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Study of Second Order Active-R Filter Using a Combination of Current Feedback Operational Amplifier (Cfoa) and Classical Operational Amplifier (Cloa) Realising Composite Circuit for Mobile Applications

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Abstract: *The second order Active-R Bandpass filter using a combination of classical op-amp (CLOA) and current feedback op-amp (CFOA) to realize a composite circuit was designed simulated and results presented. The circuit utilized two op-amps OPA627AM of CLOA type and OPA603AP of CFOA type, 7 resistors with different values, input and output sources, NI Multisim software for simulation. The Active-R filter was also utilized due to its advantages over the Active-RC filters. Results showed good agreement with filter specification; therefore it can be used in the implementation in any Mobile Communications Receiver systems.*

Keywords: Study, Second order, CFOA, CLOA, Active-R, filter, Centre frequency, Quality factor

1. INTRODUCTION

Traditionally, the design of active filters was based on embedding into a passive *RC* network one or more ampli-fiers whose gain was assumed to be large and independent of frequency. In actuality, however, active devices, such as transistors and amplifiers, have complex gains that exhibit lowpass behaviour, i.e. their magnitudes decrease with increasing frequency and they have a nonzero phase. This nonideal behaviour of amplifiers has long been known to cause sensitivity and stability problems, in addition to limiting applications of active filters to relatively low fre-quencies. As a result, several workers in the field have developed criteria for comparing the performance of active filters based on their sensitivity to the gain roll-off of the amplifiers;others have, with varying degrees of success, employed special design techniques or compensation methods that attempted to eliminate or minimise errors introduced by the frequency-dependent amplifier gain (Umesh, K.,and Sushi, K.S.1990).

In an alternative approach to this problem, the internal parasitic reactances of transistors, instead of being con-sidered undesirable, were exploited to implement active inductive impedances, which together with capacitors were used to build active microwave filters. Later, recognis-ing that the lowpass characteristic of transistors could be employed to eliminate all external reactances, Capparelli and Liberatore and Paphitis and Murata built pure transistor-resistor filters, using a method that was shown by Berman and Newcomb to be a general state-variable synthesis procedure, using transistors as lossy integrators.

Although this method does work in principle for arbitrary transfer functions and provides the means of building high-frequency active filters without the need for reactances, there are a number of difficulties that apparently discouraged further development of this design technique. The most important are:

(i) the extremely poor repeatability of parasitic transi-sistor parameters and their dependence on temperature and bias conditions
(ii) the finite input and output impedances of tran-sistors, which necessitate buffering and complicate any tuning procedure
(iii) the need for d.c. bias circuitry, which will interfere with the a.c. transfer function.

It was soon recognised that Berman and Newcomb's method could still be used and that the problems associated with (ii) and (iii) above could largely be avoided if, instead of on individual transistors, the design would be based on well developed and inexpensive integrated operational amplifiers (Op-amps), whose gain also exhibits a lowpass or integrator characteristic. Thus, in rapid succession, a large number of papers appeared in which op-amps and resistors were used to implement inductors, oscillators and 2nd or higher-order active filters. (A closely related technique uses CMOS inverters for the active devices.) A few of those circuits also use 'external' lumped capacitors,but the majority employ only resistors and internally compensated Op-amps, thus being denoted 'active *R'* filters in contrast to the usual active *RC* designs.

The main drawbacks of active-RC network implementations are as follows.

(i) Operational amplifiers have a finite bandwidth which limits most active filters to audio-frequency applications. Because of this, filter response is band-limited in practice.

(ii) Component drifts in manufacture or drilis due to environmental changes, which are referred to as sensitivity, have a greater role to play in active filters.

(iii) A major drawback is the requirement of a relatively large number of com-ponents for realisation.

(iv) Amplifier gain is assumed infinite in active-RC design; otherwise the design becomes cumbersome. This is not so in practice.

(v) Filter parameters depend on absolute values of circuit components. It is very difficult to control variations in absolute values.

(vi) The problems of accuracy and stability are encountered due to network sen-

sitivity and non-ideality of the OA.

Networks which use only op amps, resistances and no capacitors in their implementation and derive their frequency response from the internal dynamics of the OA are referred to as active-R circuits.

Some important advantages of active-R circuits are as follows.

(i) The elimination of external capacitors makes active-R circuits highly suitable for micro-miniaturisation, from the considerations of ease of implementation and cost reduction.

(ii) These circuits generally have low sensitivities and good stability.

(iii) The design equations describe them adequately over a wide range of fie-quencies and result in circuits with a more predictable and satisfactory high fre-quency performance.

(iv) They are adaptable from the low audio range up to several MHz, having a quality factor ranging from below unity to several hundred.

(v) Filter parameters such as pole frequency, co,, pole quality factor, Q, and flat gain are established by the gain-bandwidths (GBWs) of the amplifiers and ratios of resistors. Since resistor ratios can be maintained to higher precision with hybrid or monolithic technology than their absolute values, more accuracy of component values is guaranteed in active-R implementation than in active-RC where absolute values of resistance and capacitance are involved.

(vi) We are left with the task of finding a means to stabilise the amplifier GBWs both in manufacture and with temperature.

(vii) Passive sensitivities are all less than one. Active sensitivities are halved in magnitude.

The active-R circuit is most suited for monolithic integration and this synthesis technique can take full advantage of the most important feature of monolithic ICs, namely low-cost batch processing (i.e, high volume production) capability (Umesh, K.,and Sushi, K.S.1990).

It is desirable in designing an active network that the circuit should be commer-cially viable and have prospects for integration as well as reliable performance in terms of low sensitivity, high stability and large frequency range of operation. For economic integration and cost reduction it is preferable that the networks should use a minimum number of components, particularly condensers. In this respect active-R networks offer great advantages over active-RC networks. Also, in the design, large value resistances should be eliminated or minimised, maximum use should be made of the matched characteristics of components and the close track-ing of components with ambient temperature variations. It is always desirable to have filter parameters in terms of resistance ratios, rather than resistances, and over a narrow range. Since ratios can be implemented within small tolerance limits in monolithic technology, the prospects of true integration of filters increase. These points are met in active-R circuits (Umesh, K.,and Sushi, K.S.1990).

So we see that the importance of active-R circuits in the present world can never be over-emphasized. They make possible a switch from hybrid to monolithic integration.

Classical op-amps have excellent performance in applications where the required gain band-width is low compared to the gain-bandwidth product of the op amp. However, increasing closed-loop gain decreases the error-reducing loop gain. Furthermore, starting at relatively low frequencies, the loop gain rolls-off at 20dB/decade of signal frequency increase. In combination these effects can produce significant errors, especially at higher frequencies where the loop gain can be very low. (Tim K., Tony W., And Mark Stitt, R. 1991)

Current-feedback op amps, on the other hand, have good dynamic performance at both low and high gains. This is because the feedback components set both closed-loop gain and open-loop gain, making loop gain and dynamic per-formance relatively independent of closed-loop gain. Unfor-tunately, the DC performance (V_{OS}, dV_{OS}/dT, CMR, etc) of current feedback amplifiers is poor compared to classical op amps. (Tim K., Tony W., And Mark Stitt, R. 1991)

DC performance of the composite amplifier is excellent. Since the CFOA is in the feedback of the Classical Op-amp (CLOA), the composite amplifier retains the excellent DC characteristics of the CLOA. In fact, since it does not drive the load directly, its DC accuracy can be better than the CLOA alone. Thermal feedback within an amplifier driving large loads will cause errors due to internal thermal gradients and package self-heating. The composite amplifier with a CFOA can drive 150□ loads to10V with no thermal feedback to the Op-amp.

The gain of the composite amplifier is set by R_1 and R_2 alone. Errors due to R_3 and R_4 do not affect the gain of the composite amplifier. The gain of the second amplifier, set by R_3 and R_4, should be within 5% to assure expected dynamic performance. Slew rate and full-power response of the classical amplifier are boosted in the composite amplifier. Since the CFOA adds gain at the output of the CLOA, the slew rate of the CLOA is increased by the gain of the CFOA. For example, in the gain-of-100 composite amplifier, the slew rate and full-power response of the CLOA is increased from 40V/µs min (600kHz) to over 700V/µs (11MHz).

The current feedback operational amplifier otherwise known as CFOA or CFA is a type of electronic amplifier whose inverting input is sensitive to current, rather than to voltage as in a conventional voltage-feedback operational amplifier (VFA). The CFA was invented by David Nelson at Comlinear Corporation, and first sold in 1982 as a hybrid amplifier, the CLC103. A Current Feedback Op-amp is a translinear Current Conveyor (CCII+) followed by a translinear voltage buffer. CFOAs have attracted prominent attention in analog circuit design due to their two significant properties namely, the gain-bandwidth independence and very highslew rates together with their commercial availability as off-the self ICs from almost all leading IC manufactures.

A CFOA basically comprises of CCII, voltage follower and node impedance. It is shown in the following figure,

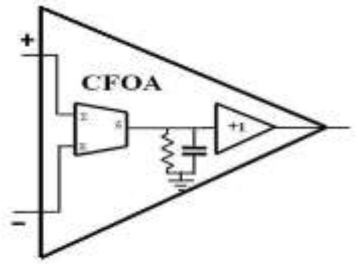


Figure 1. Symbol of CFOA

OPA603AP

The OPA603AP is a high speed monolithic operational amplifier fabricated using Analog Devices' junction isolated complementary bipolar (CB) process. It combines high bandwidth and very fast large signal response with excellent dc performance. It has a high slew rate of 2000V/µs with 60 MHz Unity-GBW (gain-bandwidth) as compared to .5V/µs of conventional op amp. It has a high speed and excellent DC specification combined with low power consumption and high output drive capability. It is used for fast ADC (analog to digital converter), pulse circuitry, cable drivers and video sisnal amplifier etc. It can be used as a differntial amplifier as well as a differential line driver.

Composite amplifiers comprising two or more amplifying elements are generally designed to achieve performances unachievable by a single device (Apex Micro technology, 2012: Franco, 2002; Gerstenhaber & Tran, 2002; Mikhael & Michael, 1987; OA-07 current feedback, 2002; Redmayne, 2002; Stofka, 2008; Williams, (1986). These modules usually involve the operational amplifiers (OPA), and they have been used to increase loop gain (Franco, 2002), phase accuracy (Graeme, 1993; Wong, 1987), bandwidth (Geiger, 1977; Stofka, 2008) noise reduction (schmid, 1994) and bandwidth constancy (Maundy, Gift, & Westwick, 2009) in amplifier systems (Stephen, J.G. & Brent, M, 2015). They have also been applied in active filters (Budak, Wullink, & Geiger, 1980; Geiger & Budak, 1979) and oscillators (Wostyna, 1992).

A composite op amp, as its name implies, is an op amp topology obtained from the combination of at least two other op amps. Generally, the composite op amp offers an improvement over single or conventional op amp performance in terms of extended useful bandwidth, low sensitivity to component and op amp mismatch, and wide dynamic range. (Mikhael, & Michael, 1987).

The gain bandwidth product, the product of the finite gain of the operational amplifier and the 3db frequency, is generally considered to be a constant in a given op. amp. Speed, determined input offset voltage are not, usually nor a variable that can be adjusted in a single op. amp designs. Composite operational amplifiers effectively extend the range of single op. amps and lessen the impact of the single op. amp imitations. (Eldon, W.B).

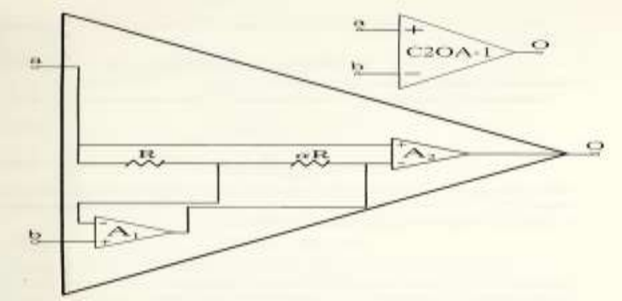


Figure 2. Symbol of the Composite Op-amp

In this paper, single pole model second order bandpass filter using composite operational amplifier combined with the current Feedback Operational Amplifier (CFOA) is designed and simulated that is applied in an Active-R filter for ultra-high frequency (UHF) Radio Frequency Identification (RFID) systems. A composite op. amp offers an improvement over single or conventional op. amp. Performance in terms of extended useful bandwidth, low sensitivity to component and op. amp mismatch and wide dynamic range which can substantially suit in the filter design for the UHF RFID range. Also no literature has been found utilizing the design and implementation of a bandpass filter using composite op. amp for UHF RFID Application. A composite operational amplifier and the current-feedback amplifier can combine the best qualities of both amplifiers. Hence this paper

2. MATERIALS AND METHODS

The research made use of a second order Active R Band pass filter coupled with current feedback operational Amplifiers (CFOA) of OPA603AP type, of Gain Bandwidth product 60MHz and a classical Op-amp (CLOA) of OPA627 AM type also, 7 resistors of different resistances were calculated, input power source, an output connector, grounded connectors and Multisim version 14.2 software for simulation.

The operational Amplifiers were first mounted on the circuit board and the resistors after calculating and determining their values. Furthermore, the input power source was mounted together with the output connector. The components were finally joined together with the aid of wires. The Band pass filter designed is presented in Figure 3.

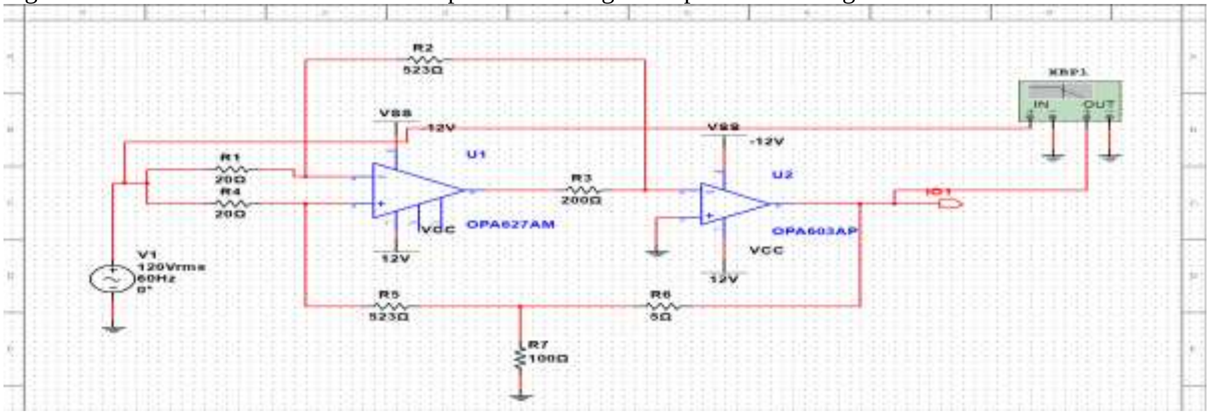


Figure 3. Second Order Active-R Bandpass Filter Using CFOA and CNOA Amplifiers

2.1 DESIGN SPECIFICATION

The filter utilized only Active-R type with Centre frequency ω_o of 11.4MHz, Quality Factor, Q=5 and a gain factor K of 10. The resistor values were calculated using design equations 12, 13 and 14.

2.2 DESIGN EQUATION

Figure 3 represents a new active-R Bandpass filter which uses two op. amp (OA's) and seven resistors. By direct analysis of the network assuming

$A_i = \frac{GBi}{S}$ (1)

Where Gb is the gain bandwidth product of the OA, and assuming $R_{5 \gg} R_{7,}$ the transfer function is given by:

$$\frac{V_3}{V_1} = \frac{-GB_2R_3}{(R_1+R_2+R_3)S} \times \frac{S^2+SGB_1\left(\frac{R_1+R_2}{R_3}\right)\left(\frac{R_5}{R_4+R_5}-\frac{R_2}{R_1+R_2}\right)}{S^2+S\left(\frac{GB_1R_1}{R_1+R_2+R_3}\right)+\frac{nGB_1GB_2R_4(R_1+R_2)}{(R_4+R_5)(R_1+R_2+R_3)}} \quad (2)$$

Where $n = \frac{R_7}{R_6+R_7}$ (3) $Taking$ $\frac{R_5}{R_4} = \frac{R_2}{R_1}$ (4)

And defining $a = \frac{R_3}{R_1}$ (5) $b = 1 + a + \frac{R_2}{R_1}$ (6)

$$M = \frac{R_4}{R_4 + R_5} \quad (7)$$

The transfer function reduces to

$$\frac{V_3}{V_1} = \frac{-\frac{a}{b}GB_2S}{S^2 + S\left(\frac{GB_1}{b}\right) + m.n.GB_1.GB_{2.}\left(\frac{b-a}{b}\right)} \quad (8)$$

Which realizes an inverting band pass characteristics having?

$$\omega_o = \sqrt{\left[m.n.GB_{1.}GB_{2.}\left(\frac{b-a}{b}\right)\right]} \quad (9)$$

$$Q = \sqrt{\left[m.n.\frac{GB_{2.}b(b-a)}{GB_1}\right]} \quad (10)$$

$$K = |gain|\omega_o = a.\left(\frac{GB_2}{GB_1}\right) \quad (11)$$

It is seen that the gain K can take any arbitrary value.

For a specified ω_o, Q and K, the design equations of the band pass filter are given by:

$$\frac{R_3}{R_1} = K.\frac{GB_1}{GB_2} \quad (12)$$

$$\frac{R_2}{R_1} = \frac{R_5}{R_4} = Q.\frac{GB_1}{\omega_O} - \left(1 + K.\frac{GB_1}{GB_2}\right) \quad (13)$$

$$\frac{R_6}{R_7} = \frac{GB_2}{\omega_O Q} - 1 \quad (14)$$

Therefore resistor values were calculated using equations 12, 13 and 14 as follows;

$$\frac{R_3}{R_1} = K.\frac{GB_1}{GB_2} = 10 \rightarrow R_3 = 10R_1 \rightarrow 200 = 10R_1 : R_1 = \frac{200}{10} = 20\Omega$$

$$\frac{R_2}{R_1} = \frac{R_5}{R_4} = 5 \times \frac{60 \times 10^6}{11.4 \times 10^6} = (1 + 10 \times 1) = 26.30 \rightarrow R_2 = R_5 = 26.30 \times 20 = 526\Omega$$

$$\frac{R_6}{R_7} = 0.05 \quad let\ R_7 = 100\Omega \quad \rightarrow R_6 = 5\Omega$$

$R_1 = R_4 = 20\Omega$
$R_2 = R_5 = 526\Omega$
$R_3 = 200\Omega$
$R_6 = 5\Omega$
$R_7 = 100\Omega$

Under the condition; $R_3 \gg R_1R_4$

Table 1. Calculated and preferred resistor values

		Resistor Values (Ω)							Prefered Values(Ω)		
s/n	Quality factor	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_2	R_3	R_5
1	5.0	20.00	526.00	200.00	200.00	526.00	5.00	100.00	526.30	1.50K	526.30

R_2 Can be tuned to realize the desired cut off frequency
R_7 Can be tuned to realize the gain.

3. RESULT AND DISCUSSION

The Second Order Active-R Bandpass filter using CFOA and CNOA presented in Figure 3 was simulated and the Magnitude and Phase response curves obtained through Bode Plotter as presented in Figures 4 and 5, results were read and recorded as presented in Table 2.

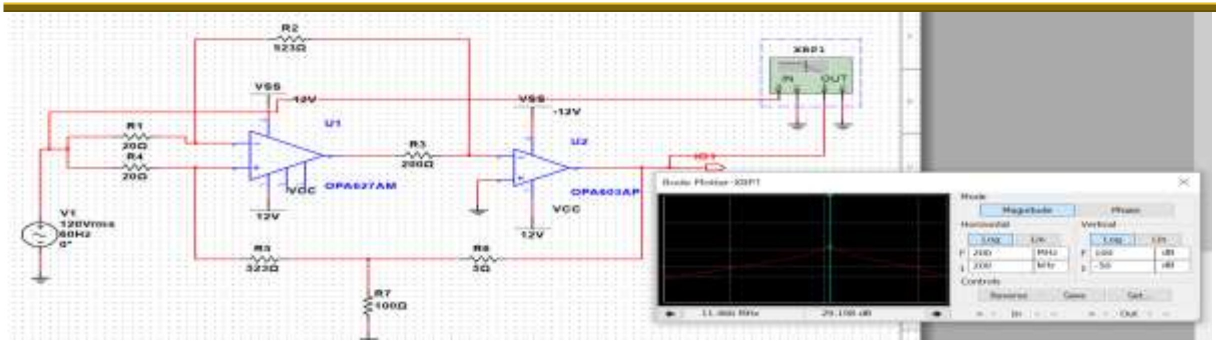
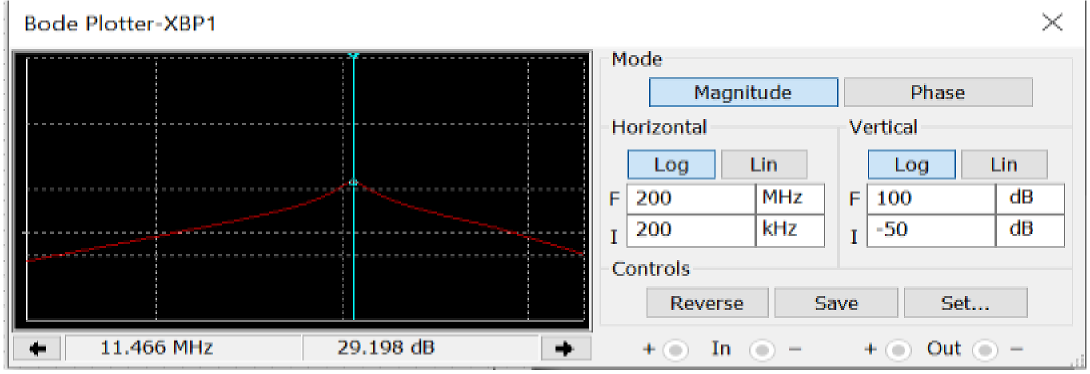


Figure 4. Shows the Circuit Diagram of the Second Order Active-R Filter using CFOA and CNOA with its Output.



Mode: Magnitude
Horizontal: Log
F 200 MHz
I 200 kHz
Vertical: Log
F 100 dB
I -50 dB
11.466 MHz
29.198 dB

Figure 5. Shows the Frequency Response Curve using the Bode Plotter

Table 2. Simulated Filter parameters of CFOA Active – R Bandpass Filter.

S/N	Quality factor	Centre freq. ω_o (MHz)	Mid band gain (dB)	-3dB Gain	Higher cut off frequency (MHz)	Lower cut off freq. (MHz)	Bandwidth (BW) (MHz)	Roll-off rate dB/ decade
1	5	11.466	29.198	26.198	13.30	3.58	3.58	-40.46

The magnitude and phase response curves of the simulated Second Order Active-R Bandpass Filter using CFOA and CNOA is presented in Figure 6 While measurement was carried out with the aid of Bode plotter in terms of filter parameters like centre Frequency ω_o, Midband gain G, - 3dB gain, Bandwidth (BW) and roll off rate (ROR) and result presented in Table 2.

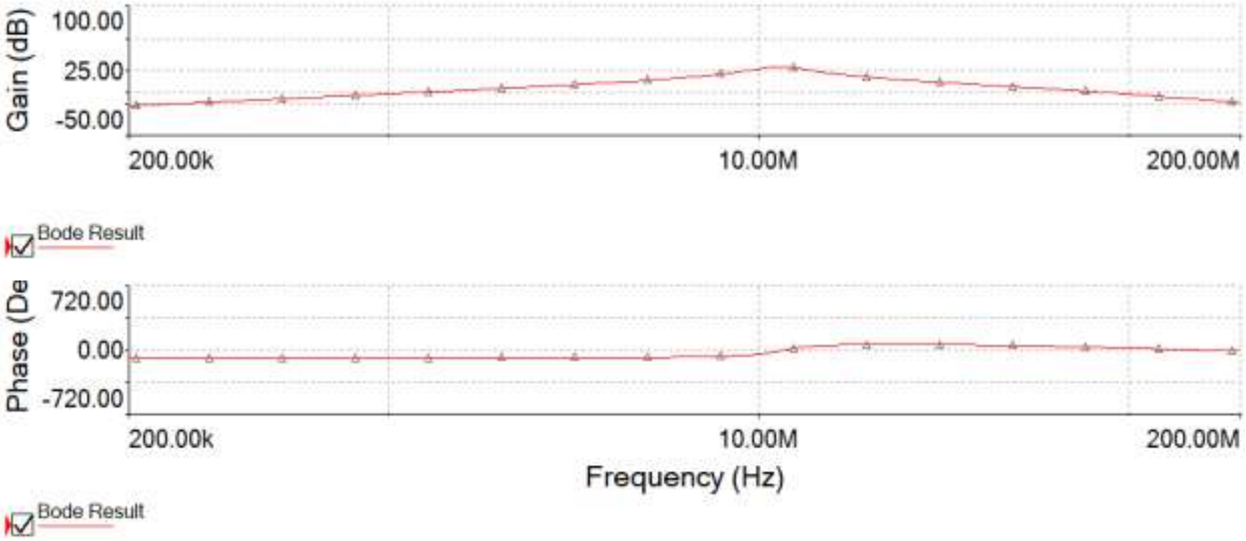


Figure 6. Magnitude and Phase Response Curves of the Second Order Active-R Filter using CFOA and CNOA

The result shows a Centre Frequency of 11.466 MHz and the Midband gain of 29.198dB. The filter recorded a Bandwidth of 3.58 MHz and a roll-off rate of -40.46dB/decade which approached a second order double pole filter. Theoretically the second-order filter with double pole approaches -40dB/decade.

The above result is in agreement with the set specification with a slight variation which could be solved when proper tuning is carried out on the filter resistor R_2 that controls the ω_o.

4. CONCLUSION

The second order Active-R Bandpass filter using a combination of classical op-amp and current feedback op-amp to realize a composite circuit was designed simulated and results presented. Results show good agreement with filter specification; therefore it can be used in the implementation in any Mobile Communications Receiver systems.

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6. 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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