Indian Journal of Pure & Applied Physics
Vol. 59, September 2021, pp. 629-637

Electronically Tunable SIMO type Mixed-mode Biquadratic Filter using Single FTFNTA

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Received 10 February 2021; accepted 20 July 2021

In this manuscript, a new electronically tunable single input multiple output (SIMO) type a mixed-mode biquad filter is proposed. It is made up of a single Four Terminal Floating Nullor Transconductance Amplifier (FTFNTA) as an Active Building Block, one resistor, and two grounded capacitors. So, the presence of grounded capacitors renders the circuit compatible for IC development. As it is a SIMO type structure so no matched inputs are required. Also, the matching of passive components is not an issue with this design. For current as an input, the proposed design can generate current mode (low-pass, high-pass, and band-pass) filters as well as transimpedance mode (band-pass and inverting low-pass) filters. Similarly, when given a voltage as input, it can generate voltage mode (high-pass and inverting band-pass) filters as well as transadmitance mode (inverting band-pass and inverting high-pass) filters at the same time. The pole frequency (ω_0) and quality factor (Q_0) of designed filters can be tuned electronically through a grounded capacitor without disturbing the bandwidth (ω_0/Q_0). The effectiveness of the proposed design is checked through PSIPCE simulation. Monte Carlo, sensitivity, and noise analysis are also performed to ensure the robustness of the proposed design.

Keywords: Active filter, FTFNTA, Mixed-mode filter, PSPICE, SIMO, FTFN

1 Introduction

The FTFNTA is a conjuction of Four Terminal Floating Nullor (FTFN) and Operational Transconductance Amplifier (OTA). The FTFN can operate in both the current mode (CM) and voltage mode (VM) because the nullator and the norator are isolated (*i.e.* isolated voltage follower and current follower nodes) from each other. *i.e.* in VM the output signal is directly obtained from the low impedance terminal and a high impedance terminal provides current as an output signal. However, FTFN suffers from a lack of electronic tunning, which is achieved by using OTA in conjunction with it. So by combining the properties of FTFN and OTA, the FTFNTA becomes a versatile active building block. In literature different active building blocks (ABBs) are available which are used to develop various analog signal processing applications such as analog filters, oscillator, inductance simulator, *etc*. Here we are going to discuss analog filters.

Analog filters are a key element in various domains, like communication and control engineering, signal generators and processing units[1]. Analog filters are those electronic devices that allow certain frequencies to pass and block the other frequencies. Based on the availability of mode of operation filters are widely categorised as a standard mode or single-mode, dual-mode, and mixed-mode or multiple-mode (CM, VM, TAM, and TIM) filter.

A mixed-mode filter can be further categorised on the basis of the number of inputs applied and the number of output taken. These multifunction filters are classified as single input single output (SISO), multiple input multiple output (MIMO), multiple input single output (MISO), and single input multiple output (SIMO). The SISO and MISO type filters cannot generate all filter functions simultaneously, while MISO and MIMO type filters suffer from matching constraint of input signals. However, SIMO type filters have only one input signal so no matching condition required and it generates all filtering responses simultaneously. Whereas, MISO type filters produce a single filter function at a time in a particular mode. So, SIMO type configurations become an obvious choice for filter designing over other configurations.

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In a single input configuration, the input signal may be either current or voltage. So according to the applied input signal filter circuit is called a current mode (CM) for current input and voltage mode (VM) for voltage input. However, the current-mode configuration has been widely used for filter designing over the voltage-mode configuration due to its salient features like wide BW, large slew rate, better linearity, and dynamic range[2]. So it may be concluded that the current mode SIMO configuration is more suitable for filter designing due to its advantageous features.

Further, according to input and output signal combination, filters are classified as CM, VM, transadmittance mode (TAM) and transimpedance-mode (TIM) filter. In CM and VM structure, both input and output as current and voltage respectively, in TIM structure, current as input and voltage as output, and in TAM mode structure, voltage as input and current as output is used to obtain the filter transfer functions. As different nature of the signals available at the input and output of these filters, V-I and I-V converters are required to provide the interface while cascading the VM and CM structures. In such case, mixed-mode filters play an important role. It is also possible that this mixed-mode filter can process the signals in the meantime, during V-I interface, which increase the overall effectiveness of the circuit. Hence, it is worthy to explore the mixed-mode filters.

Thus, Irrespective of classification, applications, and advantages of various mixed-mode filters using different ABBs have been studied intensively in[3-41]. The structures presented in[3-11] is either single-mode or dual-mode and mixed-mode structures were proposed in[12-41]. A comparative study of mixed-mode filters shows that they suffered from one or more than one drawbacks, as mentioned below:

(i) Consist of floating capacitor[15,38-41]

(ii) Use of more passive components[12,13,15,17,18,20,24,26,31-33,37,38,40]

(iii) The presence of an excessive number of ABBs[12-15,17,18,21-26,28,31-37,41]

(iv) Not a universal filter in all the four modes[12-15,17,18,20-25,31,39]

(v) Multiple input configuration[12,14,17,23,28,31,32,37-41]

(vi) Lack of electronic tuning[12,13,15,17,18,20,24,26,37]

(vii) No orthogonal controllability of ω_0 and Q_0[13,15,17,22,25,28,34,38.40,41]

(viii) No independent tunability of the parameters ω_0 and bandwidth (ω_0/Q_0)[12,14,18,24,25,28,37]

(ix) No high Z_{in} for input voltage[12,13,15,17,20,21,26,34,41]

(x) No low Z_{in} and high Z_{out} for input current[12-15,17,20-26,41]

(xi) Matching constraint required[25,28,35,38,40,41]

(xii) High active and passive sensitivity[20,24]

Various ABBs are used to design the mixed-mode circuits such as conventional current conveyors (CCIIs)[12,17,29,30,32], current feedback operational amplifiers (CFOAs)[13], differential voltage current conveyors (DVCCs)[18], differential difference current conveyors (DDCCs)[16,24,26,37], fully differential current conveyors (FDCCIIs)[20,33], FTFNs[15], OTAs[14,19,22,23,27,41], current controlled current conveyors (CCCIIs)[21,28,31,34], Voltage Differencing Extra X Current Conveyor (VD-EXCCII)[38], Extra X Current Controlled Conveyor (EX-CCCII)[39], Extra X current conveyor transconductance amplifier (EXCCTA)[40], and current controlled current conveyor transconductance amplifiers (CCCCTAs)[25,35,36].

As can be seen, there are numerous issues related with the design of mixed mode filters. The most prevalent issue is the necessity for more active and passive components, which is bad for chip integration, as well as the need of floating capacitors, which increases chip space. Only references[28,38,39] use fewer components but reference[28] is designed using the grounded capacitor. Another critical issue is the requirement for matched passive components, which is extremely difficult to realize. There are some performance issues as well, such as a lack of electronic tuning and the interdependence of various performance parameters, such as frequency, bandwidth, and quality factor. Electronic tunning provides a lot of versatility to mixed mode filters in terms of the operation. Different filter parameters can be independently modulated through bias current without altering the value of passive elements. However one or more of these filter parameters is modulated simultaneously because they depend on the same passive elements. So if we modulate the operating frequency then the quality factor and bandwidth will also change. This is undesirable for a good filter design. Hence, the parameters of the filter are orthogonally and independently controllable. Also, the designed filters must have good cascadability. To achieve this input impedance of the filter must be high when a voltage signal is applied as an input. Similarly, for the current signal as an input, the filter has low input impedance and high output impedance. Filters with higher cascadability can be simply connected to another circuit without the use of voltage to current or current to voltage converters. So, the main purpose of this manuscript is to design a SIMO mixed mode filter that can overcome these challenges.

In this manuscript a new configuration is proposed to realize a mixed-mode filter with electronic tunability. The proposed structure made up of a single FTFNTA, one resistance, and two grounded capacitors. For an input current, the proposed structure simultaneously realizes CM low-pass (LP), band-pass (BP), and high-pass (HP) filter and TIM BP and inverting LP filter responses. Similarly, if the applied input signal is voltage the proposed structure can realize voltage mode HP and inverting BP filter along with TAM mode inverting BP and inverting HP filter functions. However, ω_0 and Q_0 can be tuned electronically through a grounded capacitor without disturbing the bandwidth (ω_0/Q_0) but ω_0 and Q_0 cannot be adjusted independently. All sensitivities are below the specified range. A comparative analysis of the proposed structure with existing mixed-mode filters is presented in Table 1.

2 FTFNTA Description

The FTFNTA is an ABB which combines the properties of FTFN and OTA[42]. The schematic of an FTFNTA is illustrated in Fig. 1 and its characteristic equation[43] is stated in Eq. (1).

$$\begin{bmatrix} I_X \\ I_Y \\ V_X \\ I_Z \\ I_{0+} \\ I_{0-} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ \alpha & 0 & 0 \\ 0 & -\beta & 0 \\ 0 & 0 & \gamma g_m \\ 0 & 0 & -\gamma g_m \end{bmatrix} \begin{bmatrix} V_Y \\ I_W \\ V_Z \end{bmatrix} \quad \text{... (1a)}$$

$$g_m = \left(I_B \mu_n C_{ox} \left(\frac{W}{L} \right) \right)^{1/2} \quad \text{... (1b)}$$

Where g_m is the transconductance, α, β, and γ are the voltage, current and transconductance transfer gain accuracies respectively. α, β, and γ are non-ideality parameters of FTFNTA. In ideal situation the value of α, β, and γ is one.

I_B is the bias current, μ_n is the mobility of the electron, C_{ox} is gate-oxide layer capacitance, W is channel width and L is the channel length.

The CMOS structure of FTFNTA is illustrated in Fig. 2. It comprises of high g_m FTFN and a dual

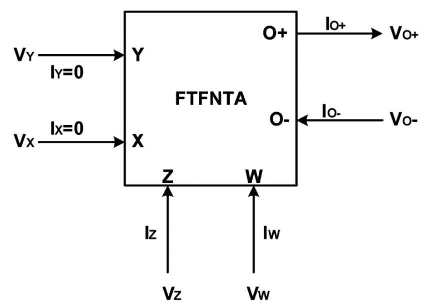

Fig. 1 — Circuit schematic of an FTFNTA

Table 1 — Comparison of the proposed structure with existing mixed-mode filters

Ref.	Number of ABBs	Number of Passive Elements	Electronically tunable	All five filter responses in all the four modes	component matching required	low Z_{in} and high Z_{out} for current input	high Z_{in} for voltage input	only grounded capacitors used	orthogonal control of ω_0 and Q_0	independent control of ω_0 and ω_0/Q_0	low sensitivity	configuration
[12]	7 CCIIs	2C+8R	No	No	No	No	No	Yes	Yes	Yes	Yes	MISO
[13]	4 CFOAs	2C+9R+1switch	No	No	No	No	No	Yes	No	Yes	Yes	SIMO/MISO
[14]	7 OTAs	2C	Yes	No	No	No	Yes	Yes	Yes	Yes	Yes	MISO
[15]	3 FTFNs	2C+3R	No	No	No	No	No	No	No	No	Yes	SIMO
[17]	3 CCIIs	3C+4R+2switch	No	No	No	No	No	Yes	No	Yes	Yes	SIMO/MISO
[18]	3 DVCCs	2C+3R	No	No	No	Yes	Yes	Yes	Yes	No	Yes	SIMO
[20]	1 FDCCII	2C+3R	No	No	No	No	No	Yes	Yes	No	No	SIMO
[21]	5MOCCCIIs	2C	Yes	Yes	No	No	No	Yes	Yes	No	Yes	SIMO
[22]	4 OTAs	2C	Yes	No	No	No	Yes	Yes	No	No	Yes	SIMO
[23]	5 OTAs	2C	Yes	No	No	No	Yes	Yes	Yes	No	Yes	MISO
[24]	3 DDCCs	2C+3R	No	No	No	No	No	No	Yes	No	No	SIMO
[25]	3 CCCCTAs	2C	Yes	Yes	No	No	Yes	Yes	No	No	Yes	SIMO
[26]	3 DDCCs	2C+4R	No	Yes	No	No	No	Yes	Yes	No	Yes	SIMO
[28]	4MOCCCIIs	2C	Yes	No	No	Yes	Yes	Yes	No	No	Yes	MISO
[33]	1 FDCCII, 1 DDCC	2C+6R	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	SIMO
[34]	4MOCCCIIs	2C	Yes	Yes	No	Yes	No	Yes	No	No	Yes	SIMO
[35]	3 CCCCTAs	2C	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	SIMO
[36]	3 CCCCTAs	2C	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	SIMO
[37]	3 DDCCs	2C+4R	No	No	No	No	No	Yes	No	Yes	Yes	MISO
[38]	1 VD-EXCCII	2C+3R	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	MISO
[39]	1 EXCCCII	2C+1R	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	MISO
[40]	2EXCCTAs	2C+4R+1switch	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	SIMO/MISO
[41]	5 OTAs	2C	Yes	Yes	Yes	No	Yes	No	No	Yes	Yes	MISO
Proposed	1 FTFNTA	2C+1R	Yes	No	No	Yes	Yes	Yes	No	Yes	Yes	SIMO

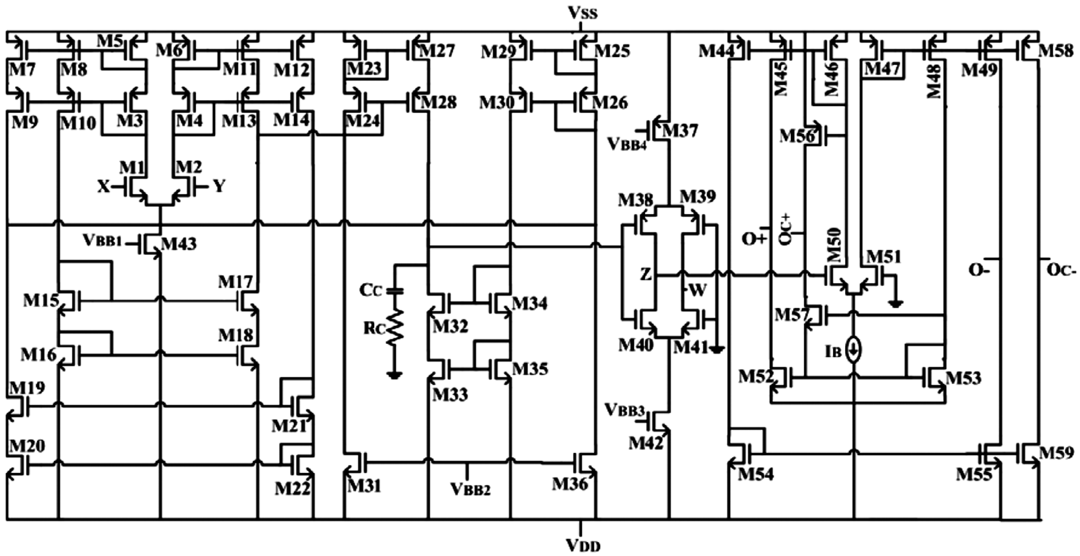

Fig. 2 — CMOS structure of FTFNTA

output OTA element. FTFN is an agile ABB because it features the VM and CM competencies. Transistors M1-M43 is used to realise the high g_m FTFN and transistor M44-M59 are used to design the dual output OTA. I_B is used to steer the transconductance of the circuit. M56-M57 and M58-M59 transistor pairs act as a copying circuit which copies the current of the terminal O+ and O- respectively. R_C and C_C are used for pole zero compensation. The compensation capacitor is connected to a high impedance node. The W/L ratio of different transistors and the specification of other biasing components are defined in Table 2.[11]

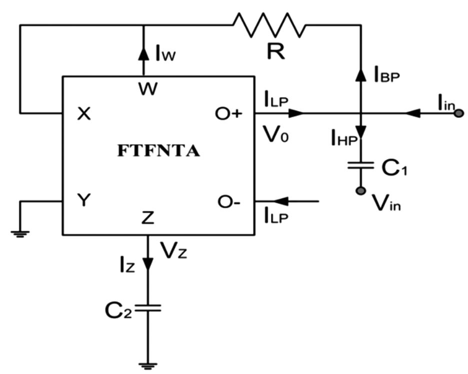

Fig. 3 — Mixed-mode Universal Filter Circuit

3 Proposed Structure

The proposed structure is demonstrated in Fig. 3. It is convenient for the IC process due to the presence of grounded capacitors. Also, it has low Z_{in} and high Z_{out} for the current signal; and high Z_{in} for the voltage signal. So no buffer circuit is required for cascading. It is a SIMO type topology. Depending on the input-output variable the proposed filter can produce various filtering responses in the different mode of operations. The transfer functions of the designed filter in all four modes are described below.

3.1. CM and TIM mode filters

When V_{in}=0 and an input signal current I_{in} is applied then CM and TIM filters will be designed.

In the current mode we get LP, HP, and BP responses as described below in Eqs. (2) to (4)

$$\left.\frac{I_{LP}}{I_{in}}\right|_{LPF} = \frac{g_m/C_1C_2R}{D(s)} \quad \text{... (2)}$$

Table 2 — Aspect ratios and design parameters of FTFNTA

CMOS Transistors	L (μm)	W (μm)
M1-M2	0.6	5
M3-M6	0.6	1.2
M7-M14, M42	0.6	50
M15-M22	0.6	212
M23-M26	0.7	4
M27-M30	0.7	20
M31, M36	0.7	3
M32-M35	0.7	7
M37	0.7	78
M38-M39	0.7	150
M40-M41	0.7	120
M43	0.6	18
M44, M47	0.18	1.44
M45-M46, M56	0.18	0.72
M48-M49, M52-M53, M57-M58	0.18	0.54
M50-M51	0.18	5
M54-M55, M59	0.18	1.44

V_{DD} = -V_{SS} = 1.65V, I_B = 600μA, V_{BB1} = V_{BB2} = -1V, V_{BB3} = 0.8V and V_{BB4} = 0.5V

$$\left.\frac{I_{HP}}{I_{in}}\right|_{HPF} = \frac{s^2(C_1/C_2)}{D(s)} \qquad \text{... (3)}$$

$$\left.\frac{I_{BP}}{I_{in}}\right|_{BPF} = \frac{s/C_2R}{D(s)} \qquad \text{... (4)}$$

In transimpedance-mode we get non-inverting BP and inverting LP responses as described below in Eqs. (5) and (6)

$$\left.\frac{V_Z}{I_{in}}\right|_{BPF} = \frac{s/C_1}{D(s)} \qquad \text{... (5)}$$

$$\left.\frac{V_0}{I_{in}}\right|_{Inverting\ LPF} = -\frac{1/C_1C_2R}{D(s)} \qquad \text{... (6)}$$

3.2. VM and TAM mode filter

When $I_{in} = 0$ and an input signal voltage V_{in} is applied then VM and TAM filters will be designed.

In voltage mode we get non-inverting HP and inverting BP responses as described below in Eqs. (7) and (8)

$$\left.\frac{V_0}{V_{in}}\right|_{HPF} = \frac{s^2}{D(s)} \qquad \text{... (7)}$$

$$\left.\frac{V_Z}{V_{in}}\right|_{inverting\ BPF} = -\frac{s/C_2R}{D(s)} \qquad \text{... (8)}$$

In transadmittance-mode we get inverting BP and inverting HP responses as described below in Eqs. (9) and (10)

$$\left.\frac{I_{LP}}{V_{in}}\right|_{inverting\ BPF} = -\frac{s\,g_m/C_2R}{D(s)} \qquad \text{... (9)}$$

$$\left.\frac{I_{BP}}{V_{in}}\right|_{inverting\ HPF} = -\frac{s^2/R}{D(s)} \qquad \text{... (10)}$$

Where, characteristic equation D(s) is described in Eq. (11)

$$D(s) = s^2 + \frac{s}{C_1R} + \frac{g_m}{C_1C_2R} \qquad \text{... (11)}$$

From Eq. (11), we can get pole frequency (ω_0), bandwidth (BW) and the Quality factor (Q_0) as specified in Eq. (12)

$$\omega_0 = \left(\frac{g_m}{C_1C_2R}\right)^{1/2};\ BW = \frac{\omega_0}{Q_0} = \frac{1}{C_1R}; \quad and \quad Q_0 = \left(\frac{g_mC_1R}{C_2}\right)^{1/2} \qquad \text{... (12)}$$

From Eq. (12) we can say that the proposed structure is electronically tunable by transconductance (g_m). It's also worth noting that the grounded capacitor (C_2) can adjust the Q_0 and BW separately, with no matching constraints. Moreover, different values of ω_0 can be adjusted as per requirement without disturbing the parameter BW.

4 Non-ideal and Sensitivities Analysis

Under the consideration of nonideality, the characteristic equation D(s) of designed filter, stated in Eq. (11), will modify as follows

$$D(s) = s^2 + \frac{s}{C_1R} + \frac{\beta\gamma\, g_m}{C_1C_2R}\ . \qquad \text{.. (13)}$$

Equation (13) clearly indicates that the designed filter response is independent of the nonideality parameter α.

The other characteristic parameters i.e. (ω_0), BW and (Q_0) will modify as follows

$$\omega_{0n} = \left(\frac{\gamma\beta g_m}{C_1C_2R}\right)^{1/2};\ (BW)_n = \frac{\omega_{0n}}{Q_{0n}} = \frac{1}{C_1R}; \quad and \quad Q_{0n} = \left(\frac{\gamma\beta g_mC_1R}{C_2}\right)1/2 \qquad \text{... (14)}$$

Where ω_{0n} is pole frequency, $(BW)_n$ is band width, and Q_{0n} is the quality factor under non-ideal condition. By comparing the Eq. (12) and Eq. (14) we can say that bandwidth of the filter is independent from the nonidealities.

The sensitivity analysis of filter parameters is investigated in both ideal and non-ideal conditions as follows:

For the ideal condition

$$S_{g_m}^{\omega_0} = -S_{C_1}^{\omega_0} = -S_{C_2}^{\omega_0} = -S_R^{\omega_0} = \frac{1}{2} \qquad \text{... (15)}$$

$$S_{g_m}^{Q_0} = S_{C_1}^{Q_0} = -S_{C_2}^{Q_0} = S_R^{Q_0} = \frac{1}{2} \qquad \text{... (16)}$$

For the non-ideal condition

$$S_{g_m}^{\omega_{0n}} = -S_{C_1}^{\omega_{0n}} = -S_{C_2}^{\omega_{0n}} = -S_R^{\omega_{0n}} = S_\gamma^{\omega_{0n}} = S_\beta^{\omega_{0n}} = \frac{1}{2};\quad S_\alpha^{\omega_{0n}} = 0 \qquad \text{... (17)}$$

$$S_{g_m}^{Q_{0n}} = S_{C_1}^{Q_{0n}} = -S_{C_2}^{Q_{0n}} = S_R^{Q_{0n}} = S_\gamma^{Q_{0n}} = S_\beta^{Q_{0n}} = \frac{1}{2};\quad S_\alpha^{Q_{0n}} = 0 \qquad \text{... (18)}$$

So it can be concluded that all the sensitivities are low and lie in the specified range, i.e. from -1 to 1.

5 Simulation Results

To examine the functionality of the proposed circuit, as depicted in Fig. 3, PSPICE simulations are performed with 180 nm technology. In Fig. 3, if we select the component values as: R = 2kΩ, $C_1 = C_2$ = 1nF, and transconductance (g_m) = 195.64μS at bias current (I_B) = 500 μA, then all filter responses leading to a centre frequency of f_0 = 157.28 kHz. The circuit has a power supply of $V_{DD} = -V_{SS}$ = 1.65V. Fig. 4 to Fig. 7 shows the frequency response of the proposed mixed-mode filters. All four modes of filtering responses have been verified with theoretical results. As the frequency of operation of all the simulated filters is approximately 158 kHz which is precisely matched with the calculated value 157.28 kHz. Fig. 4(a-c) presents the simulated current mode HP, BP and LP filter response respectively while Fig. 5(a-b) are showing the TIM mode BP and inverting LP filter responses respectively. Fig. 6(a-b) is inverting BP and HP filter responses respectively in voltage mode configuration. The TAM mode based inverting BP and inverting HP filter responses are illustrated in Fig. 7(a-b).

Monte Carlo analysis collects the statistical data according to the tolerance present in various passive

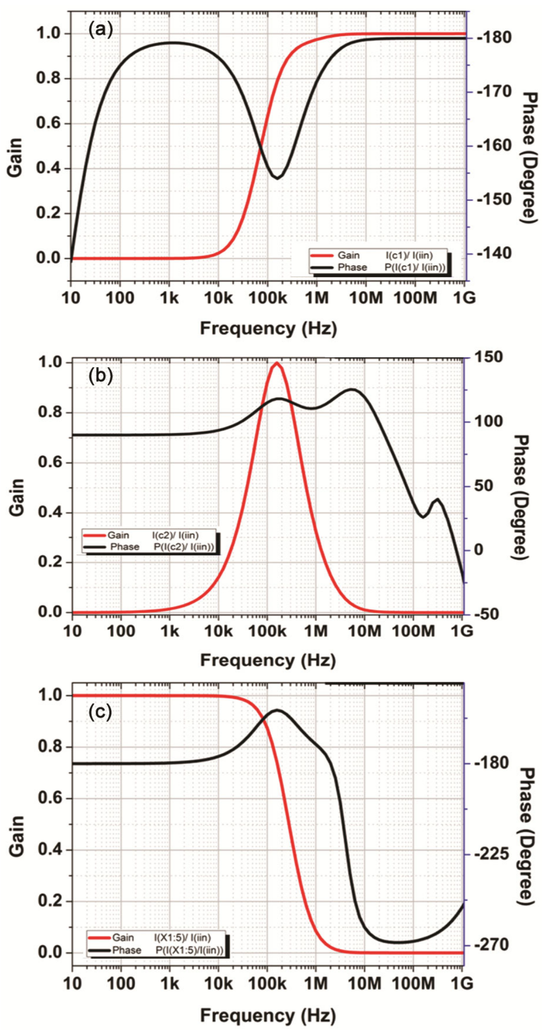

Fig. 4 — Frequency response of Current Mode (a) High Pass Filter (b) Band Pass Filter (c) Low Pass Filter

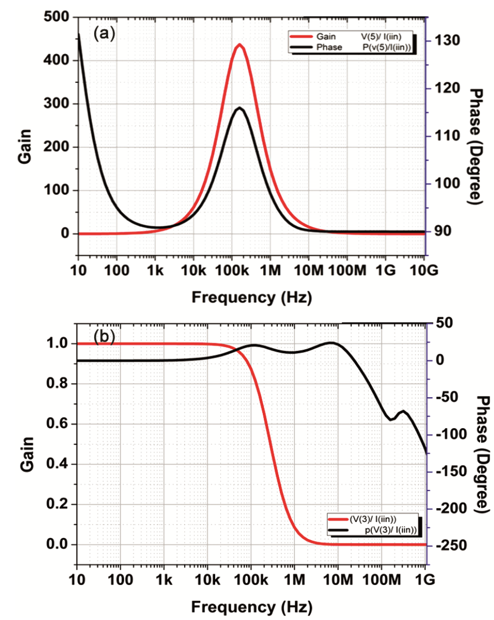

Fig. 5 — Frequency response of TIM (a) Band Pass Filter (b) Inverting-Low Pass Filter

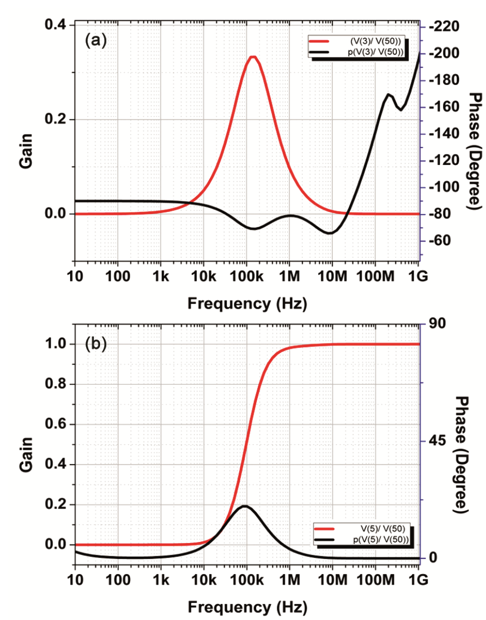

Fig. 6 — Frequency response of Voltage Mode (a) Inverting-Band Pass Filter (b) High Pass Filter

components. The tolerance arises due to the manufacturing defects i.e. the value of passive components deviates from its actual value. A Monte Carlo analysis is executed to investigate the robustness of the designed CM filter functions under a 10% Gaussian deviation on all passive component values i.e. capacitor (C_1, C_2) and resistor (R) for a sample set of 10 samples, as illustrated in Fig. 8(a–c).

Also, Monte Carlo (MC) analysis for the time-domain response of a BP filter is accomplished. This transient analysis is observed separately for 10% uniform distribution variations in capacitance and resistance for twenty runs each. For a sinusoidal input of amplitude 0.5 mA and 1.59 MHz frequency, the deviation in gain and ω_0 of CM-BPF for 10% tolerance in capacitance and resistance values are demonstrated in Fig. 9 and Fig. 10 respectively. By seeing these two figures, it can be concluded that tolerance of passive components does not severely impact on the circuit's productivity.

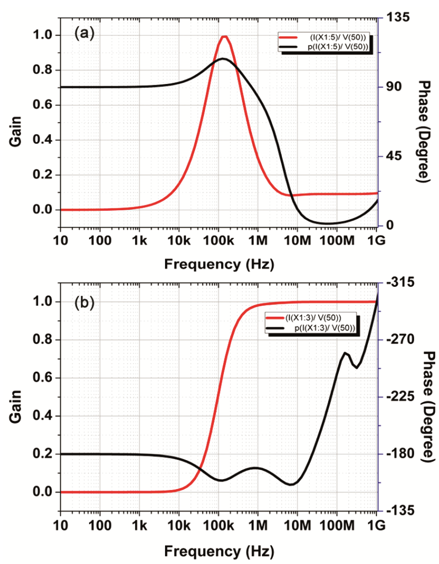

Fig. 7 — Frequency response of TAM (a) Band Pass Filter (b) High Pass Filter

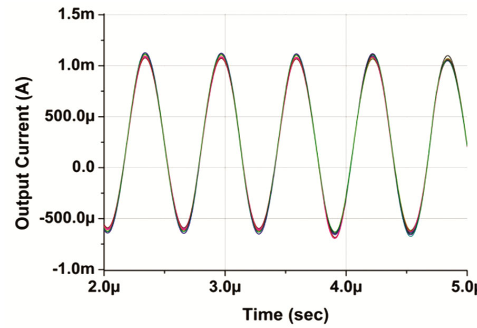

Fig. 9 — Transient response of BP output for 10% variation in capacitance (C_1 and C_2) with Monte-Carlo analysis

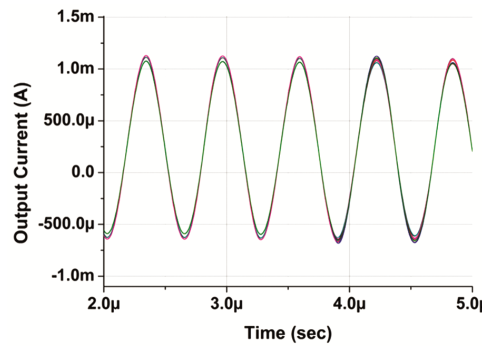

Fig. 10 — Transient response of Band Pass output for 10% variation in Resistance (R) with Monte-Carlo analysis

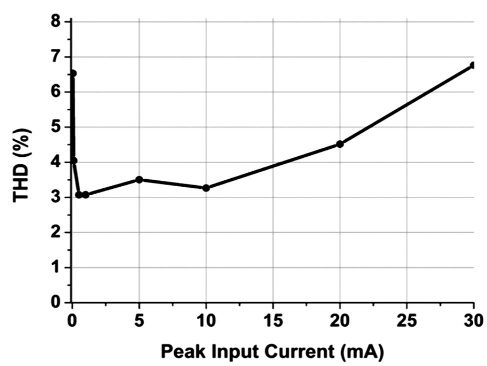

Fig. 11 — THD variations of CM-BPF with peak input sinusoidal signal at 157.24 KHz

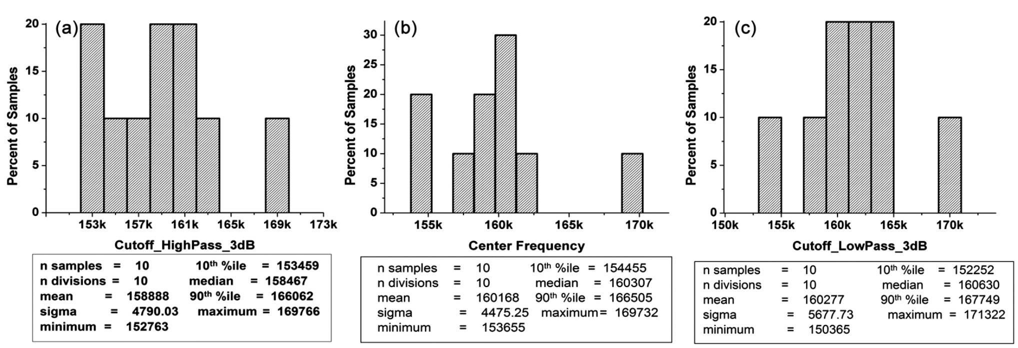

Fig. 8 — Histogram of Monte-Carlo analysis with a 10% deviation in resistance and capacitance value for current mode (a) HPF (b) BPF (c) LPF

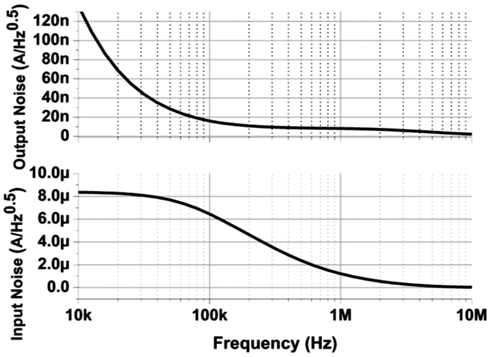

Fig. 12 — Input and related output noise versus frequency

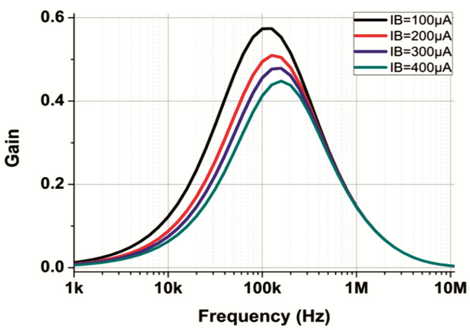

Fig. 13 — Variation in ω_0 of CM-BPF with frequency for different values of I_B

Further, some other important properties like the total harmonic distortion (THD) and input-output noise, for a CM-BP filter, is also evaluated. The change in THD with peak sinusoidal input current of 157.28 kHz frequency is illustrated in Fig. 11 where a load resistor of 1 kΩ is connected. The minimum value of THD is 3.073%. The dynamic range of CM-BPF lies between 0.1 mA to 16 mA (peak amplitude) without significant noise disturbance and non-linear distortion (for less than 4% THD value). Also, the input and related output noise for the designed LP filter is illustrated in Fig. 12.

To observe the electronic tunability of the proposed circuit, PSPICE simulations have been performed for different values of I_B of the FTFNTA. The frequency response of CM-BPF, for I_B =100 µA, 200 µA, 300 µA, and 400 µA is demonstrated in Fig. 13. It is revealed that the ω_0 can be tuned electronically by modulating the magnitude of I_B i.e. by altering the g_m of the FTFNTA. However, the value of the quality factor will also change with the transconductance.

The transient analysis of the CM-BP filter for the sinusoidal input current of 2 mA peak-to-peak and 1.59 MHz frequency, leads to a 1.59 MHz sinusoidal output current with a phase shift of 90° and DC component 0.217 mA, as shown in Fig. 14.

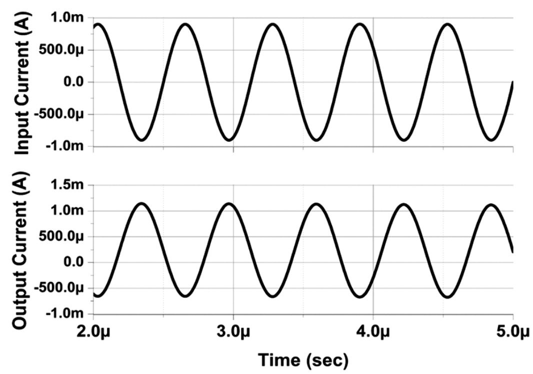

Fig. 14 — Transient analysis of CM-BPF for 1.59 MHz sinusoidal input current with 2 mA peak-to-peak amplitude

6 Conclusions

By observing the detailed explanation of the proposed SIMO mixed-mode filter, designed using single FTFNTA and thee passive components, we can conclude that the proposed circuit produce all generic filter function in CM and generate some filters in other modes. These designed filters have electronic tunability along with independent control of ω_0 and Q_0 with respect to bandwidth. the circuit is feasible for IC realization because of the presence of grounded capacitors. Monte Carlo analysis shows that the effect of tolerance of passive components is low. It is also acknowledged that the value of noise, sensitivity, and THD level is sufficiently low. This work may be further extended to realize all the filter responses in all the four modes and to provide the orthogonal control between ω_0 and Q_0.

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