

Transformation of Ladder Based All Pass and Biquad Filters into Active All Pass and Biquad Filter using CFOA

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Abstract

In this paper ladder based all pass and biquad filters are transformed into CFOA based all pass and biquad filters. The ladder based approach is used for design of prototypes. The new circuits have attractive properties of greater linearity, high dynamic rate, high slew rate and high signal bandwidth. A new technique for the conversion has been proposed. The technique uses signal flow graph and converts the existing LC ladder based filter into CFOA based configurations. The design of all pass and Biquad filter has been realized using the proposed technique. The proposed configuration is implemented using CFOA as an active device and all the capacitors are grounded. The new configurations are suitable for various signal processing applications. Simulation has been carried out using simulation software PSpice (v10.2). The simulation results have been demonstrated and discussed.

Keywords: Current feedback operational amplifier; Ladder filter; Signal flow graph; Current mode; Voltage mode; All pass filter; Biquad filter

Introduction

Signal flow graph is a diagram that represents set of simultaneous linear algebraic equations. They are used widely in characterizing sequential circuits of the Moore and Mealy type, synthesis of non-linear data converters and also in stochastic signal processing. The design procedure using signal flow graphs is also simple as compared to functional relation simulation and element simulation methods.

Ladder based Filters are used as a prototype for the transformation [1-6]. Passive ladder based filter are transformed into CFOA based circuits using Signal Flow Graph. First Kirchoff's voltage and Current Laws were applied to obtain the current equations of the ladder based prototype. The equations were then converted into Voltage form and then were used to obtain their Signal Flow Graph. CFOA based circuits for allpass and biquad filters are proposed with the help of signal flow graphs.

CFOA's are widely used in many filtering and signal processing applications. Symbol diagram of the CFOA is shown in Figure 1.

Many scientists have proposed op-amp based configuration of biquad filters. For example Jurisic et al. proposed an op-amp based configuration of biquad filter [6]. However, these circuits which are voltage mode possess a large number of disadvantages. Some of the disadvantages are:

- Gain Bandwidth product was not constant.
- The configuration was more sensitive to variations in external parameters as temperature, stray fields etc.

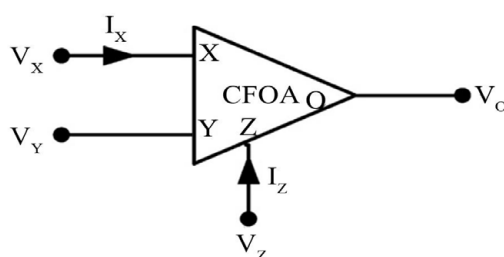


Figure 1: CFOA building block.

- Slew rate was limited.
- Configuration was having ripples in its output, hence far away from ideal output.

Many of the disadvantages were overcome by CFOA based Biquad Filter. The Circuits were nearly gain bandwidth independent. Circuits were able to produce very high slew rate which gives very high full power bandwidth. The output current has large driving capacity. Gain bandwidth is constant and variable gain amplifiers can be designed easily with CFOA based biquad filter.

Previously, Rathore and Khot [7] have designed a Low Pass and High Pass filter configuration using CFOA. They have given a systematic method of deriving CFOA based all grounded capacitor filter from Current Mode RLC prototype ladders. Sinha et al. proposed a Signal Flow Graph approach for realisation of RLC Ladder filters [8] into CFOA type filters. Referring to the Low Pass and High Pass configurations presented in his research paper [7,8], we prepared two different combinations of Band Pass and Band Reject Filter presented in research paper [9]. In this paper, active realization of Allpass and Biquad filter using current feedback operational amplifier (CFOA) has been presented.

Transformation of Ladder Allpass Filter into CFOA Based Allpass Filter

All pass Filter provides phase correction and removes the interference present in magnitude response. However in practice, these responses are influenced by component variations. Since all pass functions are non minimum by definition, therefore the use of ladder based design possess many problems. The Passive ladder based all pass filter contains inductor which are bulky and takes too much space in IC

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fabrication. Hence CFOA based all pass filter are designed which takes less space on chip. The conversion of ladder based all pass filter into CFOA based filter consists of transforming the passive filter into signal flow graph which is shown in Figure 2.

Apply KVL and KCL in the circuit

$$I_{IN} = \frac{V_{IN} - V_1}{R_1} \quad (1)$$

$$V_1 = \frac{I_{IN} - I_2}{sC_1R} \quad (2)$$

$$I_2 = \frac{V_1 - V_2}{sL_1} \quad (3)$$

$$V_2 = \frac{I_2 - I_4}{sC_2} \quad (4)$$

$$I_4 = \frac{V_2 - V_3}{sL_2} \quad (5)$$

$$V_3 = \frac{(I_4 - I_6)(s^2LC + 1)}{sC} \quad (6)$$

$$V_0 = I_6 R_2 \quad (7)$$

$$I_6 = \frac{V_3 - V_0}{sL_3} \quad (8)$$

Conversion into voltage form

These equations are converted into voltage form to remove current element and hence we get the following equations:

$$RI_{IN} = \frac{R(V_{IN} - V_1)}{R_1} \Rightarrow V_{IN} = \frac{R(V_{IN} - V_1)}{R_1} \quad (9)$$

$$V_1 = \frac{R(I_{IN} - I_2)}{sC_1R} \Rightarrow V_1 = \frac{(V_{IN} - V_2)}{sC_1R} \quad (10)$$

$$RI_2 = \frac{R(V_1 - V_2)}{sL_1} \Rightarrow V_2 = \frac{R(V_1 - V_2)}{sL_1} \quad (11)$$

$$V_2 = \frac{R(I_2 - I_4)}{sC_1R} \Rightarrow V_2 = \frac{(V_2 - V_4)}{sC_1R} \quad (12)$$

$$RI_4 = \frac{R(V_2 - V_3)}{sL} \Rightarrow V_4 = \frac{R(V_2 - V_3)}{sL} \quad (13)$$

$$V_3 = \frac{R(I_4 - I_6)(s^2LC + 1)}{sCR} \Rightarrow V_3 = \frac{(V_4 - V_6)(s^2LC + 1)}{sCR} \quad (14)$$

$$RI_6 = \frac{R(V_3 - V_0)}{sL_3} \Rightarrow V_6 = \frac{R(V_3 - V_0)}{sL_3} \quad (15)$$

$$V_0 = RI_6 = \frac{R_2}{R} \Rightarrow V_0 = V_6 = \frac{R_2}{R} \quad (16)$$

Signal flow graph

With the help of these equations we make a signal flow graph which has been shown in Figure 3.

CFOA filter

Using the signal flow graph, CFOA based allpass filter has been made as shown in Figure 4.

Observations

The passive and CFOA based ladder allpass filter circuits shown in Figures 2 and 4 are designed and evaluated in PSPICE CAPTURE using

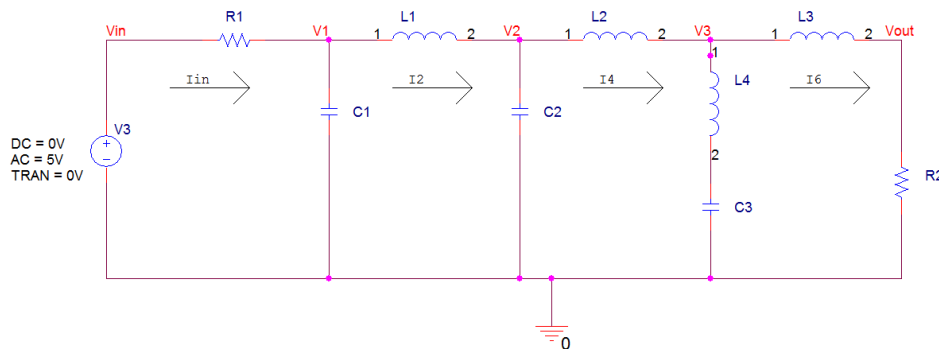


Figure 2: Ladder based all pass filter.

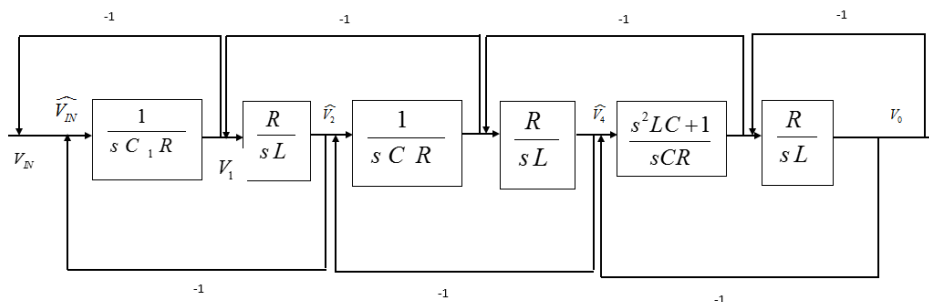


Figure 3: Signal flow graph of ladder based allpass filter.

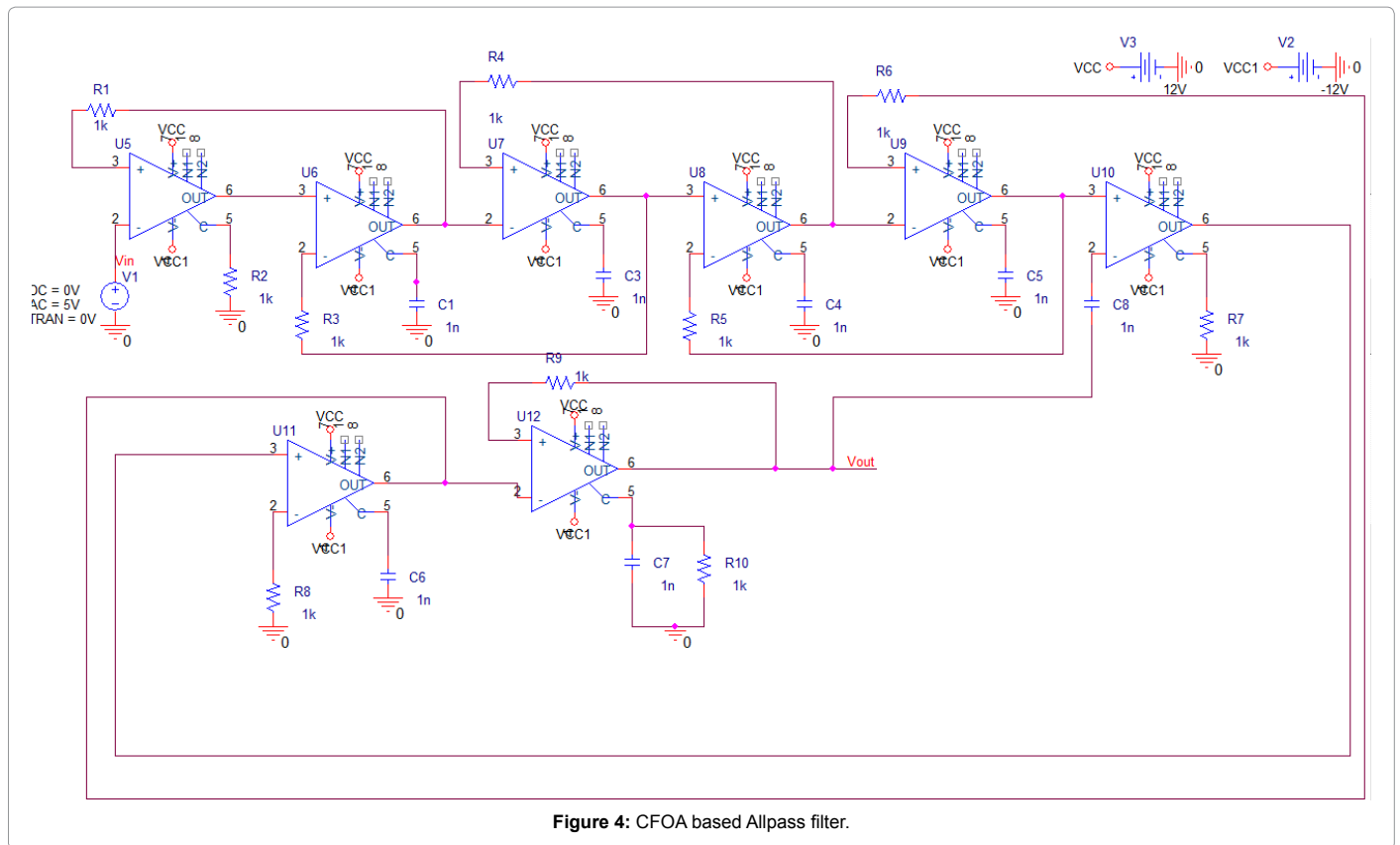


Figure 4: CFOA based Allpass filter.

conventional resistors, inductors, capacitors and AD844 IC as CFOA. Inductors are used for the passive ladder based circuit.

Now the circuit is simulated in PSPICE CAPTURE with input voltage as $5 \sin(2\pi \times 10^3 t)$ and its AC analysis is done.

Response of CFOA based all pass filter

CFOA allpass filter uses the AD844 IC and a power supply to drive it. The circuit is simulated in PSPICE CAPTURE with input voltage as $5 \sin(2\pi \times 10^3 t)$ and its AC analysis is done. The graphical output obtained is given below in Figure 5.

In Figure 5, Magnitude Plot is represented by the Green colour line and the Phase Plot is represented by the Red colour line. The magnitude curve is constant and the phase varies from 0 degrees to -180 degrees.

Noise response of CFOA based all pass filter

The circuit is simulated with input voltage as $5 \sin(2\pi \times 10^3 t)$ and its noise analysis is done. The graphical result obtained is shown in Figure 6.

Transformation of Ladder Based Biquad Filter Into CFOA Based Biquad Filter

The RLC based biquad filter has been shown in Figure 7.

Mathematical analysis

After applying KVL and KCL in Figure 7, the following equations have been obtained:

$$I_{IN} = \frac{V_{IN} - V_1}{R_1} \quad (17)$$

$$V_1 = \frac{I_{IN} - I_1}{sC} \quad (18)$$

$$I_1 = \frac{(V_1 - V_2)(s^2LC + 1)}{sL} \quad (19)$$

$$V_2 = \frac{I_1 - I_2}{sC} \quad (20)$$

$$I_2 = \frac{(V_2 - V_3)(s^2LC + 1)}{sL} \quad (21)$$

$$V_3 = \frac{I_2 - I_3}{sC} \quad (22)$$

$$I_3 = \frac{(V_3 - V_0)(s^2LC + 1)}{sL} \quad (23)$$

$$V_0 = \frac{I_3 - I_4}{sC} \quad (24)$$

$$I_4 = \frac{V_0}{R} \quad (25)$$

Conversion into voltage form

$$RV_{IN} = \frac{R(V_{IN} - V_1)}{R_1} \Rightarrow V_{IN} = \frac{R(V_{IN} - V_1)}{R_1} \quad (26)$$

$$V_1 = \frac{R(I_{IN} - I_1)}{sCR} \Rightarrow V_1 = \frac{V_{IN} - V_1}{sCR} \quad (27)$$

$$RI_1 = (V_1 - V_2)\left(\frac{R}{sL}\right)(s^2LC + 1) \Rightarrow V_1 = (V_1 - V_2)\frac{R(s^2LC + 1)}{sL} \quad (28)$$

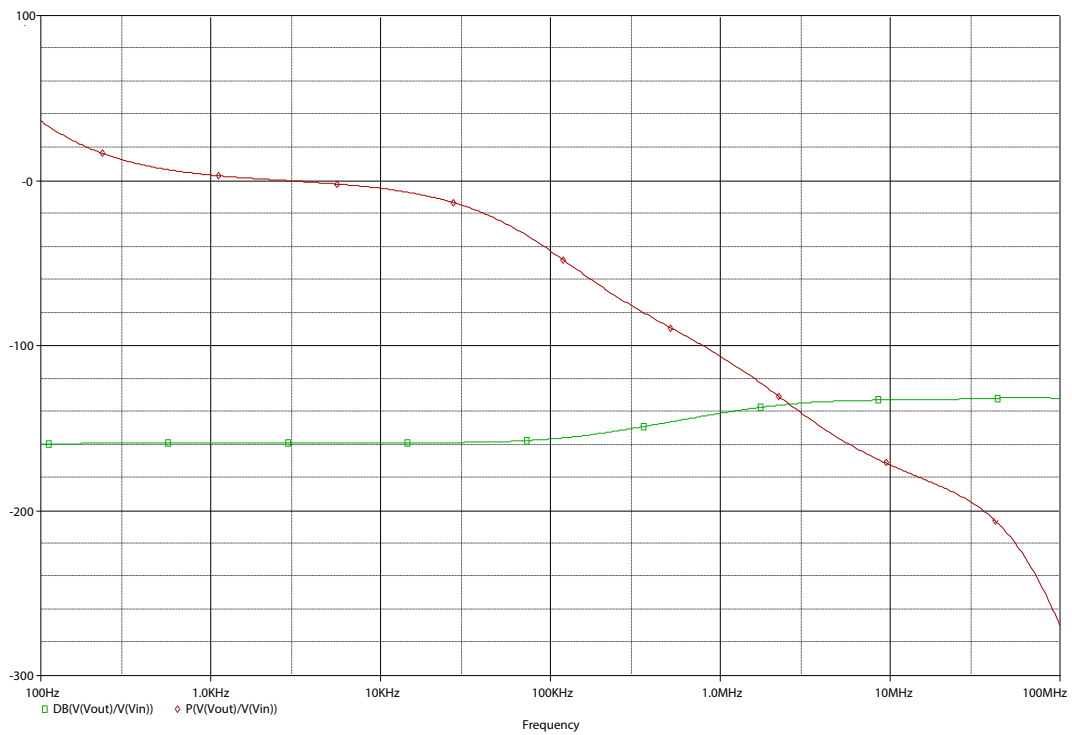


Figure 5: Response of CFOA based all pass filter.

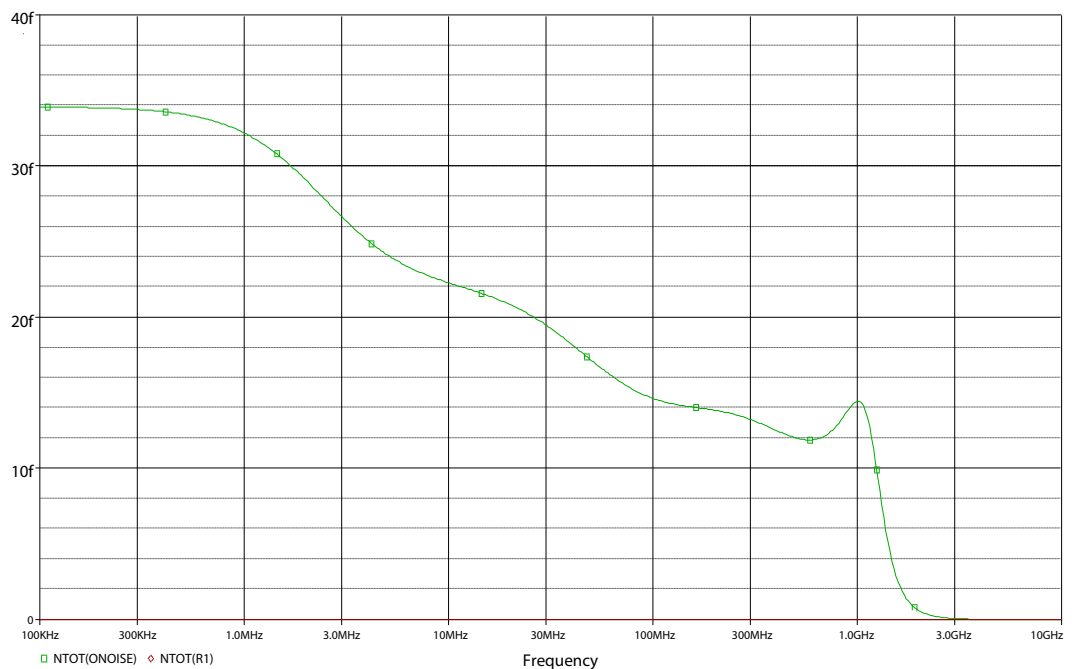


Figure 6: Noise response of CFOA based all pass filter.

$$V_2 = \frac{R(I_1 - I_2)}{sCR} \Rightarrow V_2 = \frac{V_1 - V_2}{sCR} \quad (29)$$

$$RI_2 = (V_2 - V_3) \frac{R(s^2LC + 1)}{sL} \Rightarrow V_2 = (V_2 - V_3) \frac{R(s^2LC + 1)}{sL} \quad (30)$$

$$V_3 = \frac{R(I_2 - I_3)}{sCR} \Rightarrow V_3 = \frac{V_2 - V_3}{sCR} \quad (31)$$

$$RI_3 = \frac{V_3 - V_0}{sL} R(s^2LC + 1) \Rightarrow V_3 = \frac{V_3 - V_0}{sL} R(s^2LC + 1) \quad (32)$$

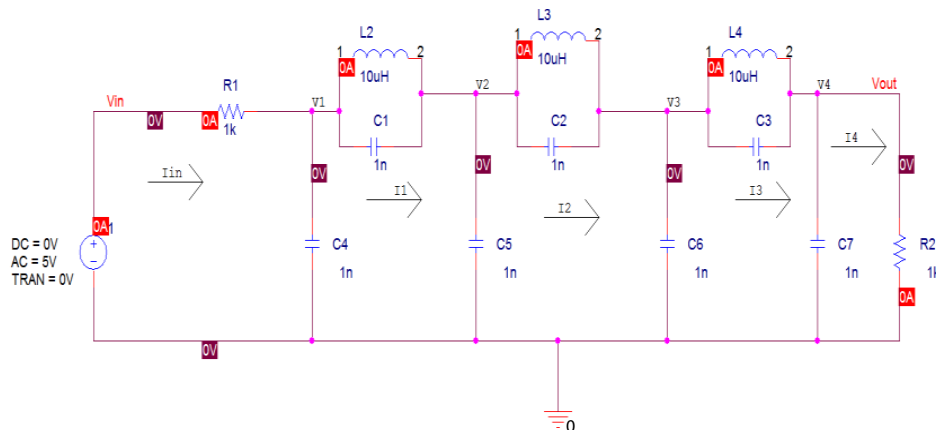


Figure 7: Ladder based biquad filter.

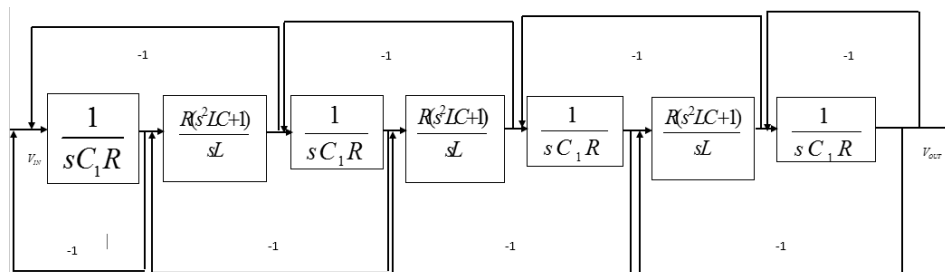


Figure 8: Signal flow graph of biquad filter (ladder based).

$$V_0 = \frac{R(I_3 - I_4)}{sCR} \Rightarrow V_0 = \frac{V_3 - V_4}{sCR} \quad (33)$$

$$RI_4 = \frac{V_0 R}{R_A} \Rightarrow V_4 = V_0 \frac{R}{R_A} \quad (34)$$

Signal flow graph

The Signal Flow Graph of biquad filter has been shown in Figure 8.

CFOA based active ladder filter

The circuit diagram for CFOA based Biquad filter has been shown in Figure 9.

The Signal Flow Graph was analysed and the blocks were converted to CFOA diagram. The passive and CFOA based ladder biquad filter circuits shown in Figures 7 and 9 are designed and evaluated using conventional resistors, inductors, capacitors and AD844 IC as CFOA.

Frequency response (Gain vs Frequency response)

The circuit is simulated with input voltage as $5 \sin(2\pi 10 \times 10^3 t)$ and its AC analysis is done. The graphical result obtained is shown in Figure 10.

Noise analysis of biquad filter

The circuit is simulated with input voltage as $5 \sin(2\pi 10 \times 10^3 t)$ and its noise analysis is done. The graphical result obtained is shown in Figure 11.

Simulation Results

Simulation results of both the cases of All Pass and biquad Filter are as follows:

Allpass filter

All Pass Filter is simulated for $R_1=R_2=R_3=R_4=R_5=R_6=R_7=R_8=R_9=R_{10}=1K\Omega$. Taking $C_1=C_2=C_3=C_4=C_5=C_7=C_6=1nF$, we have obtained the ideal frequency response.

The Magnitude response was almost constant and the Phase response varied from 0 degree to -180 degrees.

Biquad filter

A Biquad Filter is simulated for a notch frequency of $f_n=851.594$ KHz, a lower cutoff frequency of $f_l=213.911$ KHz, the lower and higher cutoff frequency for bandpass filter are $f_l'=1.997$ MHz and $f_h'=50.388$ MHz.

$R_1=50\Omega$, $R_2=1K\Omega$, $R_3=500\Omega$, $R_4=R_8=R_6=R_7=R_{11}=1K\Omega$ and $R_9=R_{10}=R_{12}=500\Omega$. Taking $C_1=C_{10}=10nF$, and $C_2=C_3=C_9=C_5=C_7=C_8=C_6=1nF$, we have obtained the ideal frequency response.

Conclusion

In the proposed configuration implementation of ladder based allpass and biquad filter has been discussed. In the proposed configuration we convert the ladder based all pass and biquad filter using signal flow graph and implemented using CFOA based circuit. In this realisation we used grounded capacitors, CFOA, resistances by seeing the mathematical equations of signal flow graph. As the capacitors are grounded it is easy to implement in VLSI chip. The author already discussed the implementation of low pass, high pass, band pass and band reject ladder based filter and its conversion into CFOA based circuit. In this paper allpass and biquad configuration has been discussed and verified by Pspice simulation.

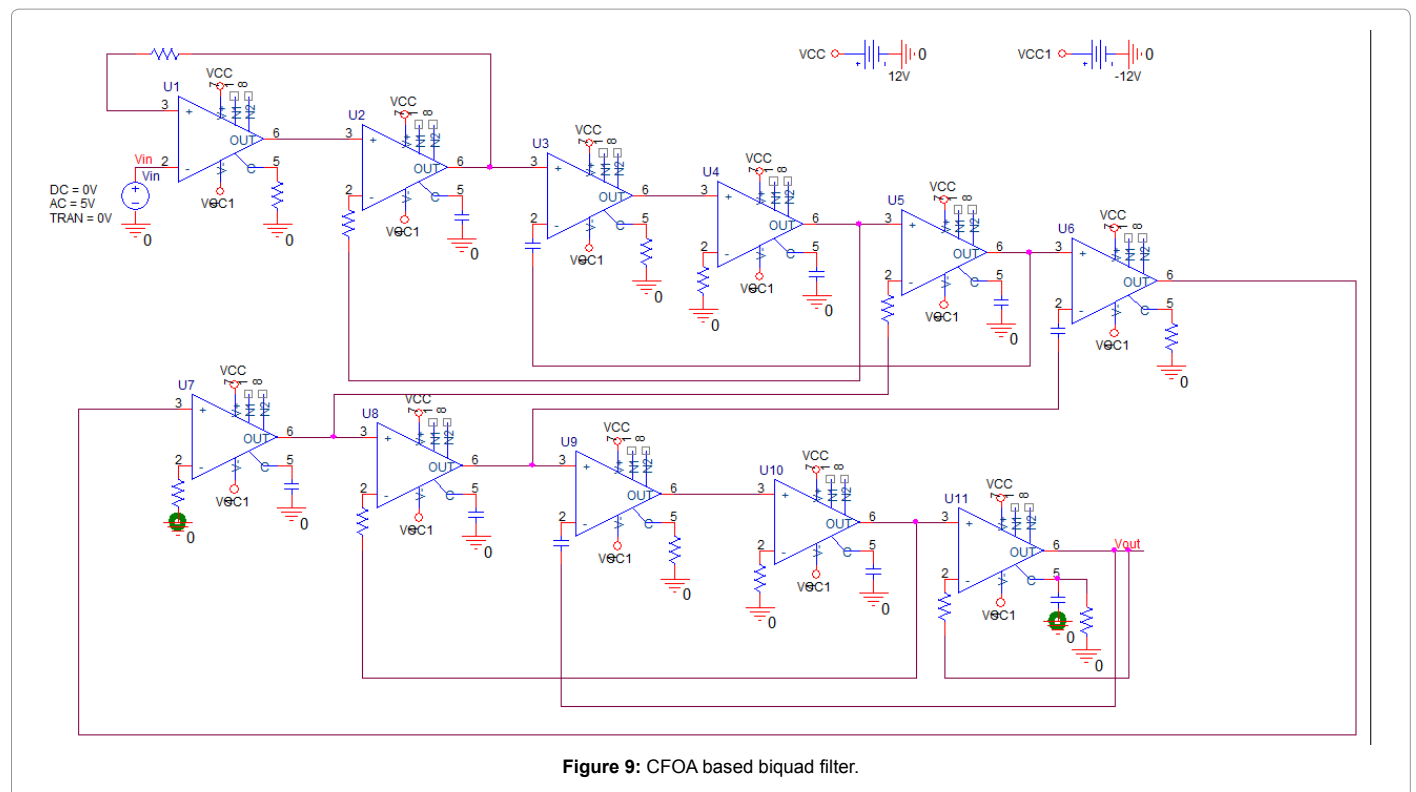


Figure 9: CFOA based biquad filter.

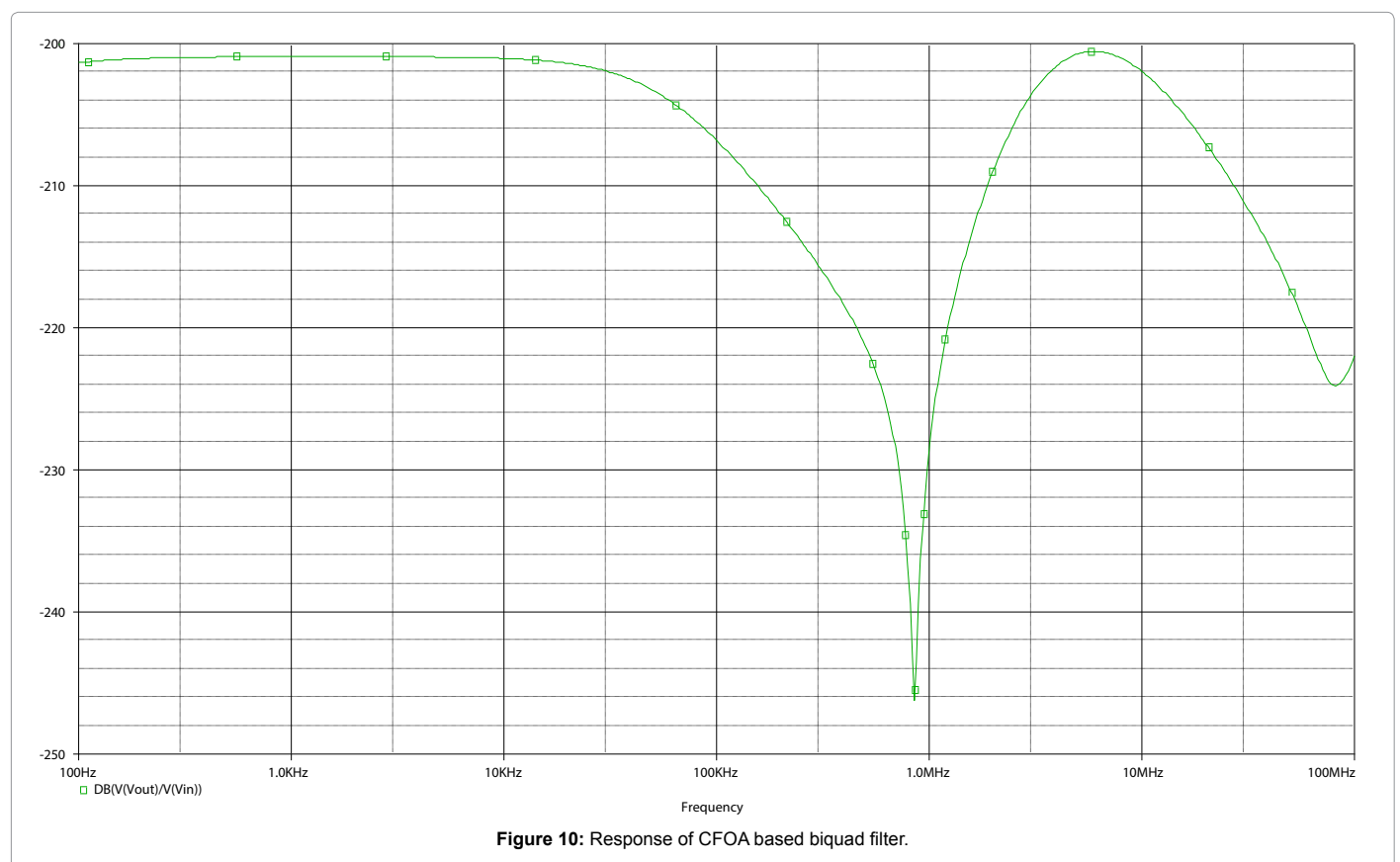
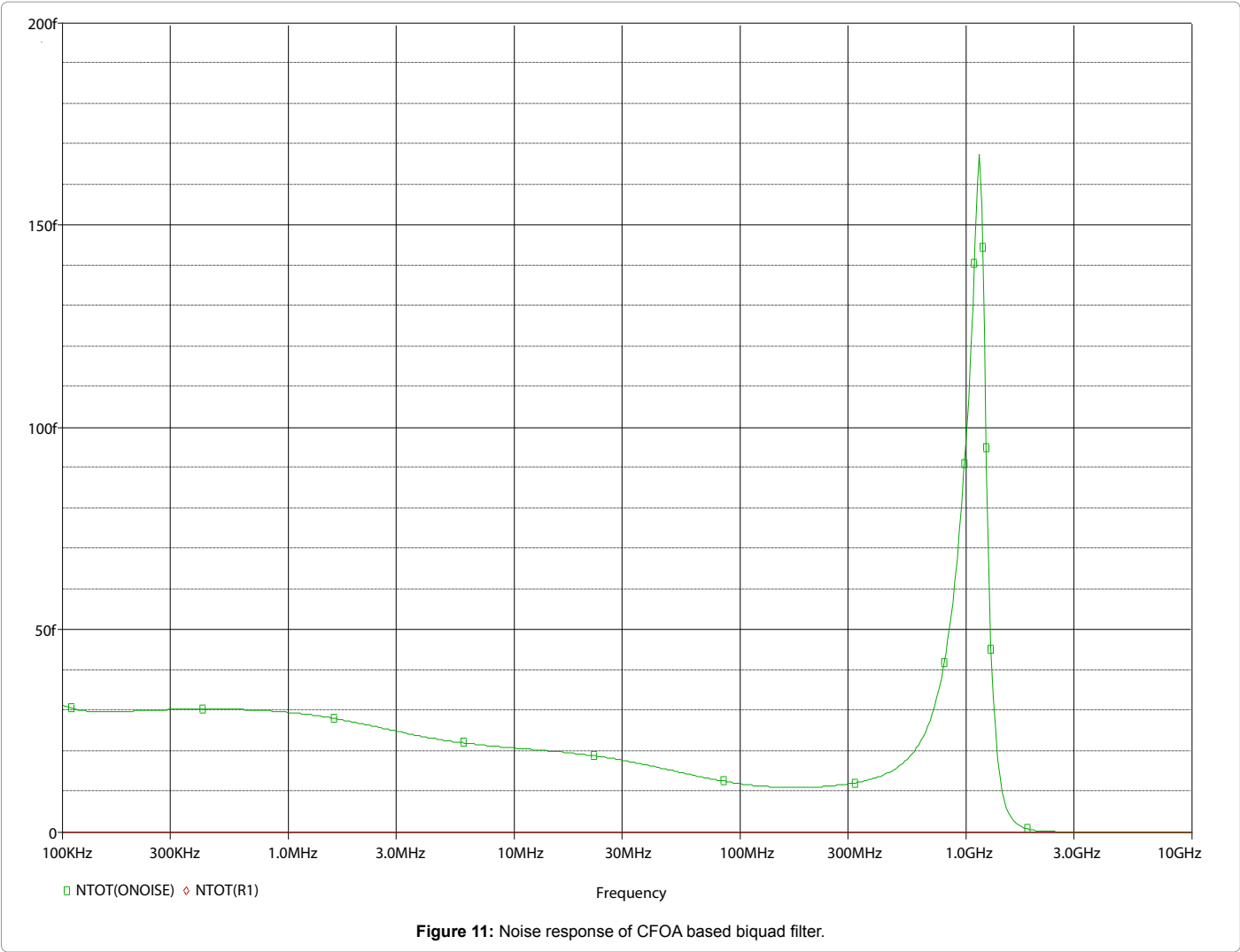


Figure 10: Response of CFOA based biquad filter.



Filter	Active Elements	External Resistors	External Capacitors	Frequency
All pass filter	8 CFOA	10 Grounded	6 Grounded	Phase varying from 0 degrees to -180 degrees
Biquad filter	11 CFOA	11 Grounded	10 Grounded	Low pass filter
				$f_i=213.911\text{KHz}$
				Notch filter
				$f_n=851.594\text{KHz}$
				Band pass filter
				$f_l'=1.997\text{MHz}$
				$f_h'=50.388\text{MHz}$

Table 1: Results of proposed realisation.

The summary of the components used the various frequencies and the bandwidth of Allpass and biquad filter used in our configuration has been illustrated in Table 1.

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