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SECOND ORDER ACTIVE MULTI-LOOP BAND PASS FILTER FOR VERY LOW FREQUENCY RECEIVER APPLICATIONS

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Abstract: This paper presents the design and simulation of the second order multiple loop feedback bandpass filter which was simulated using Multisim version 14.2 software and studied for variable Quality factors Q of 50, 60, and 70 with a constant centre frequency (ω_o) of 16.50kHz from a band of very low frequency of 3kHz to 30KHz so as to be implemented in the Receiver systems of a Very Low Frequency (VLF) wave communication system. The result shows a centre frequency ω_o for all the Q's to be 16.546 kHz while the midband gain was 21.37dB, 20.79dB, and 19.52dB respectively for 50, 60, and 70. The bandwidth for the variable Q's was 50.30kHz, 62.19kHz, and 71.38kHz respectively. From observation, the centre frequency is slightly shifted and mid band gain decreased from 21.37dB to 19.52dB furthermore, the Bandwidth increases from 50.30 kHz to 71.38 kHz. Results from the simulated filter shows good agreement with theory. As such, we can conclude that the filter can be used in the receivers of a VLF wave communication system.

Keywords: *multiple-loop, Bandpass, filter, Receiver, VLF*

I. INTRODUCTION

The most useful form of technology in recent years employed in connecting with the world over is the communication systems, without any barrier of either distance or location. It is well known that wireless communication using the very low frequency wave is one of the technologies used especially in submarine communications. It is also utilized in weather observations and research that uses electromagnetic waves. Prominent amongst this research is Atmosphere, weather, Electromagnetic system for observation, modelling and Education (AWESOME) which utilizes very low frequency (VLF) wave transmitter that is spread all around the world (AWESOME & SID, 2014).

The very low frequency receiver system is a sensor that helps monitor sudden ionosphere disturbances (SID) which is usually propagated by solar flares (Reeve, n. d). VLF waves can also be referred to as manometer wave which is a natural phenomenon generated by different natural means.

Lightning is a major natural phenomenon that generates the VLF wave dominantly in nature. Human beings also produce the VLF wave electronically and apply in various applications like the radio service navigation and military communications. (Persinger, 1974; Barr, Jones, & Rodger, 2000).

The VLF wave occupies the frequency range of 3 to 3okHz and is capable of reaching very long distances but can be easily affected by the condition of ionosphere. However , when the readily available antennas are used proves to be ineffective since it occupies a wavelength of 10km to 100km. therefore, to make up for the unavoidable matter influenced by natural phenomena, a high performance equipment is definitely required for VLF wave Communication. (Rahmat, Kusnandar, Asep, Sunubroto, Chairunnisa, & Achmad, 2014). Reliability of communication using the VLF wave is vital in order to guarantee the research runs properly. As a result of this, an active filter is an essential part of the receiver that is embedded in the overall communication system as shown in figure 1.

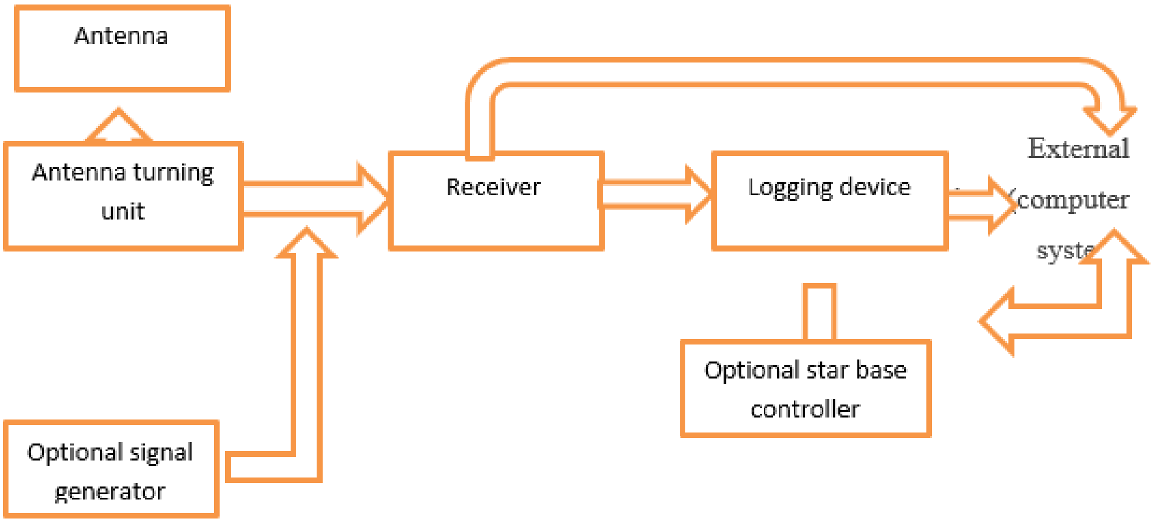

Figure 1. VLF communication System Block Diagram

The active band pass filter is utilized in the Receiver of the VLF communication system shown in figure 1. The block diagram of the receiver section is shown in figure 2.

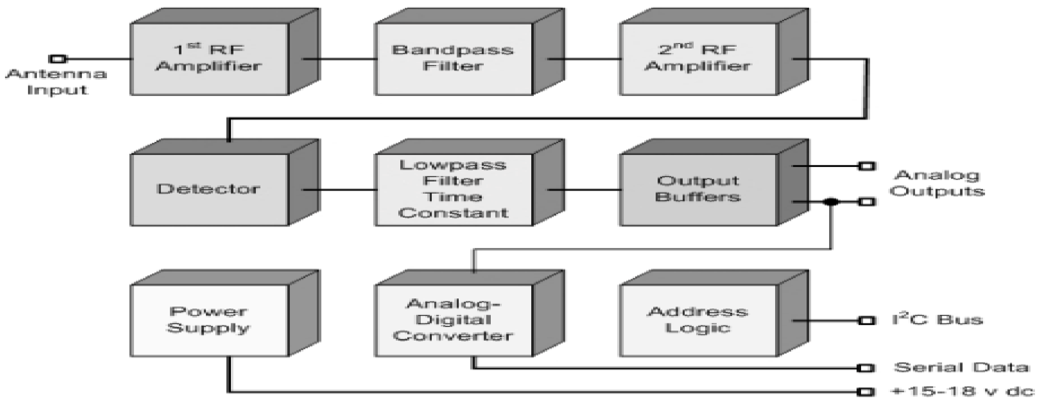

Figure 2. Block Diagram of A Receiver

The band pass filter comes immediately after the input amplifier in a receiver. Band pass filter is used in so many electronic applications like radio receivers discussed above. They are also used in electro-optical systems and communications systems. This paper presents a multi-loop feedback filter (second order multiple-loop) which is similar to the structure of the sullen-key filter. There are however differences that are key. The multiple loop has an active element in the form of an operational Amplifier (op-amp) in contrast to the Sallen-key that has a finite-gain amplifier. Again the multiple-loop filter has two feedback paths rather than one from the output of the amplifier to the RC network. This gives its name multi-loop feedback filter. The filter has advantage of realizing high quality factor (Q) and high gain. And allows for the adjustment of the quality factor, the gain at mid frequency and mid frequency independently. These advantages find it worthy for implementation in the VLF Receiver.

II. DESIGN CONSIDERATION

The multi-loop feed-back band-pass filter of second order is used in this paper for implementation in the VLF Receiver. The multi-loop feedback band pass filter has the advantage of realizing high Q, high gain. It also allows the independent adjustment of the quality factor (Q), the gain at mid-band frequency (ω_O), and mid-frequency (ω_O). The multi-loop feedback band pass filter shows less overall sensitivity to component variations and can be used in VLF bands. The diagram of the multi-loop feedback second order filter is shown in figure 3.

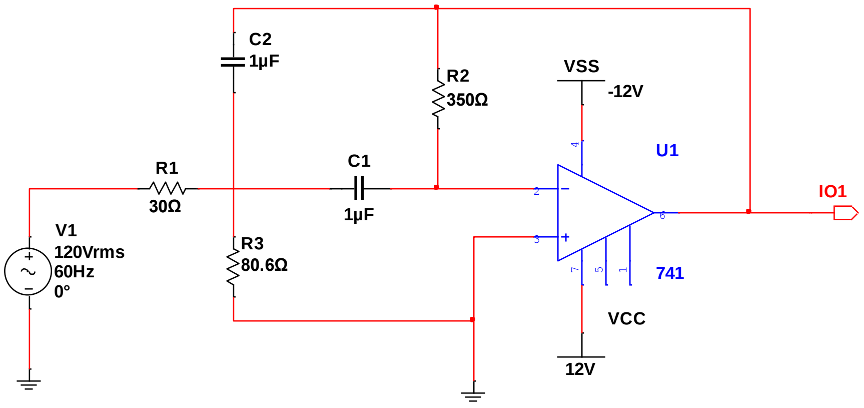

Figure 3. Second Order Multiple-Loop Feedback Bandpass Filter

The transfer function of the filter in figure 1 is given as;

$$T_{(s)} = \frac{V_O(s)}{V_i(s)} = \frac{\frac{-S}{R_1C_2}}{S^2+\left(\frac{1}{C_2R_2}+\frac{1}{C_1R_2}\right)S+\left(\frac{1}{C_1C_2R_1R_2}+\frac{1}{C_1C_2R_2R_3}\right)} \qquad 1$$

from the equation 1 we can obtain the quality factor Q, and cut-off frequency (ω_O) as;

$$Q = \frac{\sqrt{1+\frac{R_3}{R_1}}}{\sqrt{\frac{R_3C_1}{R_2C_1}}+\sqrt{\frac{R_3C_2}{R_2C_1}}} \qquad 2$$

$$\omega_O = \sqrt{\frac{1+\frac{R_3}{R_1}}{R_2R_3C_1C_2}} \qquad 3$$

We can also obtain the mid-band gain as;

$$H_{B_P} = \frac{\frac{R_2}{R_1}}{1+\frac{C_2}{C_1}} \qquad 4$$

The resistor values can be gotten from the following equations.

$$R_1 = \frac{Q}{W_OCH_{BP}} \qquad 5$$

$$R_2 = \frac{2Q}{\omega_OC} \qquad 6$$

$$R_3 = \frac{Q}{\omega_OC(2Q^2 - H_{BP})} \qquad 7$$

Take note that in equation 7, H_{BP} must be less than $2Q^2$ in order that R_2 be finite and positive.

The capacitor values are usually advised to be of equal value design which makes it convenient for use in the design which makes it convenient for use in the implementation of the multi-loop feedback band pass filter.

2.1 DESIGN SPECIFICATION

The design specifications of cut-off frequency $\omega_O = 16.5\ kHz$ (i.e from the pass band 3 kHz – 30 kHz) very low frequency (VLF) used in the mobile receivers. And then quality factor Q = 50 and gain H_{BP} = 100, we shall use the equal –value capacitor design for convenience therefore $C_1 = C_2 = C(1.0\mu F = 1 \times 10^{-6} F)$

Then we shall determine the resistance value of R_1 using the equation $R_1 = \frac{Q}{\omega_O C H_{BP}} \rightarrow R_1 = \frac{50}{16.5\times10^3\times1\times10^{-6}\times100} = 30\Omega$

Also, we determine the resistance value of R_2 using the equation

$$R_2 = \frac{2Q}{\omega_o c} = \frac{2\times 50}{16.5\times 10^3\times 1\times 10^{-6}} = 6060.60\Omega \approx 6.06k\Omega$$

Again, we determine the value of resistor R_3 using the equation

$$\mathrm{R}_3 = \frac{\mathrm{Q}}{\omega_\mathrm{O}\mathrm{C}(2\mathrm{Q}^2-\mathrm{H}_\mathrm{BP})} = \frac{50}{16.5\times10^3\times1\times10^{-6}(2\times(50)^2-100)} = \frac{50}{0.0165\times4900} = 80.85\Omega$$

Parameters: $C_1 = C_2 = C = 1\times 10^{-6}F, R_1 = 30.30\Omega, R_2 = 6.06k\Omega = 80.85\Omega, \omega_{o,} = 16.50kHz, Q = 50, H_{BP} = 100$

For $Q = 60$

$$R_1 = \frac{60}{16.50\times 1\times 10^{-6}\times 100} = 36.36\Omega$$

$$R_2 = \frac{2\times 60}{16.50\times 10^3\times 1\times 10^{-6}\times} = 7272.72\Omega \approx 7.27k\Omega$$

$$R_3 = \frac{60}{16.50\times 10^3\times 1\times 10^{-6}(2\times (60)^2) - 100} = 117.15\Omega$$

For Q = 70

$$R_1 = \frac{70}{16.50\times 10^3\times 1\times 10^{-6}\times 100} = 42.42\Omega$$

$$R_2 = \frac{2\times 70}{16.50\times 10^3\times 1\times 10^{-6}} = 8484.85\Omega \approx 8.50k\Omega$$

$$R_3 = \frac{70}{16.50\times 10^3\times 1\times 10^{-6}(2\times 70^2 - 100)} = 160.05\Omega$$

For $Q = 70, R_1 = 42.42\Omega, R_2 = 8.50K\Omega, R_3 = 160.05\Omega$

The calculated resistor values were recorded and presented in Table 1.

Table 1. Calculated resistor and capacitor values for a fixed centre frequency $\omega_o = 16.50kHz$ and variable quality factors Q.

S/n	**Quality factor (Q)**	**Capacitor values $C_1 = C_2$ (VLF)**	**R_1 (Ω)**	**R_2 (KΩ)**	**R_3 (Ω)**
1	50.00	1.00	30.30	6.06	80.85
2	60.00	1.00	36.36	7.27	117.15
3	70.00	1.00	42.42	8.50	160.05

2.2 MAGNITUDE RESPONSE RESULTS

The specifications for the filter and the calculated resistor values in Table 1 were simulated using the Multisim version 14.2 software as presented in Figure 4 while the schematic Diagrams of the Multiple-Loop Bandpass filter at varying quality factors Q of 50, 60, and 70 are presented in Figures 5,6 and 7.

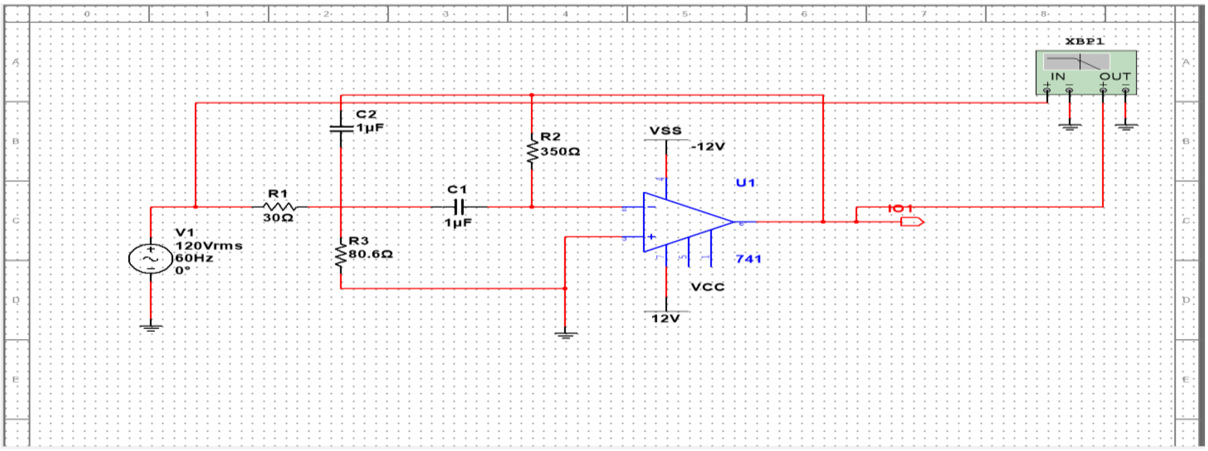

Figure 4. Simulation with Multisim Software using Bode Plotter

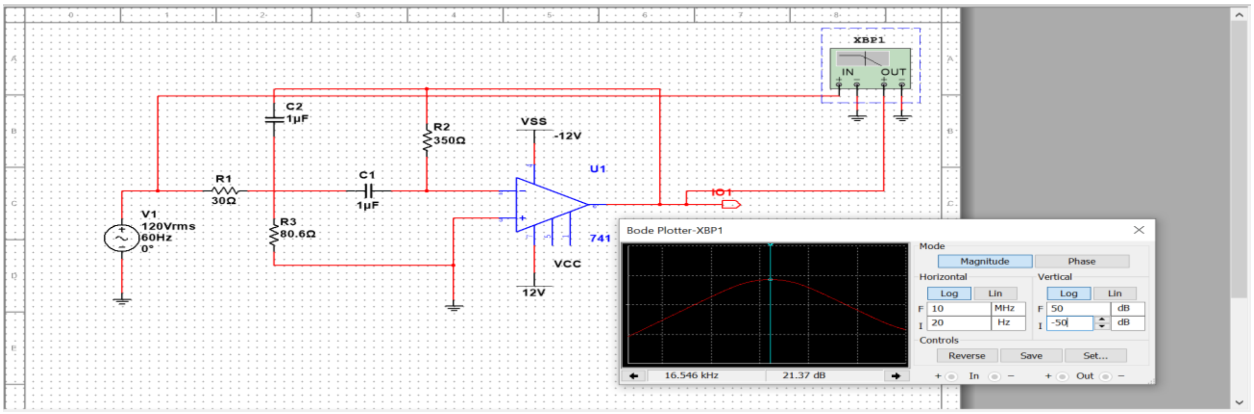

Figure 5. Shows Schematic Circuit Diagram of Multiple Loop Filter at Q=50 with its output

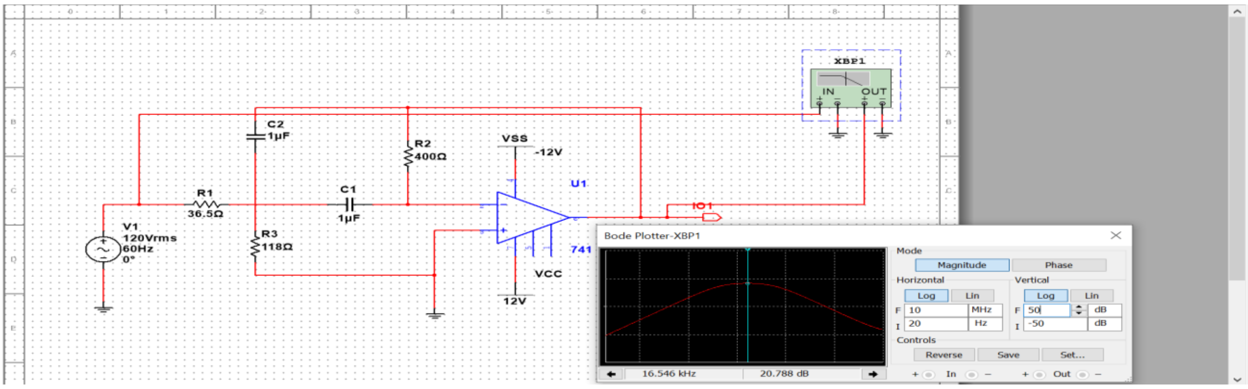

Figure 6. Shows Schematic Circuit Diagram of Second Order Multiple Loop Filter at Q=60 with its Output

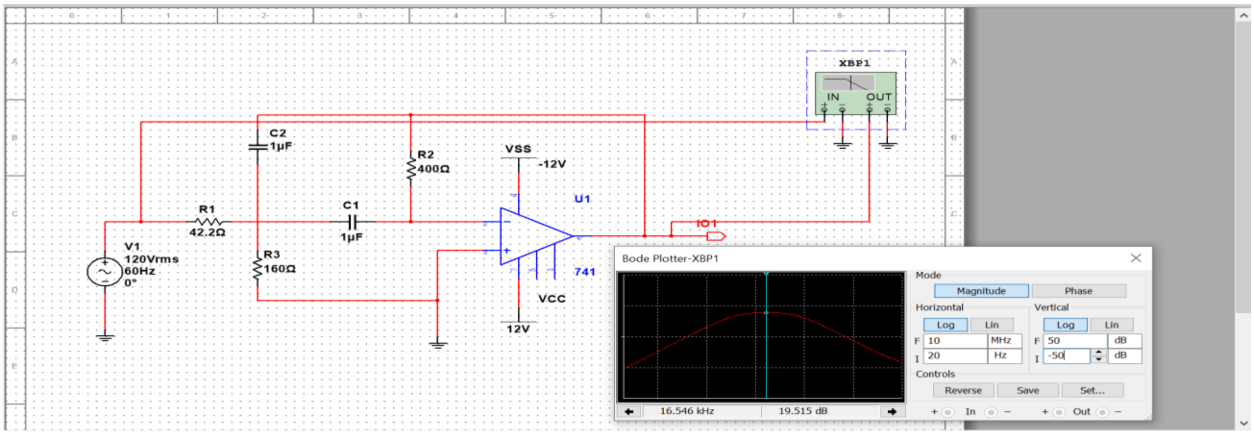

Figure 7. Shows Schematic Circuit Diagram of Second Order Multiple Loop Filter at Q=70 with its Output.

Table 2. simulated result of filter parameters of multi-loop band pass filter.

S/N	Quality factor (Q)	Centre frequency ω_o(KHz)	Mid band gain (K) (dB)	3db gain (dB)	Higher cut off frequency, ω_H (Hz)	Lower cut-off frequency, ω_L (Hz)	Bandwidth BW (Hz)
1	50.00	16.546	21.37	18.37	55.11k	4.81k	50.30k
2	60.00	16.546	20.79	17.79	66.32k	4.13k	62.19k
3	70.00	16.546	19.52	16.52	75.03k	3.65k	71.38k

III. RESULT AND DISCUSSION

The simulated result of the multi-loop feedback Bandpass filter is presented in Table 2. The result shows a filter specification of variable quality factor Q of 50, 60, and 70. With constant centre frequency ($\omega_o = 16.50kHz$) from a pass band of 3 kHz to 30 kHz which is the frequency band of very low frequency (VLF).The Magnitude and Phase response Plots for the simulated filter is presented in Figures 8 to 10.

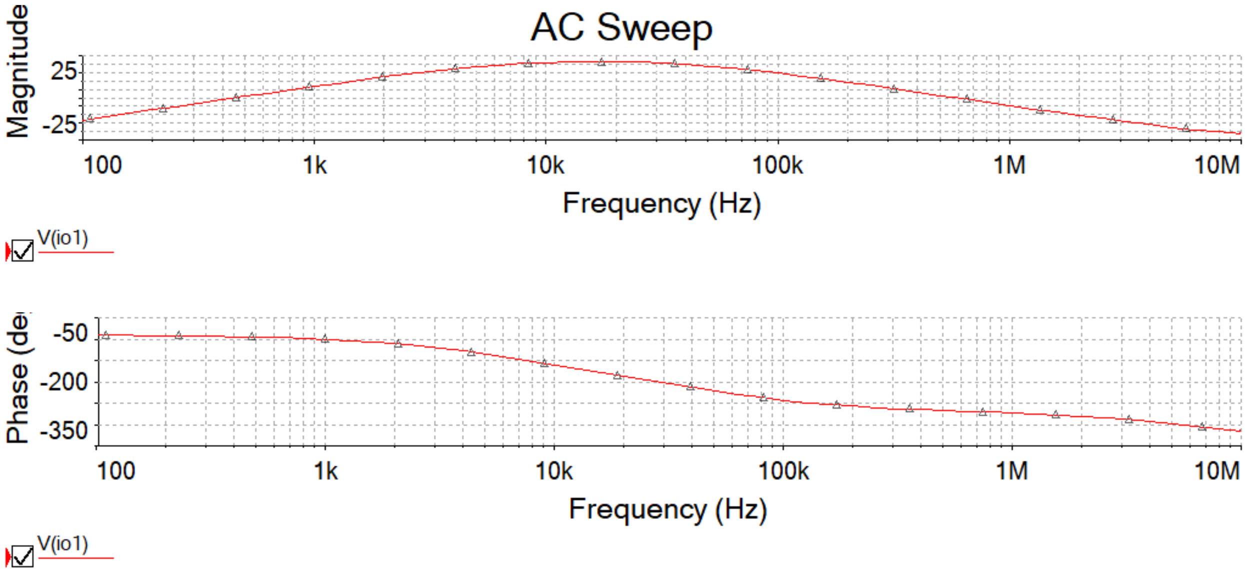

Figure 8. Magnitude and Phase Plots of the Second Order Multiple Loop Feedback Bandpass Filter at Q=50

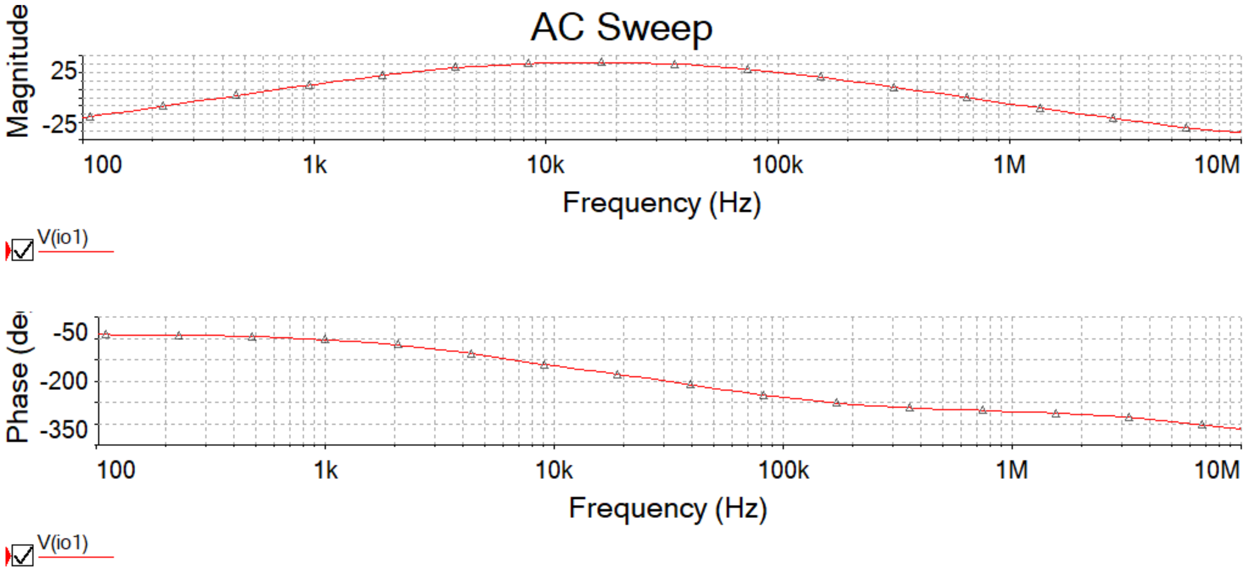

Figure 9. Magnitude and Phase Plots of the Second Order Multiple Loop Feedback Bandpass Filter at Q=60

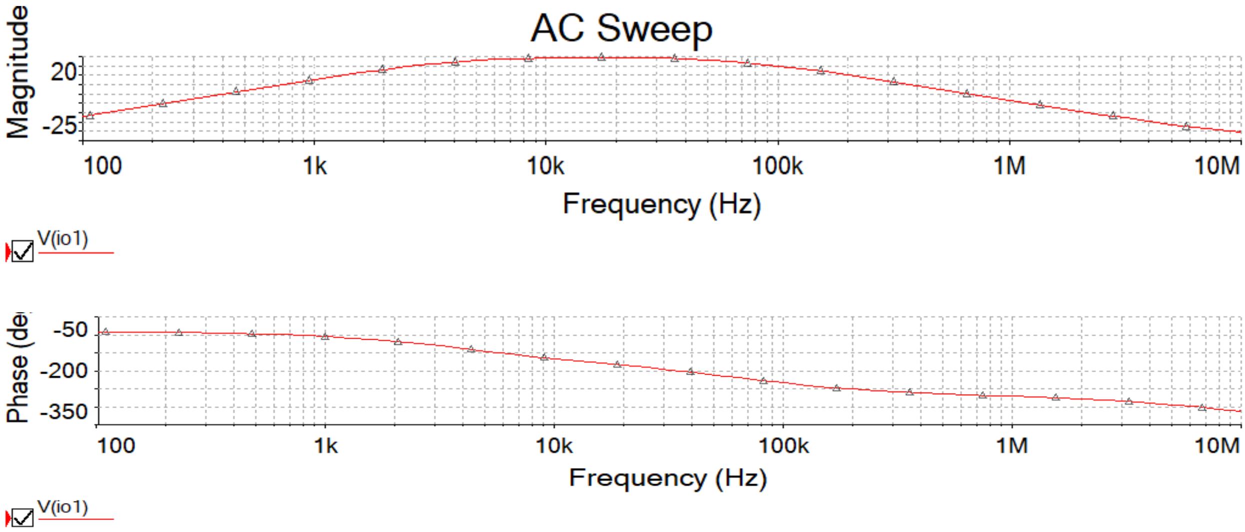

Figure 10. Magnitude and Phase Plots of the Second Order Multiple Loop Feedback Bandpass Filter at Q=70

The result shows a centre frequency ω_o for all the Q's to be 16.546 kHz while the Midband gain was 21.37dB, 20.79dB, and 19.52dB respectively for 50, 60, and 70. The bandwidth for the variable Q's was 50.30 kHz, 62.19kHz, and 71.38kHz respectively. From observation, the centre frequency is slightly shifted and mid band gain decreased from 21.37dB to 19.52dB furthermore, the Bandwidth increases from 50.30 kHz to 71.38 kHz. The simulated result is in good agreement with theory as expected and the circuit does not relatively exhibit high sensitivity to circuit components used.

IV. CONCLUSION

The multiple-loop feedback bandpass filter was simulated using studied for variable Quality factors Q of 50, 60, and 70 with a constant centre frequency (ω_o) $of\ 16.50kHz$ from a band of very low frequency of 3kHz to 30Khz so as to be implemented in the Receiver system of a VLF wave communication system. Results from the simulated filter shows good agreement with theory. As such, we can conclude that the filter can be used in the receivers of a VLF wave communication system.

It can be recommended that further studies should be carried out in the very high Frequency (VHF) band which is used in the marine or Aeronautical mobile Receiver system using this filter topology which could mitigate the cost of Airport receivers to ensure airport security and safety. Since this filter topology has tremendous advantages as discussed in this paper.

V. ACKNOWLEDGEMENT

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VI. DECLARATION OF INTEREST

I would like to state that there is no clash of interest from anywhere since this research is a privately sponsored one by one my humble self and family.

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