ECTI – CON 2020
PHUKET, THAILAND

ECTI - CON 2020

The 17th International Conference
on Electrical Engineering/Electronics, Computer,
Telecommunications and Information Technology

24 - 27 June 2020

Virtual Conference Hosted by *College of Computing, Prince of Songkla University*

PROCEEDINGS & PROGRAM BOOK

High Quality-Factor Shadow Bandpass Filters with Orthogonality to the Characteristic Frequency

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***Abstract*—The paper proposes the topology and implementation of the shadow bandpass filter. The main advantage of this work is that the bandpass filter possesses the distinctively high-quality factor whereas the control of this quality factor is independent with the tunability of the characteristic frequency. The circuit configuration is realized and satisfactorily verified via PSpice simulation.**

Keywords— Shadow Bandpass Filter, High Quality-Factor, Electronic Tuning, VDTA

I. INTRODUCTION

Bandpass filters have played a crucial role in many applications in communications, electronics, and instrumentation. Conventional circuit implementation of bandpass filters relies on passive components which is known to consume large area. Hence the use of active components gains much more popularities and it is also the choice of the presented work to utilize active components as a backbone of circuit realization. One more benefit is also obtained from the active realization that is the filter characteristics such as the center or characteristic frequency, the quality factor or bandwidth can be conveniently controlled via the circuit bias current in addition to external components. This results in the ease of parameter-compensation.

An innovative concept to build up a bandpass filter, so-called the shadow bandpass filter in introduced in [1]. The scheme makes possible to tune the various filter characteristics by acting only on the externally inserted amplifier-gain without disturbing the internal filter circuit, itself. Since the introduction of the shadow filter concept, many relating research works have been coming along over the years [1] – [9]. Various active components have been utilized to implement a shadow filter. In [4], the CFOAs are used as the main active elements in the design. The advantage is that CFOAs are readily available on the shelf. However, the design takes as many as 4 CFOAs to implement the shadow bandpass filter, not to mention a number of passive resistors and capacitors. Also, the filter characteristics are controlled via the external passive resistors. In [7], the OTRAs are used as the active components. It is noted that many passive components are employed in the design. In [8], the VDDDAs are the main active elements. The design offers electronic tuning feature; however, the characteristic frequency is not controlled via the external feedback gain but the parameters within the biquad. In [9], 3 OFCCs with quite several passive capacitors and resistors are used in the design. Notice that the bandpass filter presented offers the quality factor as high as 2. Recently, there is an attempt to improve the quality factor for a shadow bandpass filter [11]. However, there is a weakness in the design as the control of the quality factor is not independent from the characteristic frequency.

A new configuration of shadow bandpass filters is presented in the current paper. The proposed circuit enjoys orthogonal tuning quality factor and center frequency. This characteristic allows comfortable and easy to adjust filter property. The major active elements used in this work are the VDTAs. The passive components used in the design are only two grounded capacitors. The filter characteristics are electronically controlled through the bias currents. Impressively, high quality factor is achieved with independence from the control of the center frequency. Those are the reasons why the proposed filter gives more interest than the reported one.

II. CIRCUIT PRINCIPLE

The basic active building block used in the proposed work functioning as a biquad with lowpass and bandpass responses and is shown in Fig.1.

The two responses are characterized, respectively, by the following equations

$$\frac{V_{LP}(s)}{V_{in}(s)}=\frac{d}{1+as+bs^2} \tag{1}$$

$$\frac{V_{BP}(s)}{V_{in}(s)}=\frac{cs}{1+as+bs^2} \tag{2}$$

Where a , b , c and d are positive coefficients. Clearly, the bandpass filter response has the characteristic or

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center frequency and the quality factor as given, respectively, in (3) and (4)

$$\omega_0 = \frac{1}{\sqrt{b}} \tag{3}$$

$$Q_0 = \frac{\sqrt{b}}{a} \tag{4}$$

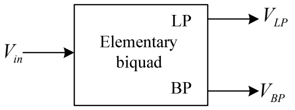


Fig.1 An elementary biquad with lowpass and bandpass responses

Adding two amplifiers blocks having the gains A_{BP} and the basic bi and arranging the circuit configuration results K_f in the following shadow bandpass filter as shown in Fig.2. From (1) – (4), the transfer function of the circuit diagram in Fig.2 can be found as

$$T(s) = \frac{A_{BP}cs}{(1+K_f d)+(a-A_{BP}K_f c)s+bs^2} \tag{5}$$

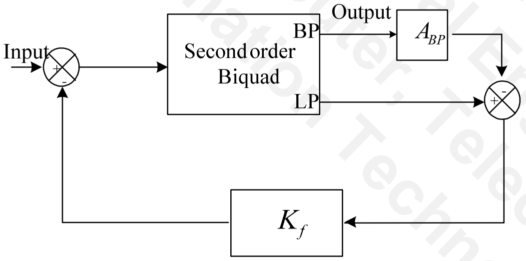


Fig.2 The proposed high-quality factor shadow bandpass filter with orthogonality

Where the amplifier gains A_{BP} and K_f are assumed to be some positive real numbers. Then the characteristic frequency and the quality factor can be found, respectively, as follows

$$\omega'_{0(1)} = \omega_0\sqrt{1+K_f d} = \omega_{0(1)} \tag{6}$$

$$Q'_{0(1)} = Q_0 \frac{\sqrt{1+K_f d}}{1-\frac{K_f A_{BP} c}{a}} = \frac{Q_{0(1)}}{1-\frac{K_f A_{BP} c}{a}} \tag{7}$$

For comparison, the firstly inspired work introduced in [1] is recalled and shown in Fig.3 The circuit diagram as above gives, respectively, the following characteristic frequency and quality factor

$$\omega_{0(1)} = \omega_0\sqrt{1+Ad} \tag{8}$$

$$Q_{0(1)} = Q_0\sqrt{1+Ad} \tag{9}$$

Comparison of (6) and (8), both produce the same form of characteristic frequency. Then (7) and (9) are inspected and it is obvious that the higher quality factor can be obtained from the proposed work by appropriately selecting the term $1-\frac{A_{BP}K_f c}{a}$, i.e.,

$$0 < 1-\frac{A_{BP}K_f c}{a} < 1 \tag{10}$$

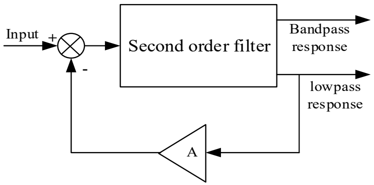
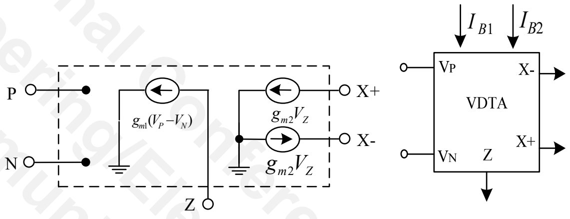


Fig.3 The primal principle of the shadow bandpass filter

III. CIRCUIT IMPLEMENTATION

Circuit implementation of the proposed work relies on the active building block, so-called the Voltage Differential Transconductance Amplifier (VDTA), the equivalent circuit and the symbol including parameters relation of which are given, respectively, in Fig.4 and equation (11). The voltages V_P and V_N are those at the high-impedance input-terminals and Z, X+ and X− are the current output-terminals. Meanwhile, g_{m1} and g_{m2} are the transconductances of the VDTA and their values are dependent on the bias currents, I_{B1} and I_{B2}, respectively



(a) Equivalent circuit (b) Symbol

Fig.4 The equivalent circuit and symbol of VDTA.

$$\begin{bmatrix} I_Z \\ I_{X+} \\ I_{X-} \end{bmatrix} = \begin{bmatrix} g_{m1} & -g_{m1} & 0 \\ 0 & 0 & g_{m2} \\ 0 & 0 & -g_{m2} \end{bmatrix} \begin{bmatrix} V_{V_P} \\ V_{V_N} \\ V_Z \end{bmatrix} \tag{11}$$

Practically, the VDTA building block in Fig.4 can be realized using the CMOS and the realization is as depicted in Fig.5 According to [10], the transconductance g_{m1} and g_{m2} can be approximated as

$$g_{m1} = (g_3+g_4)/2, \tag{12}$$

$$g_{m2} = (g_5+g_8)/2 \tag{13}$$

where as g_i is the transconductance value of the ith transistor defined by

$$g_i = \sqrt{I_{Bi}\mu_i C_{OX}\left(\frac{W}{L}\right)_i}, \tag{14}$$

μ_i is the mobility carrier for NMOS and PMOS transistor, C_{OX} is the gate-oxide capacitance per unit area, W is the effective channel width, L is effective channel length and I_{Bi} is bias current of ith transistor.

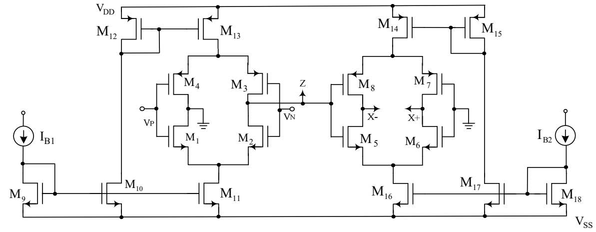


Fig.5 CMOS Realization of VDTA [10]

Based on the circuit principle described in Fig. 2 and the active building block VDTA realized as shown in Fig. 5, the proposed high-quality factor shadow bandpass filter can be implemented as depicted in Fig. 6

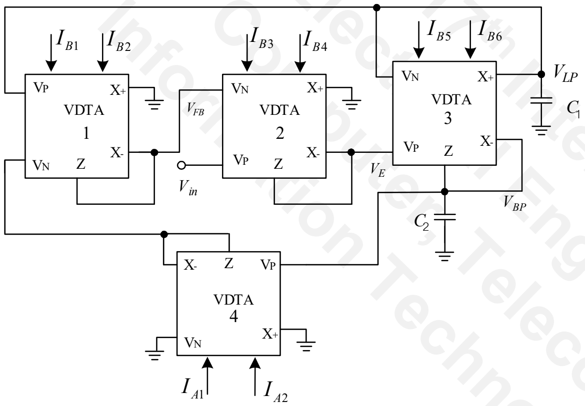


Fig. 6 The proposed high-quality factor shadow bandpass filter

It is seen in Fig. 6, the proposed circuit implementation is composed of 4 VDTAs and only two grounded capacitors. Notice that there are not any passive resistors employed in the circuit. Also a VDTA is a biquad with two types of outputs, i.e. V_{BP} and V_{LP}, correspondingly to bandpass and lowpass filter responses. Routine analysis results in the following transfer functions

$$\frac{V_{BP}(s)}{V_E(s)} = \frac{sC_1/g_{m6}}{1+s(C_1/g_{m5})+s^2C_1C_2/g_{m5}g_{m6}} \tag{15}$$

$$\frac{V_{LP}(s)}{V_E(s)} = \frac{1}{1+s(C_1/g_{m5})+s^2C_1C_2/g_{m5}g_{m6}} \tag{16}$$

Consider VDTA 2, it can be found that

$$V_{FB}(s) = K_f\left(V_{LP}(s) - A_{BP}V_{BP}(s)\right) \tag{17}$$

where $K_f \approx \frac{I_{B1}}{I_{B2}}$ and $A_{BP} \approx \frac{I_{A1}}{I_{A2}}$ Provided that

$$\frac{V_E(s)}{V_{in}(s)-V_{FB}(s)} \approx \frac{I_{B3}}{I_{B4}} \approx 1 \tag{18}$$

The transfer function of the shadow bandpass filter can be derived as follows

$$\frac{V_{BP}(s)}{V_{in}(s)} = \frac{sC_1/g_{m6}}{1+K_f+s(C_1/g_{m5}-K_fA_{BP}C_1/g_{m6})+s^2C_1C_2/g_{m5}g_{m6}} \tag{19}$$

Therefore, the characteristic frequency is

$$\omega'_{0(1)} = \sqrt{(1+K_f)}.\sqrt{\frac{g_{m5}g_{m6}}{C_1C_2}} = \sqrt{(1+K_f)}.\omega_0 \tag{20}$$

Hence, the characteristic frequency can be tuned via K_f, which, in turn, is electronically controlled via the bias currents of VDTA 1. Meanwhile, the quality factor of this shadow bandpass filter is found as follows

$$Q'_{0(1)} = \left(\frac{\sqrt{1+K_f}}{1-K_fA_{BP}\frac{g_{m5}}{g_{m6}}}\right).\sqrt{\frac{C_2g_{m5}}{C_1g_{m6}}} = \frac{Q_{0(1)}}{1-K_fA_{BP}\frac{g_{m5}}{g_{m6}}} \tag{21}$$

From (21), the quality factor $Q'_{0(1)}$ can be easily adjusted through A_{BP}. Obviously, this does not affect the characteristic frequency in any way. Also, A_{BP} is electronically adjusted through the bias currents I_{B1} and I_{B2}. Furthermore, a much higher quality factor can be obtained, provided that

$$0 < K_fA_{BP}\frac{g_{m5}}{g_{m6}} < 1. \tag{22}$$

IV. SIMULATION RESULTS

To verify the performance of the proposed algorithm, the higher quality factor shadow bandpass filter in Fig. 6 is realized with VDTAs implemented using the CMOS transistors as depicted in Fig. 5. The PSpice simulation is carried out with TSMC 0.18 µm, channel width and length as shown in Table 1, and the same value of supplied voltages $V_{DD} = -D_{SS} = 1.5$ V.

TABLE 1. CHANNEL WIDTH AND LENGTH OF THE VDTAS USED IN THE SIMULATION

Transistors	W(µm)	L(µm)
M_1, M_2, M_5, M_6	3.60	0.36
M_3, M_4, M_7, M_8	16.64	0.36
M_9 - M_{11}, M_{16} - M_{18}	20	0.36
M_{12} - M_{15}	4.2	0.36

The simulation of Fig. 6 begins with the frequency response examination. Using dc bias current $I_{B5} = I_{B6}$ =50µA $C_1 = C_2$=10pF and setting I_{B1}, I_{B2} =50µA such that K_f =1, and I_{A1} =50µA I_{A2} =100µA such that A_{BP}= 0.5, the frequency response is obtained in Fig. 7

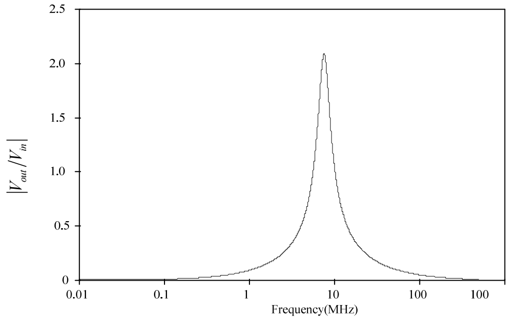


Fig. 7 The frequency response of the proposed shadow bandpass filter

As expected, the quality factor and the characteristic frequency are found, respectively, as a 5.9 and 7.3 MHz. Then Fig. 8 demonstrates the relation between the characteristic frequencies and the gain K_f. In the simulation, the values of K_f are varied from 0.1-1. This is easily carried out by setting the bias current I_{B2}= 100 μA and varying I_{B1} between 10-100 μA. For convenience, the rest of the bias currents are all 50 μA. It is seen from Fig. 8 that there are two sets of simulation. One associates with $C_1 = C_2$ = 5 pF and the other with $C_1 = C_2$ =10 pF. It is clear from the simulation results shown in Fig. 8 that the characteristic frequencies of the proposed shadow filter can be tuned by simply controlling the gain K_f.

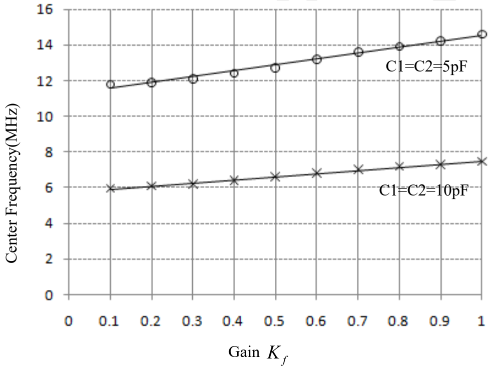


Fig. 8 The characteristic frequencies with K_f are varied

Then another simulation is performed to the circuit performance in terms of the quality factor. In the simulation, A_{BP} (quality factor control gain) is selected to have A_{BP}= 0.25, 0.5 and 1 correspondingly with dc bias currents I_{A1} = 25μA, 50 μA and 100 μA, respectively. Whereas, dc bias current I_{A2} is fixed about at 100 μA. For convenience, the two capacitors using $C_1 = C_2$ =10 pF and all the bias currents of all VDTAs are of the same value of 50 μA. Clearly, this causes K_f = 1. The simulation gives the frequency response as illustrated in Fig. 9. From the figure, the quality factor can be increased from 3.28, 6.29 and 32.24 by changing A_{BP}, respectively, from 0.25 0.5 and 1. Clearly, all the changes of the quality factor have no effect on the center frequency of filter.

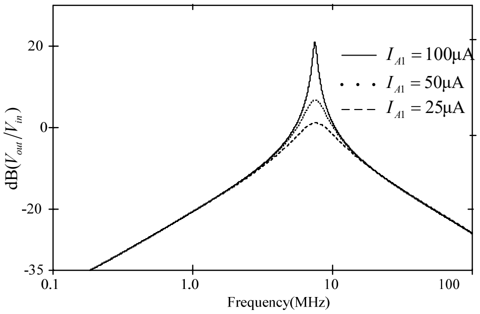


Fig. 9 Frequency response of the shadow bandpass filter

V. CONCLUSIONS

This paper proposes a new configuration of the shadow bandpass filter. The circuit implementation is based on the active building block VDTAs realized with CMOS technology. The passive components employed in the circuit are only two grounded capacitors. The major advantage of the proposed work is that an impressive high-quality factor is obtained with orthogonality with respect to the characteristic frequency. Both filter parameters are controlled independently via the external amplifier gains and hence there is no disturbance on the internal elementary functionality. The circuit performance is verified by PSpice simulation. The results confirm the theoretical proposal.

REFERENCES

[1] Y. Lakys and A. Fabre, "Shadow filters – new family of second-order filters," Electronics Letters, Vol. 46, 2010, pp. 276-277.

[2] Y. Lakys, B. Godara, and A. Fabre, "Cognitive and encrypted communications, part 2: a new approach to active frequency-agile filters and validation results for an agile bandpass topology in SiGe-BiCMOS," in Proceedings of the 6th International Conference on Electrical and Electronics Engineering (ELECO'09), pp.II16-II29, 2009.

[3] V. Biolkova and D. Biolek, "Shadow filters for orthogonal modification of characteristic frequency and bandwidth," Electronics Letters, Vol. 46, 2010, pp. 830-831.

[4] M.T. Abuelma'Atti and N. Almutairi, "New current-feedack operational-amplifier based shadow filters," Analog Integrated Circuits and Signal Processing, Vol. 86, Issue 3, 1 March 2016, pp. 471-480.

[5] A. Yesil, F. Kacar, and S. Minaei, "Electronically control bandpass filter with high quality factor and reduced capacitor value: An additional approach," AEU-Int.Journal of electronic and communication , Vol. 70, 2016, pp. 936-943.

[6] F. Khateb, W. Jaikla, T. Kulej, M. Kumngern, and D.Kubánek, "Shadow filter based on DDCC", IET Circuits, Devices & Systems, Vol. 11, 2017, pp. 631-637.

[7] R. Anurag ; R. Pandey ; N. Pandey ; M. Singh, and M. Jain, "OTRA based shadow filter'', Annual IEEE India Conference (INDICON), 2015.

[8] P. Huaihongthong, A. Chaichana, P. Suwanjan, and S.Siripongdee, W. Sunthonkanokpong, P. Supavarasuwat, W. Jaikla and F. Khateb, "Single-input multiple-output voltage-mode shadow filter based on VDDDAs," AEU-International Journal of Electronics and Communications, pp. 13-23, 2019.

[9] D.Nand and N.Pandey, "New configulation for OFCC based CM SIMO Filter and its application," Arabian Journal for Science and Engineering, pp. 3011-3022, 2018.

[10] A. Yesil, F. Kacar, and H. Kuntman, "New simple CMOS realization of voltage differencing transconductance amplifier and its RF filter application," Radioengineering, Vol. 20, 2011, pp. 632-637.

[11] S. Buakaew, W. Narksarp, and C. Wongtaychatham, "Shadow Bandpass Filter with Q-improvement," Int. Con. on Engineering, Applied Sciences and Technology (ICEAST), 2019, 2-5 July.