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Analysis and Development of First Order High Pass Active Filter

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***Abstract* - Filtering is very popular and important in the field of Electrical and Electronic Engineering. In the field of Telecommunication, filter is used in multiplexing whereby several different signals are transmitted through the same transmission channel and never mixed up because of virtue of their separated frequencies and are separated at the end of their receiving end again by the process of demultiplexing. In entertainment industries, audio circuits in the form of filters are used to give music distinct tones of bass, treble etc. In radio transmission, filters are used in separating transmission channels both in FM and AM bands thereby giving each station a distinctive transmission channel. In amplification devices using amplifiers, attempt in amplifying intelligent signals results in the amplification of unwanted signals in the form of noise. To minimize or reduce this, filters are used in removing the unwanted signals. Filters come in different forms but broadly it can be classified into analog and digital filters. It can also be classified by the nature of components used in its design. By this classification we have active and passive filters. In this paper, the development and characterization of a first order high pass active filter is shown.. Operational Amplifier chip OP AMP 741 was used in achieving this. The Transfer Function (TF) equation of the filter is derived with the Band Width (BW), Cut-off Frequency (Fc) and the Quality Factor (Q) specified. The developed first order Active High Pass filter was tested by application of varied frequencies with fixed input voltage to its input while the performance monitored at the output. Finally the frequency response plots indicative of the designed specification in ratio of Vo/Vin and in dB were plotted and shown.**

Keywords: Active filter, Operational Amplifier, Transfer Function, Band Width, Center frequency, Quality Factor.

I. INTRODUCTION

Filter is very important in electronics and telecommunications. As such its importance cannot be over emphasized. The main function of filter in a circuit is primarily to attenuate certain frequencies undesired while enhancing the hitherto wanted and desired ones. [1]. Filters can broadly be classified into two groups of Analog and Digital filters. Analog filter can be further classified by their frequency response as Low-pass filter, High-pass filter, Band-pass filter, Band-stop filter and All-pass filters [2].

Analog filters can also be classified into passive filter and active filters by the actions of the components used in its design. Active filters as the name also indicate has many advantages over the passive filter. These advantages include the following; absence of insertion loss, easy tuning, no isolation problem due to its high input impedance, pass band gain, flexibility in gain and frequency adjustment, small component size, absence of inductors and relative low cost [3]. Active filter thus gives more efficient, effective, portable and cheaper cost compared to passive filter.

The characteristics and terminologies of a high pass active filter are shown in figure 1 below. A High-Pass Filter (HPF) by its action passes all the frequencies of signal above its cut-off frequency with little or no attenuation while stopping all other frequencies which are below the cut off frequency *fc*. In HPF, attenuation stops at the cut-off frequency. The cut off frequency forms the boundary between the two bands known as pass-band and the stop-band of the filter. The pass-band is the range of frequencies which are allowed to pass through to the output by the filter without any attenuation while the stop band is the range of frequencies which are not allowed to pass through to the output by the filter. These are shown in figure 1 below.

In practice, the filter response curves are not as sharp as indicative in the figure 1 below rather the pass band does not take off immediately from the critical frequency *fc*. At *fc*, the gain of the filter is up by 3dB and after *fc*, it increases at a higher rate [4]. An intermediate band is formed between the pass-band and stop-band and is known as transition band. The ideal high-pass first order filter and the practical high-pass first filter are shown in figure 2 and 3 below respectively.

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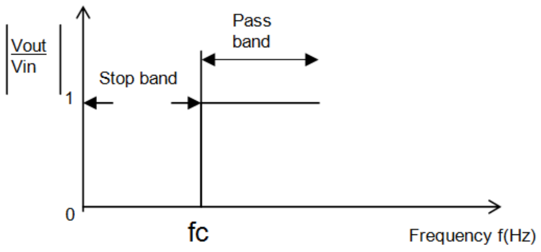

Figure 1: Ideal high-pass filter frequency response

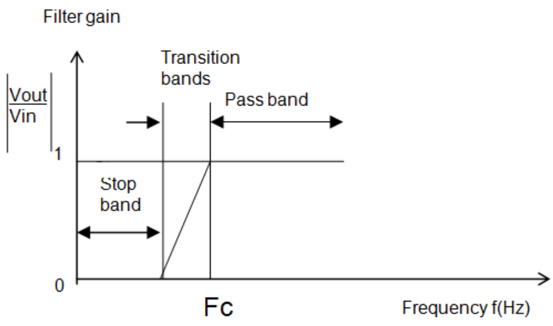

Figure 2: Practical high-pass filter frequency response

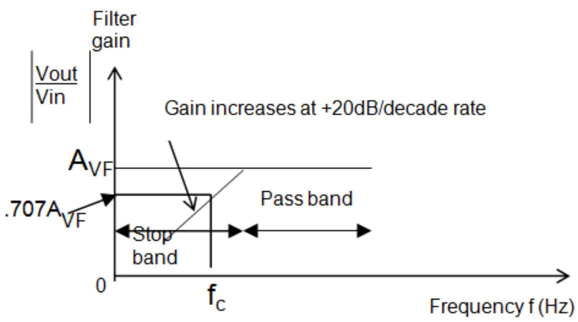

Figure 3: High-pass filter frequency response characteristics

II. MATERIALS AND METHOD

2.1 LC Filter Simulation

Inductors are one of the important components used in filter circuits mostly in combination with a capacitor giving birth to an LC filter circuits. Unfortunately inductors appear to be cumbersome and its varying is also a problem to electronic industry till today. A way around and out of this is the simulation of inductors out of filter circuits by using operational amplifies. Since LC filter structure is the cradle of active filter design its simulation by op am becomes eminent. This is done either by simulating each inductor by a gyro-capacitor combination or by transforming the basic filter structure such that it can be realized with general impedance convectors (GICS) such as Frequency Dependent Negative Resistances (FDNRS)[5]. The two methods of simulation discussed above can be realized with the Op-Amps. The circuit of inductance simulation using Op-Amp diagram is shown in figure 4 below. From the circuit of figure 4, the value of the inductance is obtained by the equation 1 below [6].

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

If a capacitor of desired value is connected across points x and y, in the circuit of figure 4, a tuned circuit is formed.

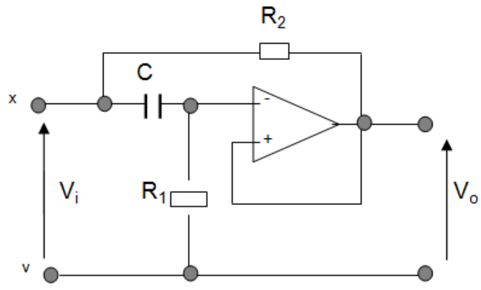

Figure 4: Inductance simulation by Op-Amp

2.2 Transfer Function of first order filter

Transfer function (TF) is a mathematical equation which relates the output to the input signal as a function of the circuit components.[7] Transfer Function is very important in every filter design as it actually determines the filter function and performance to the signal that are passed through it. Active filters are known by their order which in turn is determined by the highest power of the polynomial forming the denominator ie highest power of s in the Laplace transform operator of the transfer function.

S ----- = 1^{st} Order

S^2 ---- = 2^{nd} Order

S^n ----- = n^{th} Order

By cascading of two or more filters higher order forms of filters are obtainable. Frequency response characteristics performance is proportional to the order of filter [8]. The higher the order, the better the performance. The first order active filter under review is shown in figure 5 below.

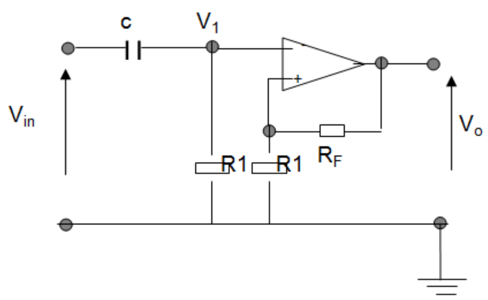

Figure 5: First order high-pass filter

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Analysis:

From figure 5 above, V_1 is the voltage across R. Applying voltage divider concept

$$v_1 = \frac{R}{R - jX_c}V_{in} \text{ ---------- (2)}$$

Since $X_c = \frac{1}{2\pi fc}$

$$v_1 = \frac{R}{R - \frac{1}{2\pi fc}}v_{in} = \frac{R}{R + \frac{1}{j2\pi fc}}$$

Since $-j = \frac{1}{j}$

$$v_1 = \frac{j2\pi fRcv_{in}}{1 + j2\pi fRc} \text{ ----------------- (3)}$$

Since $2\pi Rc = \frac{1}{f_L}$ where f_L is the cut-off frequency

$$f_L = \frac{1}{2\pi Rc}$$

Substituting values of f_L in equation 3

$$v_1 = \frac{j\left(\frac{f}{f_L}\right)}{1 + j\left(\frac{f}{f_L}\right)}v_{in} \text{ ------------ (4)}$$

Having got an expression for the input voltage, let us equally get an expression for the output voltage, *Vo*

$V_o = A_F\, V_{in}$ ------------ (5)

Where A_F is the closed loop gain.

From equation 4,

$$V_o = \frac{A_F\left(j\frac{f}{f_L}\right)}{1 + j\left(\frac{f}{f_L}\right)}v_{in}$$

Filter gain $\frac{V_{out}}{V_{in}} = \frac{A_F\left(j\frac{f}{f_L}\right)}{1 + j\left(\frac{f}{f_L}\right)}v_{in}$ ------------- (6)

The equation 6 above gives the Transfer Function (TF) of the first order high pass filter. A typical Gain Margin and Phase Angle could be arrived at by arranging equation 6 in the form of equation 7 below.

$$\frac{V_{out}}{V_{in}} = \left|\frac{V_{out}}{V_{in}}\right|\langle\theta \text{ --------------(7)}$$

Hence the magnitude becomes

$$\left|\frac{V_{out}}{V_{in}}\right| = \frac{AF}{\sqrt{1x\left(\frac{f_c}{f}\right)^2}} \text{ --------------(8)}$$

Using equation 8, the operation of the first order high pass filter may be explained as follows;-

(i) At very low frequencies ie f less than f_c

$\left|\frac{V_{out}}{V_{in}}\right|$ is less than A_F

(ii) With operating frequency increase, filter gain also increases. At $f = f_c$ at cut-off frequency,

$$\left|\frac{V_{out}}{V_{in}}\right| = \frac{A_F}{\sqrt{2}} = 0.707A_F \text{ ---------- (9)}$$

Here the filter gain is down by -3dB

(iii) At high frequencies ie f greater than f_c we have $\left|\frac{V_{out}}{V_{in}}\right| = A_F$ ie constant. The filter gain at this point remains constant at A_F in the pass band region.

2.3 Filter Component Value Computation

The adopted design features that brought about component value computation and other filter parameters are reviewed below using the transfer function earlier derived.

For the filter under consideration the following parameters are used.

Cut-off frequency (f_c) = 3kHz resulting in *Wc=18.85k rad/s, Pass band gain =3.54(11dB)*

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From figure 5 above, the value of R and C are to be calculated having set the cut-off frequency at 3kHz.

Traditionally, C is selected within the range of 0.001 μF to 0.1 μF while R is calculated from the formula in equation 11 below.

$$R = \frac{1}{2\pi f_c C} \text{ -------- (10)}$$

C selected to be 0.0047 μF

Here R = 33.86kΩ

Pass band gain $= \left(1 + \frac{R_F}{R_1}\right)$ -------- (11)

Fixing R_F= 10kΩ

From equation 11, R_1 is computed to be 3.94kΩ = 4kΩ

OP Amp used is 741

2.4 Filter Assemblage and Testing

The filter circuit component were wired up, powered and subjected to testing to verify its performance. With signal generator, a fixed input voltage (Vi) of 1Vp-p and varied frequencies, 1kHz to 10kHz injected to the filter input at a step of 100Hz while the corresponding output voltages for each input were measured and recorded. $20\log\frac{V_o}{V_i}$ 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 below.

III. RESULTS AND DISCUSSION

The frequency of response plots of the developed second order filter are shown in figures 6 and 7 below.

Figure 6 shows the response of the filter when 1volt peep-peek signal of varied frequencies (1.4kHz-5kHz) in order of 100Hz step increment was used in the testing and the output voltage measured and tabulated. The gain, ratio of the output voltage to the input (V_{out}/V_{input}) plotted against the corresponding frequencies is shown in figure 6.

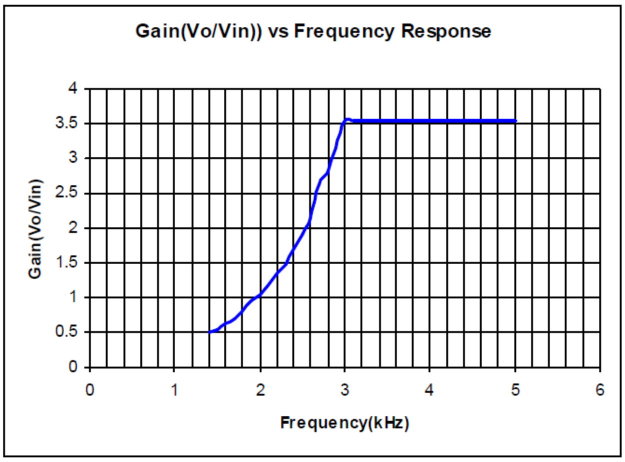

Figure 6: Frequency response of the 1st order high-pass filter

Subsequently, the gain in dB, 20log(V_{out}/V_{input}) was plotted against their corresponding frequencies and plotted as shown in figure 7 below.

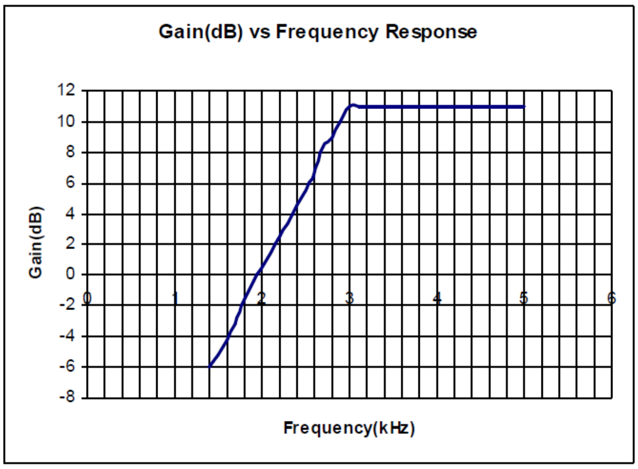

Figure 7: Freq response of filter with Gain in dB

IV. CONCLUSION

The proposed first order high-pass active filter has successfully been developed and tested. The frequency response depicts that of first order high-pass filter. This has proved the reality of simulating inductance or coil out of circuit using active element in operational amplifier when used in its inverting mode. The accuracy becomes a function of choice in the wide range of parameters and the tolerances of the other passive components used alongside the active element of the operational amplifier.

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