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REALIZATION OF OTA-C UNIVERSAL FILTER BASED ON Q- FACTOR

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Abstract— **A second order OTA-C filter based on OTA integrator and register is selected as a suitable structure in the design of universal filter by selecting proper inputs V_A, V_B and V_c. This selection reflects the Q factor sensitization in obtaining -3dB frequency in low-pass, high-pass, band-pass and band-reject filter structures. The variation in the values of C_1 and C_2 and their contribution in the values of Q factors is studied. The studied structure is superior to the other types of filters at radio and microwave frequencies in communication system.**

Keywords:- OTA-C Operational Transconductance Amplifier-Capacitor, I_{b1} Bias current of OTA1 , I_{b2}- Bias current of OTA2, BW- Band width

I. Introduction

OTAs are considered as one of the promising devices to replace OPAMPs for high-frequency applications. OTAs operate up to several hundred MHz. Filters designed using OTAs and capacitors are called OTA-C filters. OTA-C filters were the most popular applications in the past, at low frequencies. The inherent properties of OTA-C filters were flexible frequency and Q-tuning, which made them superior than passive filters.

The advantages and applications in the realization of various active filter transfer functions which have second-order are of great interests, because several counterparts of this type can be directly connected in cascade to realize higher order filters. Compared with voltage -mode (VM) filters, current-mode (CM) filters have high performance properties, such as wider signal bandwidths, larger dynamic range, greater linearity, simpler circuitry, low power consumption and occupancy of lesser chip area. Operational transconductance amplifier (OTA) is an striking device that represents the ratio of output current to that of input voltage. Transconductance of OTA can be altered by a supplied bias current. OTA has high input and output impedances.

The designs of OTA-C filters circuit need no resistors. Therefore, they are suitable for monolithic integration than the current conveyors. Moreover an OTA provides an electronically highly linear and wide tunable range of the transconductance gain. Therefore, the filters based on OTAs play a significant role in research.

To design a universal filter employing OTA, four characteristics will be taken into consideration: chip area, versatile, tunable and flexible. Universal filters usually suffer from one or more of following drawbacks:

i) The second -order filter can't expand to high-order filter.
ii) Wide variation of Q factor can't be possible
iii) Passive resistances are used in circuits which will need larger chip area for integration
iv)The basic four transfer functions of filter can't be realize from a same configuration.

In this paper, a tunable versatile and flexible OTA-C filter can easily realize all four transfer functions and expand to high-order filter without resistances. Moreover, the parameter Q can be electronically tuned through adjusting the transconductance gains of the OTAs. The quality factor is adjustable via the transconductance of two OTAs.
The circuit symbol of OTA is shown in Figure 1.

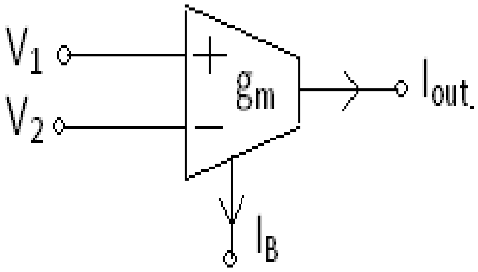

Fig 1. Circuit symbol of OTA

$$I_o = \mathbf{g_m} (V1^+ - V2^-)$$

Where $V1^+ - V2^-$ is a differential input voltage and Io is a OTA output current and g_m is the transconductance gain of OTA determined by the relation,

$$\mathbf{g_m} = I_b / 2V_T$$

I_b is the bias current of OTA and V_T is the volt equivalent temperature equal to 26mV at room temperature.OTA provides linear variation of transconductances gain g_m fairly over wide range due to dependence of g_m on bias current I_b of OTA. Circuit parameters such as Q- factor, cut off frequency, of filter of OTA-C can be electronically tuned. [1]-[7].

II. Circuit description and analysis

Basic OTA based structures use capacitors, which are attractive for integration. Component count of these structures is often very low. An OTA integrator is a OTA-C

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filter, which can be regarded as a first order low pass filter, as shown in Fig. 2. It consists of only an OTA and a capacitor. The transfer function for this integrator can be defined as,

$$\frac{V_o}{V1 - V2} = \frac{g_m}{sC}$$

This is an integration function in the Laplace domain and has a low pass property

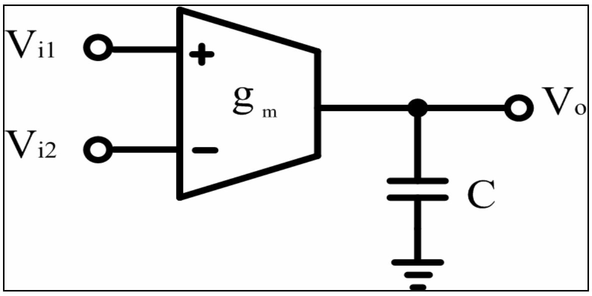

Figure 2. OTA integrator

“Fig 3” shows the structure of second-order OTA-C filters based on the OTA integrators and resistors. This filter structure contains a global negative feedback. The low-pass, high-pass, band pass and band-stop functions can be flexibly realized using this structure, by selecting the proper input from V_A, V_B, and V_C.

A second order low pass function can be obtained by choosing V_A as the input and grounding V_B and V_C. Transfer function of low pass filter is given by,

$$H(s)_{lowpass} = \frac{g_{m1}g_{m2}}{s^2C_1C_2 + sC_1g_{m2} + g_{m1}g_{m2}},$$

Input configurations of OTA-C high pass filter can be obtained by V_C as the input and grounding V_B and V_A. Transfer function of high pass filter is given by,

$$H(s)_{highpass} = \frac{s^2C_1C_2}{s^2C_1C_2 + sC_1g_{m2} + g_{m1}g_{m2}},$$

Similarly input configurations and Transfer functions for band pass and band reject filters are given as follows,

$$H(s)_{bandpass} = \frac{sC_1g_{m2}}{s^2C_1C_2 + sC_1g_{m2} + g_{m1}g_{m2}},$$

$$H(s)_{bandstop} = \frac{s^2C_1C_2 + g_{m1}g_{m2}}{s^2C_1C_2 + sC_1g_{m2} + g_{m1}g_{m2}}.$$

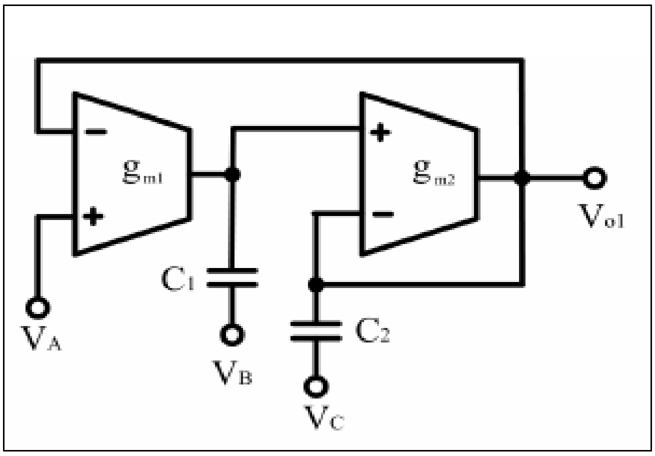

Figure. 3 Second-order OTA-C universal filter structure.

The quality factor Q is given by the following expression which depends on g_{m1} and g_{m2} that is by tuning the transconductance of two OTAs

$$Q = \sqrt{\frac{C_2g_{m1}}{C_1g_{m2}}},$$

If $g_{m1} = g_{m2}$ then quality factor is given by the relation,

$$Q = \sqrt{\frac{C_2}{C_1}}$$

In this paper we have considered $g_{m1} = g_{m2}$, above expression of quality factor is considered.[1], [8]-[10].

III. Experimental setup

The circuit of a universal filter of “Fig 4” is simulated using Proteus professional 7.5 software. Same circuit is arranged on bread board using an OTA LM13600 to verify the software results. The output of the filter is measured in respect of different values of C_1 and C_2, from the order of pF to nF. Readings are also analysed by varying the bias current from 10µA to 2mA.

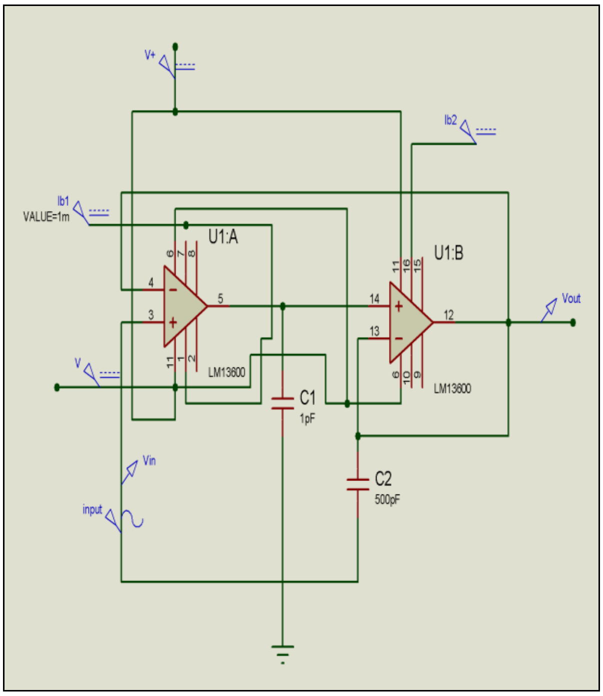

Figure 4. Circuit diagram of second-order OTA-C universal filter using Proteus professional 7.5 software

IV. Results and discussion

A *Low pass filter structure*

The studied circuit functions as a Low pass filter by choosing V_A as the input and grounding V_B and V_C. The study can be carried out under following two cases.

Case 1: Variation of Q, by varying capacitance and by keeping bias current constant.

Case 2: C_1 and C2 kept constant study carried out by varying bias current.

Case 1: By keeping bias current constant and by varying capacitances C_1 and C_2 and recording the variation in Q.

The table 1.1 and 1.2 given below gives the variation in Q, which is obtained by varying C_2 and keeping C_1 constant. Next by varying C_1 and keeping C_2 constant. By keeping bias current constant at 1mA and by varying Capacitance from 1pF to 1nF the value of Q-factor varies from .0316 to 316. Higher value of cut-off frequency is observed at Q =1 which is of order 145MHz.

TABLE 1.1 Low-pass readings Case 1 readings (C_1 is constant)
$I_{b1}=I_{b2}$= 1mA, C_1 = 1pF

C_2	$Q=\sqrt{\frac{C_2}{C_1}}$	**Cut-off Frequency In MHz**
10pF	3.162277	123
100pF	10	63
500pF	22.3606	30
1nF	31.6227	21.4
10nF	100	6
100nF	316.2277	2.10

TABLE 1.2 Case 1 Low-pass readings (C2 constant)
$I_{b1}=I_{b2}$= 1mA, C2 = 1pF

C_1	$Q=\sqrt{\frac{C_2}{C_1}}$	**Cut-off Frequency in (Hz)**
1pF	1	145MHZ
10pF	0.316227	97.4MHz
100pF	0.1	15.9MHz
500pF	0.044721	3MHZ
1nF	0.03162277	1.53MHz

Case 2: By keeping C1 and C2 constant and by varying bias current recording the variation in cutoff frequency.

By varying the bias current of OTA1 and OTA2 and by keeping capacitance constant. Bias current is varied from 10µA to 2mA..As bias current increases from 10µA to 2mA cut off frequency also increases. Maximum cut off frequency of order 283MHz is observed at **$I_{b1}=I_{b2}$ = 2mA.**

TABLE 1.3 Low-pass Case 2 readings (C_2 and C_1 constant)
C_1= C2 = 1pF and $I_{b1}=I_{b2}$

Bias current (in A)	Cut-off Frequency In (Hz)
2mA	283 MHz
1mA	144 MHz
500µA	73.2 MHz
100 µA	14.8 MHz
10 µA	1.48 MHz

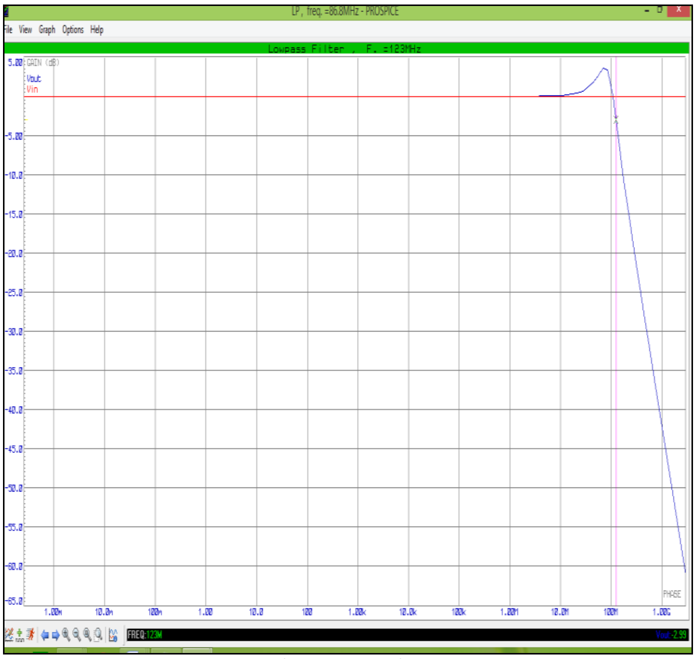

Figure.5 Frequency response of Proteus professional simulated OTA-C Low pass filter circuit, with I_{b1} = I_{b2}= 1mA with C1 = 1pF and C2= 10pF with Cutoff frequency of 123MHz

B *High pass filter structure*

The studied circuit functions as a High pass filter by choosing V_C as the input and grounding V_A and V_B.

Case 1: Variation of Q, by varying capacitance and by keeping bias current constant.

Case 2: C_1 and C2 kept constant study carried out by varying bias current.

Case 1: By keeping bias current constant and by varying capacitances gives the variation in Q

The “table 1.4” given below gives the variation in Q, which is obtained by varying $C_{2.}$ and keeping C_1 constant. By keeping bias current constant at 1mA and by varying Capacitance from 1pF to 100nF the value of Q-factor varies from 10 to 316. Higher value of cut-off frequency is observed at Q =10 which is of order 27MHz.

TABLE 1.**4** High-pass Case 1 readings (C_1 constant)
$I_{b1}=I_{b2}=$ 1mA, C_1 = 1pF

C_2	$Q=\sqrt{\frac{C_2}{C_1}}$	Cut-off Frequency (in Hz)
100pF	10	27MHz
500pF	22.3606	12MHZ
1nF	31.62277	8.90MHz
10nF	100	2.8MHZ
100nF	316.227766	871KHz

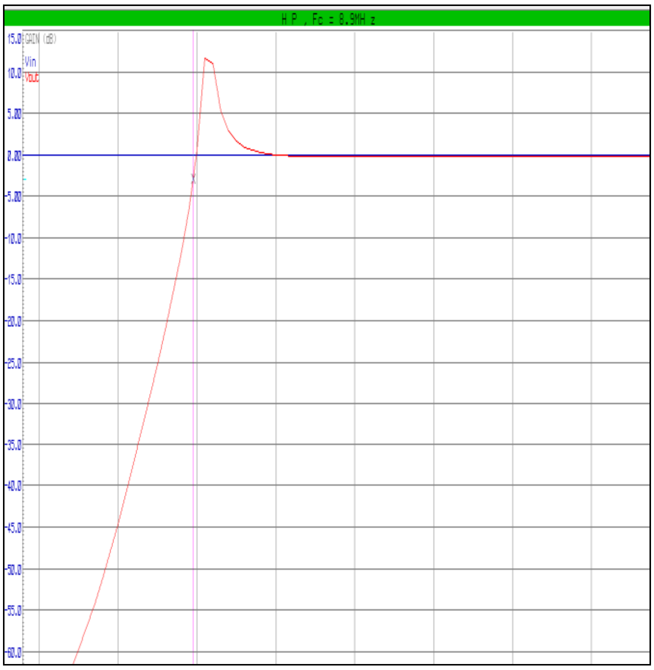

Figure.6 Frequency response of Proteus professional simulated OTA-C High pass filter circuit, with I_{b1} = I_{b2}= 1mA with C1 = 1pF and C2= 1nF with Cutoff frequency of 8.9 MHz

Case 2: By keeping C1 and C2 constant and by varying bias current

By varying the bias current of OTA1 and OTA2 and by keeping capacitance constant. Bias current is varied from 500µA to 2mA.As bias current increases from 500µA to 2mA cut off frequency also increases. Maximum cut off frequency of order 22.8MHz is observed at **$I_{b1}=I_{b2}=$ 2mA.**
C_1= C_2 = 100pF and $I_{b1}=I_{b2}$

TABLE 1.5 High-pass filter readings

Bias current	Cut-off Frequency In MHz
2mA	22.8
1mA	11.6
500µA	5.8

C *Band pass filter structure*

The studied circuit functions as a Band pass filter by choosing V_B as the input and grounding V_A and V_C.

Out of four filter configurations Band pass filter configuration is most relevant for RF and microwave applications

Band width of a band-pass filter range from 156.5Hz to 58.9MHz, was observed. By sensitizing the Q factor ranging from 1 to 1×10^{-3} such a variation in Q factor is observed by keeping C_1 & C_2 in the ratio 1: 1 , 1: 10 , 1:100 ,1:1000 and 1: 1×10^{-6} which gives the evaluation of Q in the range from 1 to 0.001 . But when C_1 = $C_{2\,,}$ Q = 1. With the mentioned ratio of C_1 and C_2 the bias current is varied from minimum 10uA to 1mA. In the present study a wide band width in MHz range is obtained. In all the studied structures the gain is constant with decrease in fall off ratio there by defining sharp bandwidth of the filter.

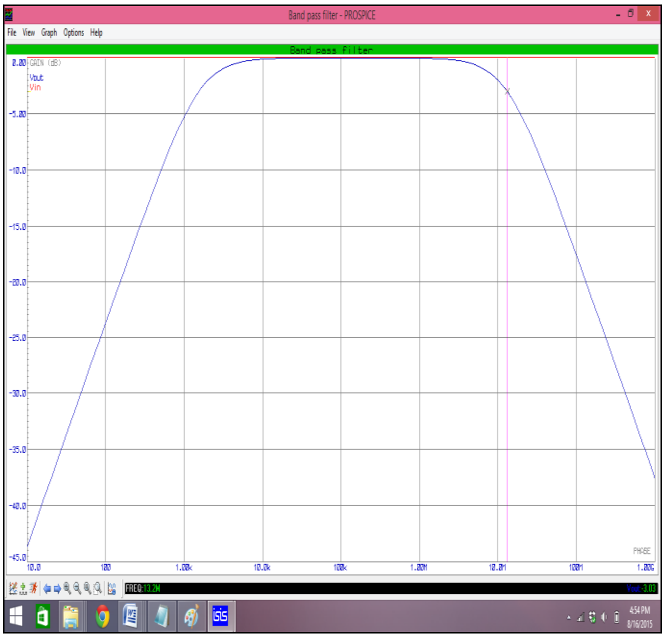

Figure.7 Frequency response of Proteus professional simulated OTA-C Band pass filter circuit, with I_{b1} = I_{b2}= 1mA with C1 = 1000nF and C2= 100pF with Band width of 13.518 MHz

TABLE 1.6 Band-pass filter readings (C_1 constant)
C_1=1000nF and $I_{b1}=I_{b2}$ F1—Lower cutoff frequency F2 –Higher cutoff frequency

C_2 Farad	$I_{b1}=I_{b2}$	$Q=\sqrt{C_2/C_1}$	F1 (in Hz)	F2 (in Hz)	BW (in Hz)
100n	10µA	0.31623	14.5	171	156.5
100n	100µA	0.31623	143	1.69K	1547
100n	1mA	0.31623	1.41K	16.6K	15.19K
10n	1mA	0.1	1.51K	154K	152.49K
10n	100µA	0.1	155	15.8K	15.645K

10n	10 µA	0.1	15.7	1.58K	1578.43
1000n	1mA	1	948	2.47K	1522
1000n	100 µA	1	96	254	158
1000n	10 µA	1	9.74	25.3	15.56
1n	10 µA	0. 031623	15.7	15.3K	1528.43
1n	100	0. 031623	158	154K	153842
1n	1mA	0. 031623	1.54K	1.51M	1508460
100p	1mA	0.01	1.53K	13.52M	13518470
100p	100 µA	0.01	155	1.36M	1359845
100p	10 µA	0.01	15.5	134K	133984.5
10p	1mA	0.0 031623	1.53K	59.9M	58998470
10p	100 µA	0.0 031623	156	6.01M	6009844
10p	10 µA	0.0 031623	15.8	600K	599984.2
1p	1mA	0.001	1.53K	59M	58998470
1p	100 µA	0.001	1.53K	59M	58998470
1p	10 µA	0.001	1.53K	59M	58998470

D *Band reject filter*

In band reject filter the Q factor is changing from few tenth to few hundreds, when the capacitor C_2 is selected in nano Farad range. When C_1 is kept fixed at 1pF. In other words for a better selectivity we need a filter of higher Q, which we obtain by setting C_2 > C1.Under this condition sharp rejection of the frequency is observed. In the same filter when $C_1 > C_2$ with I_{b1} = 1mA and by varying I_{b2} again the Q factor has a tendency to increase its value. For the bias I_{b2} of decreasing nature. Similar kind of observation is observed in the notch filter when I_{b2} is kept constant and I_{b1} is varying.

Hence by tuning g_{m1} and g_{m2} by keeping $I_{b1}= I_{b2}$ or I_{b1} fixed I_{b2} varying or I_{b2} fixed I_{b1} varying helps to tune the transconductance g_{m1} and g_{m2}. A sharp rejection of frequency increases the bias currents of any one of the above observed criteria.

TABLE 1.7 Band-reject filter table
$I_{b1} = I_{b2}$ = 1mA, C_1= 1pF

C_2	Frequency	Quality factor Q
100pF	50.3 MHz	10
500pF	20 MHz	22.36
1nF	13.9 MHz	31.6227
100nF	1.31MHz	316.22
500nF	631KHz	707

TABLE 1.8 Band-reject filter table (I_{b1} isconstant)
C_1 =1pF C_2= 500pF and I_{b1} = 1mA

I_{b2}	Frequency	Quality factor Q
100uA	12.7MHz	70.71
500uA	31.2MHz	31.62
1mA	40.1MHz	22.6

TABLE 1.9 Band-reject table (I_{b2} is constant)
C_1 =1pF C_2= 500pF and I_{b2} = 1mA

I_{b1}	Frequency	Quality factor Q
100uA	12.7MHz	7.07
500uA	25.1 MHz	15.81
1mA	39.4 MHz	22.6

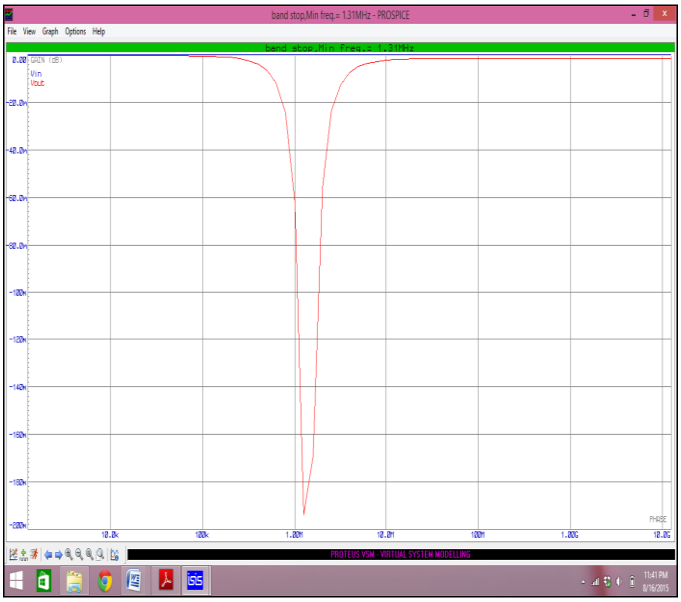

Figure.8 Frequency response of Proteus professional simulated OTA-C notch filter circuit, with I_{b1} = 1mA= I_{b2}= 1mA with C1 = 1pF and C2= 100nF with sharp rejection frequency of 1.31 MHz.

V. Conclusion

The studied structure may be considered as a universal since all kinds of filters can be realized, with variation in Q-factor. The sensitization of Q-factor in the filter design is mainly based on the values of C_1 and C_2.. The formulation of Q-factor for selected C_1 and C_2 exhibits change in -3dB frequencies with respect to the selected bias current in the setup. This also leads to the variation in the Q-factor.

In the present work the sensitization of Q in obtaining -3dB frequencies are either by selecting C_1 and C_2 or by selecting I_{Bias} for a fixed C_1 and C_2. The -3dB frequency is in the range of Hz to MHz .By selecting C_1 and C_2 with different Roll off ratio from -20dB per decade to -40dB per decade is observed. In band-pass structure we have a flexibility of obtaining a smaller band-width and also a larger band-width of Roll-off ratio. -20dB to -10dB per decade.

In notch filter a sharp rejection is observed when $C_1 > C_2$ with a fixed bias current of OTA's. However if the bias current of one of the OTAs is held constant varying the other , a sharp rejection frequency ranging from ones to tens in MHz range is observed. In all the above cases the practical results obtained agreed with the theoretical values thereby supporting the universal structures.

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Queen's University Kingston, Ontario, Canada (September, 2008) by You Zheng .

References

[1] You Zheng "Operational transconductance amplifier for Giga Hertz Applications" A thesis submitted to the, Department of Electrical and Computer Engineering, Queen's University Kingston, Ontario, Canada (September, 2008).

[2] R. L. Geiger and E. Sanchez-Sinencio, "Active filter design using operational transconductance amplifiers: A tutorial," *IEEE Circuit and Device Magazine*, vol.1, pp. 20-32, Mar. 1985.

[3] James Moritz Yichuang Sun "100MHz, 6th Order, Leap-Frog gm-C High Q Bandpass Filter and On-ChipTuning Scheme" 0-7803-9390-2/06/$20.00 ©) 2006 IEEE

[4] Riyas T M, Anusooya S "Design of Low Power Linear Multi-band CMOS Gm-C Filter" International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering Vol. 3, Issue 2, February 2014.

[5] Katoh, T. Tsukutani, Y. Sumi and Y. Fukui, "Electronically Tunable Current-Mode Universal Filter Employing CCCIIs and Grounded Capacitors," *Int. Symp. Intelligent Signal Processing and Communication Systems*, pp.107-110, 2006.

[6] C. Chang and S. Tu, "universal voltage-mode filter with four inputs and one output using two CCII+s,"*Int.. J. Electron.*, vol. 86, pp. 305-309, 1999.

[7] Rahul Kumar, D. S. Ajnar, P. K. Jain "**Design of Biquad Universal Filter Using Operational Transconductance Amplifier in 180nm Technology"** *Journal of Engineering Research and Applications www.ijera.com ISSN: 2248-9622, Vol. 4, Issue 5(Version 2), May 2014, pp.120-125.7*

[8] H.–P. Chen, S.S.Shen, and J.–P.Wang, ―Electronically tunable versatile voltage-mode universal filter, ‖ International Journal of Electronics and Communications, vol.62, pp. 316-319, 2008.

[9] Dalibor Biolek, Viera Biolková, and Zdeněk Kolka "Universal current-mode OTA-C KHN biquad" 2007. 9

[10] C.-M. Chang, and S.-K. Pai, „Universal Current-Mode OTA-C Biquad with the Minimum Components", *IEEE Trans. on CAS*, vol. 47, No. 8, 2000, pp. 1235-1238.

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