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Novel Current-Mode Universal Filter using single FTFNTA

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In this paper, a novel universal filter using single Four Terminal Floating Nullor Transconductance Amplifier (FTFNTA), two capacitors and one/two resistor has been proposed. Sensitivity of pole frequency (ω_0) and quality factor (Q_0) is analysed. Workability of proposed filter has been demonstrated by PSPICE simulations in 0.18μm TSMC CMOS technology.

Keywords: FTFNTA, Biquad Universal Filter, Current Mode, FTFN.

1 Introduction

Filters are the essential modules for signal processing applications *i.e.* speech processing, data acquisition, mobile switching centres (MSCs), phase shifting[1-2], etc. Behaviourally, analog filters are grouped by their mode of operation such as current-mode (CM) or voltage-mode (VM) filter. They are also classified according to their input (i/p) output (o/p) combination such as single i/p multiple o/p (SIMO) and multiple i/p single o/p (MISO) filter. However, the CM filters are more popular than VM filters[3] due to its advantage over VM. Therefore, various CM active filters have been proposed and studied in the literature.

In this manuscript, an advance variant of Four Terminal Floating Nullor (FTFN) *i.e.* Four Terminal Floating Nullor Transconductance Amplifier (FTFNTA) is used as an active building block. FTFN is a protean active building block because it incorporates the VM and CM capabilities. There are various FTFN based filters were developed in[5-13]. These structures are able to design all filter functions for different input-output combinations. Previously reported filters based on FTFN are suffering from various limitations such the use of floating components, the requirement of an auxiliary circuit, need of too many active and /or passive components and pole frequency (ω_0) and quality factor (Q_0) dependency.

In this manuscript, a MISO CM universal filter using a single FTFNTA is proposed. For different input combinations, different filters will be realized *i.e.* low-pass (LPF), band-pass (BPF) and high-pass (HPF) filter, one at a time. The operation of the proposed design is validated by PSPICE simulation using 0.18 μm technology.

2 Basic Concept of the FTFNTA

The FTFNTA, a recently introduced CM active block, is a combination of FTFN at i/p stage accompanied with OTA at o/p stage[4]. The CMOS realization of the FTFNTA is shown in Fig. 1. The value of the supply and bias voltage is V_{DD} = 1.65V, V_{SS} = -1.65V, $V_{BB1} = V_{BB2}$ = -1V, V_{BB3} = -0.8V and V_{BB4} = 0.5V. The value of bias current I_B is chosen as 600μA. The aspect ratios of the transistors PMOS and NMOS of the FTFNTA are listed in Table 1. The circuit schematic of an FTFNTA is shown in Fig. 2.

It is a six-port device. Amongst the available ports, the X and Y are I/P ports and Z, W, O+ and O- are the O/P ports. Port W evinces low impedance while all other port has high impedance. Both X and Y ports are buffered, i.e. no current will flow through these ports. The output current I_{O+} and I_{O-} has a transconductance gain incorporated with it. The characteristic equation of FTFNTA is stated in Eq. (1).

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

$$g_m = \sqrt{I_B \mu_n C_{ox} \left(\frac{W}{L}\right)} \quad \ldots(2)$$

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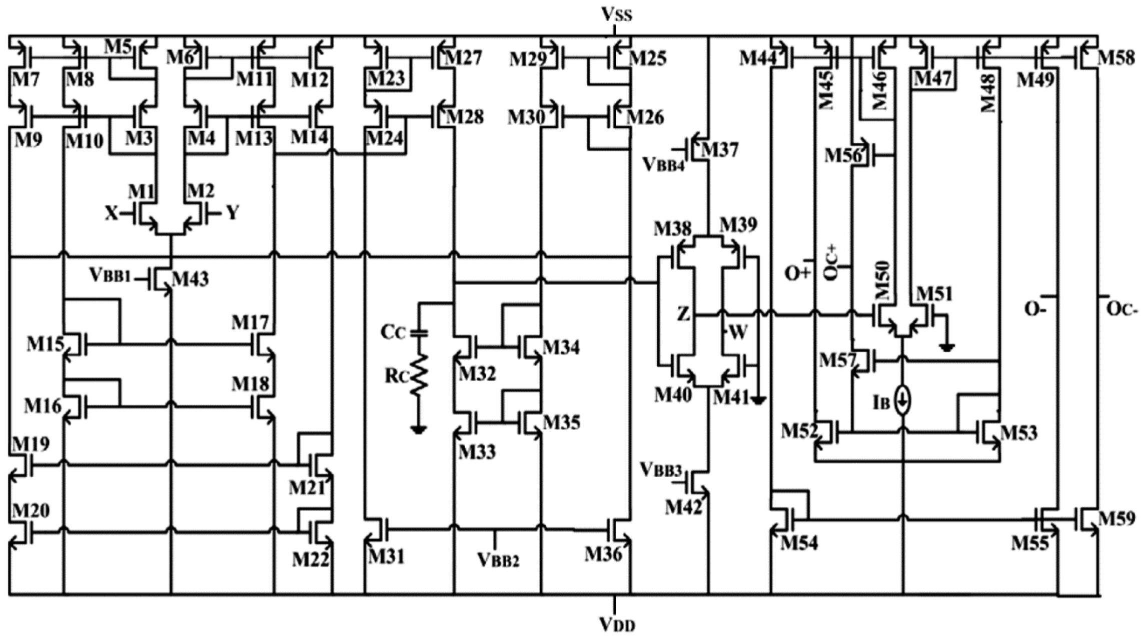

Fig. 1 — CMOS Realization of the FTFNTA, as presented in[4]

Table 1 — Aspect ratios of the transistors of the FTFNTA[4]

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

Where,

I_B -Bias current

μ_n - Mobility of free charge carrier present in the channel

C_{ox} - Gate-oxide layer capacitance

W - Channel width

L - Channel length.

α is the voltage transfer gain, β is the current transfer gain and γ is the transconductance transfer accuracy. Ideally, the value of α, β and γ is unity.

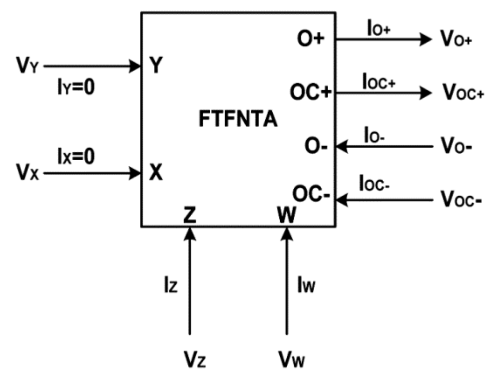

Fig. 2 — Circuit Schematic of a FTFNTA

These α, β and γ are accountable for the non-ideality of FTFNTA.

3 Proposed Circuit Descriptions and Analysis

Proposed MISO Biquad Filter consists of only one FTFNTA as an active element. The general circuit of TISO is shown in Fig. 3.

Typical nodal analysis of the structure in Fig. 3 relent the general transfer function as given below in Eq. (3). Here I_1, I_2, and I_3 are the current i/p signals and I_{out} is the current o/p signal. Y_1-Y_6 are admittance parameters, either resistance or capacitor.

From Eq. (3), it is clear that the most suitable of i/p signals and admittance parameters Y_1-Y_6, different filtering functions can be perceive across o/p terminal (O_{C+}) as depicted in Table 2.

$$I_{out} = \frac{g_m(Y_1+Y_2)(Y_5+Y_6)I_1 - Ag_mY_5I_2 + g_mY_5(Y_1+Y_2)I_3}{g_m(Y_1+Y_2)(Y_5+Y_6) + Y_5(Y_1+Y_2)(Y_3+Y_2) + AY_5(g_m+Y_2)} \quad \ldots(3)$$

Where "A" is constant given as:

$$A = \frac{(Y_4+Y_5)(Y_5+Y_6)-Y_5(Y_5+Y_2)}{Y_5} \quad ..(4)$$

3.1 Low pass filter

After applying the conditions mentioned in Table 2 the modified structure of LPF is shown in Fig. 4 and its transfer function is given by

$$\frac{I_{out}}{I_{LP}} = \frac{I_{out}}{I_3} = \frac{Y_1Y_5}{Y_4Y_6+Y_4Y_5+Y_5Y_6+Y_1Y_6+Y_1Y_5} \quad \ldots(5)$$

For $Y_1=1/R_1$, $Y_5=1/R_5$, $Y_4=sC_4$, $Y_6=sC_6$

$$\frac{I_{out}}{I_{LP}} = \frac{I_{out}}{I_3} = \frac{{}^{1}/_{R_1R_5C_4C_6}}{s^2+s\left(\frac{1}{C_6R_5}+\frac{1}{C_4R_5}+\frac{1}{C_6R_1}\right)+\frac{1}{R_1R_5C_4C_6}} \quad \ldots(6)$$

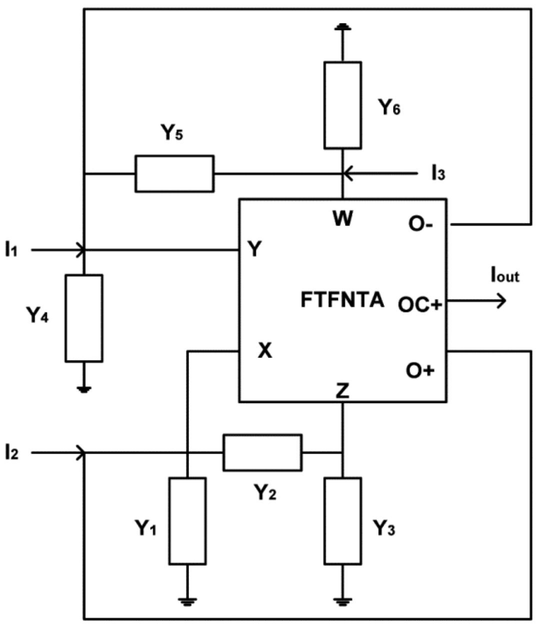

Fig. 3 — Proposed MISO Biquad filter

If $R_1 = R_5 = R$ and $C_4 = C_6 = C$ then

$$\frac{I_{out}}{I_{LP}} = \frac{I_{out}}{I_3} = \frac{{}^{1}/_{R^2C^2}}{s^2+3s\frac{1}{RC}+\frac{1}{R^2C^2}} \quad \ldots(7)$$

3.2 High pass filter

After applying the conditions mentioned in Table 2, the modified structure for designing of HPF is shown in Fig. 5 and its transfer function is given by

$$\frac{I_{out}}{I_{HP}} = \frac{I_{out}}{I_2} = \frac{g_mY_5(Y_2-Y_6)}{Y_2Y_6Y_5+g_mY_6(Y_2+Y_5)} \quad \ldots(8)$$

For $Y_6=1/R_2$, $Y_5=sC_5$, $Y_2=sC_2+1/R_2$

$$\frac{I_{out}}{I_{HP}} = \frac{I_{out}}{I_2} = \frac{g_mR_2s^2}{s^2+s\left(\frac{1}{C_2R_2}+\frac{g_m}{C_5}+\frac{g_m}{C_2}\right)+\frac{g_m}{R_2C_2C_5}} \quad \ldots(9)$$

If $R_2 = R$ and $C_2 = C_5 = C$ then

$$\frac{I_{out}}{I_{HP}} = \frac{I_{out}}{I_2} = \frac{g_mRs^2}{s^2+s(\frac{1}{RC}+\frac{2g_m}{C})+\frac{g_m}{RC^2}} \quad \ldots(10)$$

3.3 Band pass filter

After applying the conditions mentioned in Table 2 the modified structure for designing of BPF is shown in Fig. 6 and its transfer function is given by

$$\frac{I_{out}}{I_{BP}} = \frac{I_{out}}{I_1} = \frac{g_mY_2}{Y_2Y_3+g_mY_4+Y_2Y_4} \quad \ldots(11)$$

For $Y_4=1/R_4$, $Y_2=sC_2$, $Y_3=sC_3$

$$\frac{I_{out}}{I_{BP}} = \frac{I_{out}}{I_1} = \frac{sg_m/C_3}{s^2+s\frac{1}{C_3R_4}+\frac{g_m}{R_4C_2C_3}} \quad \ldots(12)$$

If $R_4 = R$ and $C_2 = C_3 = C$ then

$$\frac{I_{out}}{I_{BP}} = \frac{I_{out}}{I_1} = \frac{sg_m/C}{s^2+s\frac{1}{RC}+\frac{g_m}{RC^2}} \quad \ldots(13)$$

It is observed from Eq. (7), (10) and (13) that LP, BP, and HP filters are designed from the proposed structure. Further, the parameters like ω_0,

Table 2 — Functionality of the proposed filter

S. No	Parameter	Input Current	Type of the filter	Transfer Function	ω_0	Q_0	BW
1.	$Y_2=Y_3=0$ $Y_1=1/R_1$, $Y_5=1/R_5$ $Y_4=sC_4$, $Y_6=sC_6$	$I_1=0$ $I_2=0$ $I_3=I_{LP}$	LPF	I_{out}/I_{LP}	$\sqrt{\frac{1}{R_1R_5C_4C_6}}$	$\frac{\sqrt{R_1R_5C_4C_6}}{C_4R_1+C_6R_1+C_4R_5}$	$\frac{1}{C_6R_5}+\frac{1}{C_4R_5}+\frac{1}{C_6R_1}$
2.	$Y_1=Y_3=Y_4=0$ $Y_6=1/R_2$, $Y_5=sC_5$ $Y_2=sC_2+1/R_2$	$I_1=0$ $I_2=I_{HP}$ $I_3=0$	HPF	I_{out}/I_{HP}	$\sqrt{\frac{g_m}{R_2C_2C_5}}$	$\frac{\sqrt{g_mR_2C_2C_5}}{C_5+g_mR_2C_2+g_mR_2C_5}$	$\frac{1}{C_2R_2}+\frac{g_m}{C_5}+\frac{g_m}{C_2}$
3.	$Y_1=Y_6=0$, $R_5=0$ $Y_4=1/R_4$, $Y_2=sC_2$ $Y_3=sC_3$	$I_1=I_{BP}$ $I_2=0$ $I_3=0$	BPF	I_{out}/I_{BP}	$\sqrt{\frac{g_m}{R_4C_2C_3}}$	$\sqrt{\frac{g_mR_4C_3}{C_2}}$	$\frac{1}{C_3R_4}$

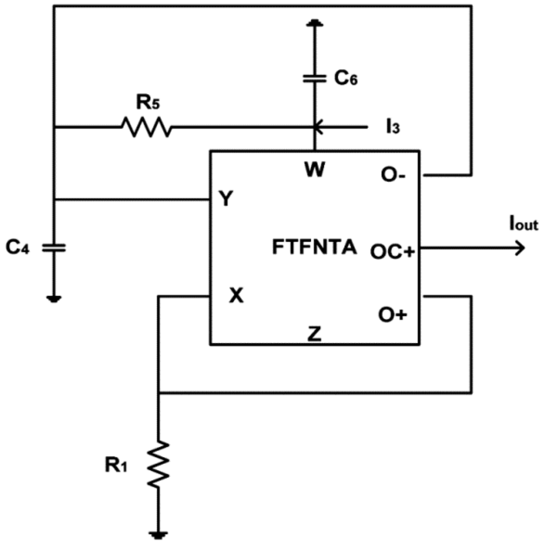

Fig. 4 — Proposed LPF configuration

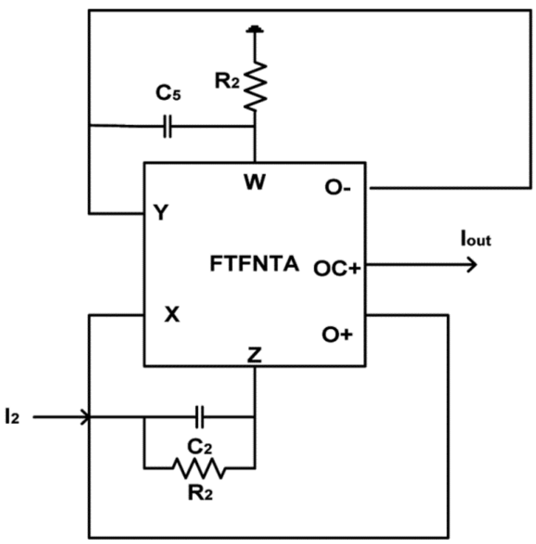

Fig. 5 — Proposed HPF configuration

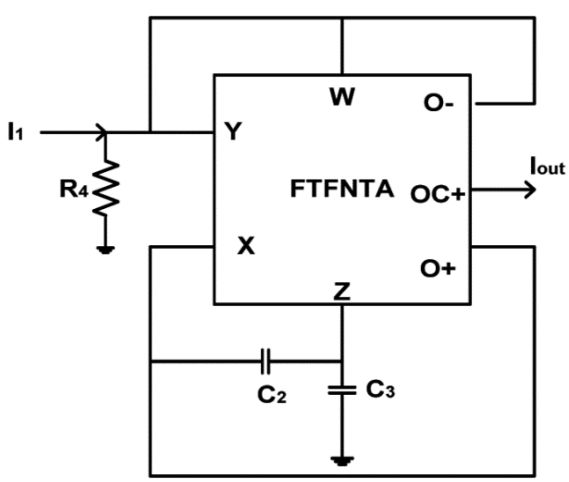

Fig. 6 — Proposed BPF configuration

Q_0 and BW of the filter is calculated and mentioned in Table 2.

4 Sensitivities Analysis

Variation of the filter variables, ω_0 and Q_0 are calculated w.r.to the variation of the active and passive components. So the sensitivity of the proposed filter is derived as follow:

For LPF

$$0 < S^{Q_0}_{R_1 R_5 C_4 C_6} < \frac{1}{2}$$

$$S^{\omega_0}_{R_1 R_5 C_4 C_6} = -\frac{1}{2} \qquad \ldots(14)$$

For HPF

$$0 < S^{Q_0}_{g_m R_2 C_2 C_5} < \frac{1}{2}$$

$$S^{\omega_0}_{g_m R_2 C_2 C_5} = -\frac{1}{2}$$

$$S^{\omega_0}_{g_m} = \frac{1}{2} \qquad \ldots(15)$$

For BPF

$$S^{Q_0}_{g_m R_4 C_3} = \frac{1}{2};$$

$$S^{Q_0}_{C_2} = -\frac{1}{2}\; S^{\omega_0}_{R_4 C_2 C_3} = -\frac{1}{2}$$

$$S^{\omega_0}_{g_m} = \frac{1}{2} \qquad \ldots(16)$$

It is clear from Eqs. (14) - (16) that all the values are lying in the specified range from -1 to 1.

5 Simulation Results

To verify the response of the proposed universal filter PSPICE simulation is performed using CMOS 0.18 μm technology. The simulated frequency response of the designed LPF, HPF, and BPF is demonstrated in Figs 7-9 respectively and it is observed that the

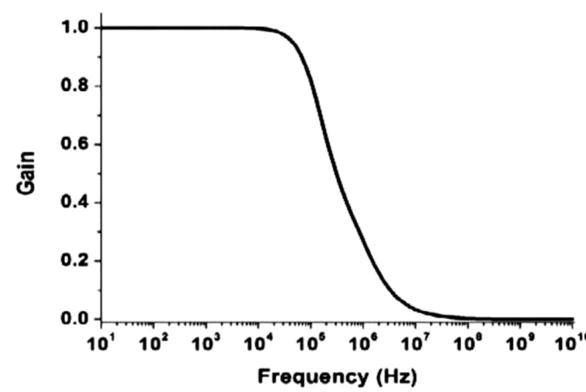

Fig. 7 — Frequency response of LPF

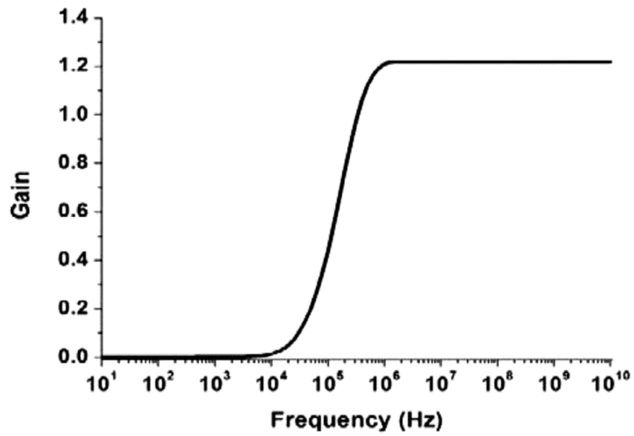

Fig. 8 — Frequency response of HPF

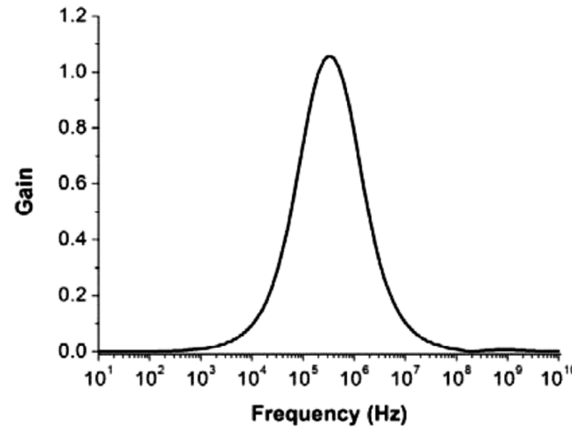

Fig. 9 — Frequency response of BPF

Table 3 — Comparisons of the proposed oscillator with previous reports in references[5-13]

Ref.	Configuration type	Number and type of active element	Number of passive element	Filter type
5	SIMO	1 FTFN	5 (2C+3R)	LP, HP
			5 (3C+2R)	BP
			6 (3C+3R)	BR, AP
6	MISO	1 FTFN+1CFA	5 (2C+3R)	LP, HP, BP,BR,AP
7	MISO	2 FTFN	4(2C+2R)	LP, HP, BP,BR,AP (Current mode)
		2 FTFN	5 (2C+3R)	LP, HP, BP,BR,AP (Voltage mode)
8	SISO	1 FTFN	7 (3C+2R)	LP, HP, BP,BR,AP
9	SISO	1 FTFN	3 (1C+2R)	1ST Order AP
10	MISO	1 FTFN	4(2C+2R)	LP, HP
11	SIMO	3 FTFN	5 (2C+3R)	LP, HP, BP
12	SIMO	3 FTFN	5 (2C+3R)	LP, HP, BP(Current, Voltage and Transimpedance mode)
				HP,BP (Transadmittance mode)
13	SISO	2 FTFN OR 1 FTFN+1 CCII	5 (3C+2R)	BP+HP
			5 (2C+3R)	BP+LP
Proposed	MISO	1FTFN	4 (2C+2R)	LP
			3 (2C+1R)	HP, BP

value of f_0 is 147 kHz for BPF and HPF and 163 kHz for LPF which is approximately equal to the calculated value 139.27kHz for BPF and HPF; and 159.15 kHz for LPF, for g_m=697 μS, R=1kΩ and C=1nF.

A comparison of the proposed work with existing filters using FTFN is given in Table 3. From the comparison table it is evident that very few filters were designed using single FTFN ABB but requires more passive components.

6 Conclusions

A current mode universal biquad filter is designed using single FTFNTA. Sensitivity analysis is also performed for the proposed structure. A wide comparison is also done with the other FTFN based filters. This work can further be explored for designing of band reject filter and all-pass filter.

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