished by either changing the fundamental filter structure such that General Impedance Convectors (GICS) like Frequency Dependent Negative Resistances (FDNRS) may be used to realize it, or by emulating each inductor using a gyro-capacitor combination (Harowitz, 1989). The Op-Amps may be used to implement the two simulation techniques mentioned above. For inductance simulation, utilize the circuit on inductance simulation utilizing Op-Amp design shown in figure 4 below. Equation 2 provides the inductance value for this circuit (Ezema, 1990).

$$L = \frac{R_2 C(R_1 - R_2)}{1 + W^2 R_2{}^2 C^2} \text{(Henry)} \qquad (2)$$

Where **L** is the inductance in Henry (H)
R is the resistance in Ohm (Ω)
C is the capacitance in Farad (F)
W is the angular frequency in Hertz (Hz)

By connecting a capacitor across x and y, a tuned circuit is obtained.

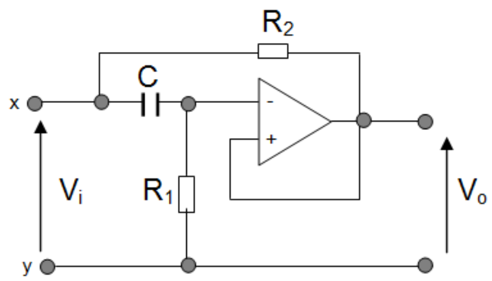

Figure 4: Inductance Simulation by Op-Amp

2.2 Transfer Function of first order filter

An equation known as the transfer function (TF) links the input signal to the output as a function of the circuit's components (Denton, 1989). This has an important effect on filter design. The order of active filters describes them. The greatest power of the polynomial that forms the denominator, or the highest power of s, the Laplace transform operator, defines this order.

$$s ----1^{st}\ order$$
$$s^2 ---- = 2^{nd}\ order$$
$$s^n ------- = n^{th} order$$

Filters can be cascaded to get higher order filters. The frequency response properties of the filter created are better the higher the order (Gottlieb, 1990). Figure 5 displays the first-order active band-pass filter under examination, and Figure 6 displays the frequency response.

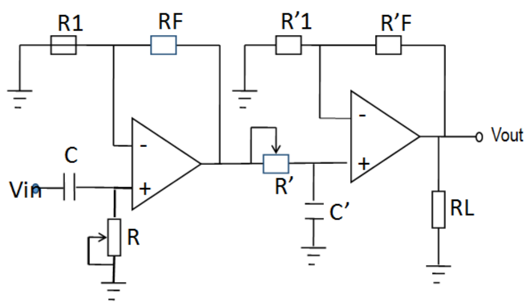

Figure 5: First Order Band-Pass Feedback Filter Circuit

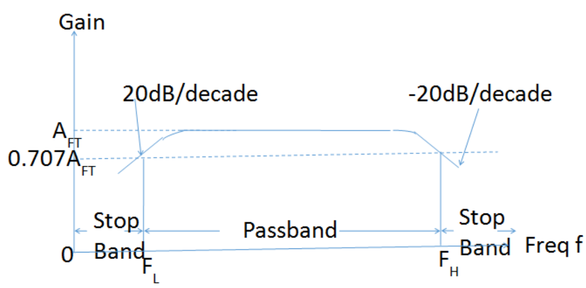

Figure 6: Frequency Response of Band-Pass Filter

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In analyzing the band-pass filter, the following observations are drawn from figure 6;

i. The circuit is formed by the cascading of a first order high pass filter and a first order low pass filter.
ii. The cascading resulted in the frequency response shown in figure 6.
iii. It has two cut off frequencies.
iv. Total passband gain is as given in equation 3:

$$A_{FT} = A_{F1} x A_{F2} \qquad (3)$$

Where **AF_1** is Gain of the high pass filter
AF_2 is gain of the low pass filter
AF_T is total passband gain

i) The cut off frequency is given in equation 4:

$$F_C = \sqrt{F_H F_{L1}} \qquad (4)$$

Where;

$$F_L = \frac{1}{2\pi\sqrt{RC}} \qquad (5)$$

And

$$F_H = \frac{1}{2\pi\sqrt{R'C'}} \qquad (6)$$

ii) Quality Factor Q of the Filter is given by equation 7:

$$Q = \frac{Fc}{F_H - F_L} = \frac{F_C}{BW} \qquad (7)$$

iii) Filter Bandwidth is given by equation 8:

$$BW = F_H - F_L \qquad (8)$$

The following parameters are used for the filter under design;

F_L = 100 kHz; F_H = 1 kHz with passband gain of 4.

2.3 Circuit Component Value Realization

i) Starting with the Low pass filter components:

$$F_H(LP) = 1000Hz$$

a) Fix C' = 0.01µF (choice made over range of values)

$$Since\ F_H = \frac{1}{2\pi\sqrt{R'C'}},\quad R' = 15.9k\Omega$$

b) AF_2 = 2(Gain of the Low pass filter)

$$Since\ AF_2 = 1 + \frac{R'F}{R'1}$$

$$R'F = R'1 = 10k\Omega$$

Low pass filter component values are as follows

$$R'1 = 10k\Omega, \quad R' = 15.9k\Omega, \quad R'F = 10k\Omega, \quad C' = .01\mu F$$

ii) High Pass Filter component realization:

a) Fix C' = 0.05µF (choice made over range of values)

$$R = \frac{1}{2\pi F_L} = 31.83k\Omega$$

b) Gain of high pass filter AF_2 =2

$$2 = 1 + \frac{R_F}{R_1}$$

$$R_F = R_1 = 10k\Omega$$

The high pass filter's component values are displayed below.

$$R_1 = 10k\Omega, \quad R = 3.18k\Omega \approx 3k\Omega$$

$$R_F = 10k\Omega;\ C = .05\mu F$$

iii) Q Factor

$$Q = \frac{F_L}{F_H - F_L}$$

$$F_C = \sqrt{F_H F_L}$$

$$Q = \frac{\sqrt{F_H F_L}}{F_H F_L} = 0.351$$

As $Q < 10, the\ filter\ is\ a\ wide\ range\ filter.$

2.4 Organization and Testing

Tests were conducted on the constructed and set-up filter circuit component to determine its performance. A fixed input voltage (Vi) of 1Vp-p was injected into the filter input using a signal generator, and the corresponding output voltages were monitored. The frequency of the injection was changed from 0.4 kHz to 20.0 kHz. $20\log\frac{V_o}{V_i}$ was computed and tabulated with the other variables; Freq. (Hz), Vi, Vo, $\frac{V_o}{V_i}$, $20\log\frac{V_o}{V_i}$ (dB). The frequency response (dB vs Freq.) is shown on the graph in figure 6 above.

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III. RESULTS AND DISCUSSION

Figures 7 and 8 display the frequency response plots of the first-order band-pass filter that was successfully created. When a 1-volt peak-peak signal with a range of frequencies (50 Hz to 1.15 kHz) was employed in testing, Figure 7 demonstrates the filter's response in increments of 200 Hz. After measurement, the output voltage was tallied. Figure 8 displays the gain, or the ratio of output voltage to input (V_{out} / V_{input}), plotted against the relevant frequencies.

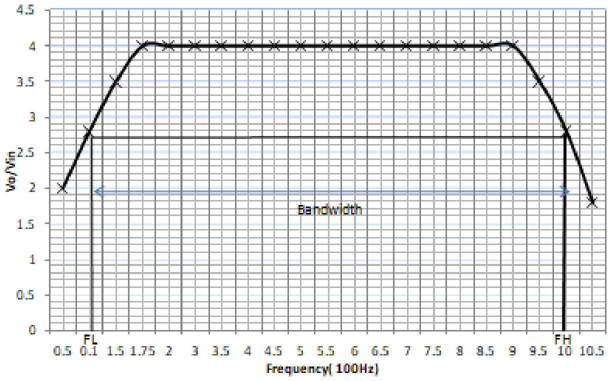

Figure 7: Frequency Response of the Second Order Band-Pass Filter

Subsequently, 20log(V_{out}/V_{input}) in decibel was plotted against their corresponding frequencies and is shown in figure 8.

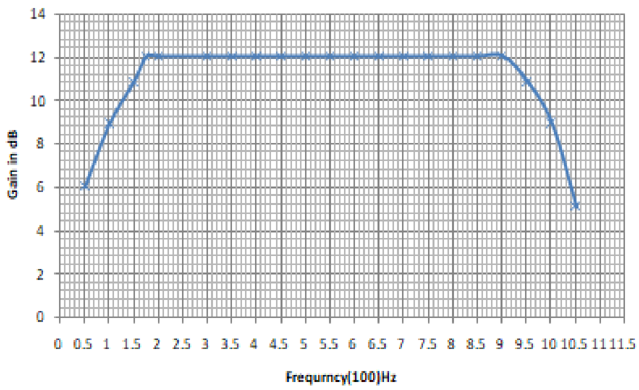

Figure 8: Frequency Response of Filter with Gain in dB

IV. CONCLUSION

The first-order band-pass filter that was suggested has been effectively created and tested. A first-order band-pass filter-like result is obtained from the frequency response. This demonstrates how an operational amplifier's active element, when employed in its inverting mode, may be used to simulate inductances or coils out of the circuit. The operational amplifier's accuracy is determined by the selection of various parameters and the tolerances of additional passive components that are added to the active element.

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