TUNABLE UNIVERSAL FULLY-DIFFERENTIAL FILTER WITH OPERATIONAL TRANSRESISTANCE AMPLIFIER

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Abstract: The new single-ended (S-E) second order frequency filter providing transfer function of Low Pass (LP), High Pass (HP), Band Pass (BP), Band Stop (BS) and All Pass (AP) is presented in this paper. The cut-off frequency is tunable up to 3 MHz. Also the fully-differential (F-D) version of the filter is presented and so is the transformation method which is in this case the Signal Flow Graph (SFG). The design filter can be implemented with discretive active devices or as an Integrated Circuit (IC). The features of both S-E and F-D filters are verified using PSpice simulations comparing ideal and behavioral models of the active devices.

Keywords: Fully-Differential Frequency Filter, Signal Flow Graph, Universal Filter, OTRA

1 INTRODUCTION

The frequency filters are electronic circuits with frequency-dependent response to the input signal. The most common analog frequency filters are Low Pass (LP), High Pass (HP), Band Pass (BP), Band Stop (BS) and All Pass (AP) filters. The frequency filters modify both magnitude and phase of the input signal. All Pass is an exception as it only modifies the phase in the ideal case [1].

The important features of the filters are also the order and whether it is an active or a passive filter. The order of the filter is given according to the decrease of the magnitude in the stopband. Second order filters, with the descrease of 40 dB per decade, are the most common. Higher-order filters may be designed by simply cascading lower-order filters. It is also possible to design a fractional-order filter with the optional decrease per decade [2].

It is possible to process both differential and non-differential input signals. The F-D filters have several benefits compared to the S-E filters: greater dynamic range, higher common mode rejection ratio and lower harmonic distortion [3]. F-D filter is thus desirable and there is an elegant way to transform the S-E filter into a F-D one presented in this paper [4].

However, there are also drawbacks to the F-D structure: the number of outputs and inputs of the active elements increases, the number of passive elements increases, the power consumption increases, the PCB or IC layout area is bigger and the design is more complicated [3].

2 THE DESIGN

The new filtration structure and the corresponding SFG are shown in Fig. 1. The active elements are Operation Tranconductance Amplifier with balanced output (BOTA), specified by parameter g_m, the transconductance. Current Follower (CF), copying or inverting the input current. And Operational Transresistance Amplifier (OTRA), specified by parameter R_m [5], the transresistance.

The F-D version of the designed filter and the corresponding SFG is shown in Fig. 2. The transformation begun with the SFG. The SFG was mirrored. The number of loops increased significantly and the analysis of the graph became much more complicated. However, it can be mathematically proved that the equations describing the S-E filter are the same as the equations describing the F-D one.

There are changes in parameters given by the rules for transformation from S-E to F-D filter: $R_{\mathrm{mD}} = \frac{R_{\mathrm{m}}}{4}$, $C_{\mathrm{D}} = 2.C$ and $G_{\mathrm{D}} = 2.G$. Also the number of the passive elements doubles, as is shown in Fig. 2, and their values change according to the transformation rules [6].

2.1 Numerical design

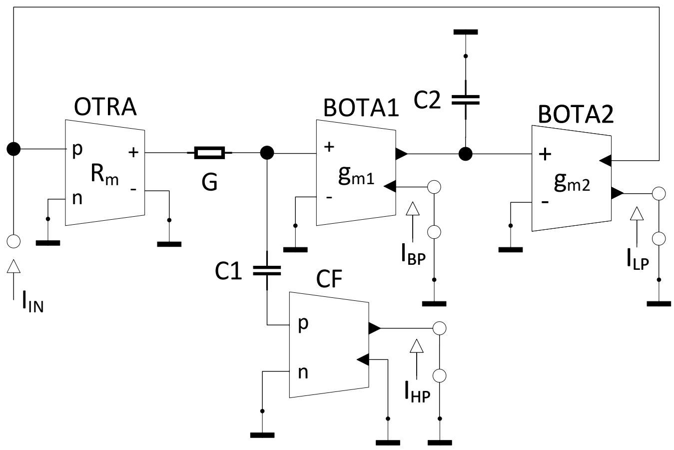
The determinant of the SFG is described by [4]:

$$\Delta = \mathbf{p}^2 C_1 C_2 + \mathbf{p} C_2 G + R_m G g_{\mathrm{m1}} g_{\mathrm{m2}}. \tag{1}$$

The transfer functions of the HP, BP, LP, BS and AP are described by [1]:

$$\frac{I_{\mathrm{HP}}}{I_{\mathrm{IN}}} = \frac{\mathbf{p}^2 C_1 C_2 G R_{\mathrm{m}}}{\Delta},\ \frac{I_{\mathrm{BP}}}{I_{\mathrm{IN}}} = \frac{\mathbf{p} C_2 G R_{\mathrm{m}} g_{\mathrm{m1}}}{\Delta},\ \frac{I_{\mathrm{LP}}}{I_{\mathrm{IN}}} = \frac{G R_{\mathrm{m}} g_{\mathrm{m1}} g_{\mathrm{m2}}}{\Delta},\ \frac{I_{\mathrm{BS}}}{I_{\mathrm{IN}}} = \frac{I_{\mathrm{HP}} + I_{\mathrm{LP}}}{\Delta},\ \frac{I_{\mathrm{AP}}}{I_{\mathrm{IN}}} = \frac{I_{\mathrm{HP}} + I_{\mathrm{LP}} + I_{\mathrm{iBP}}}{\Delta}. \tag{2}$$

There are conditions to be considered to prevent the Band Pass and High Pass from amplifying the input signal. $R_{\mathrm{m}}.G = 1$, $R_{\mathrm{m}}.g_{\mathrm{m1}} = 1$, $G = g_{\mathrm{m1}} = g$. These conditions influence the equations describing



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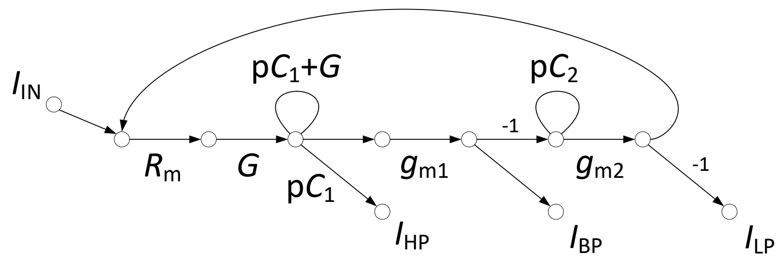
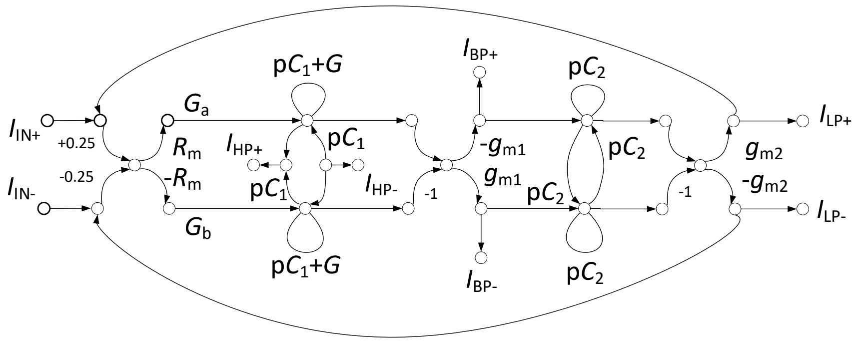
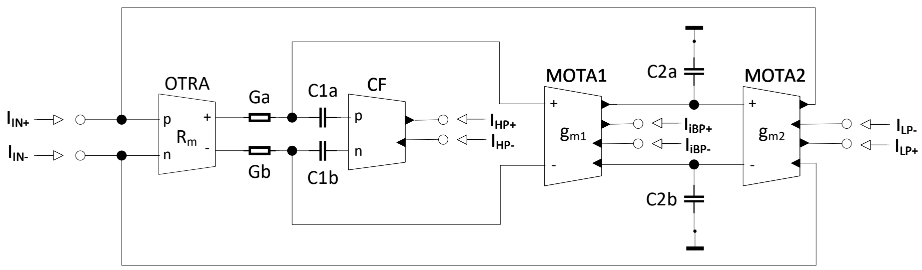


(b)

Figure 1: a) S-E version of the filter, b) corresponding SFG.



(a)



(b)

Figure 2: a) F-D version of the filter, b) corresponding SFG.

the cutoff frequency and quality factor [1]:

$$\omega_{\mathrm{m}} = \sqrt{\frac{1}{R_{\mathrm{m}}C_1}\frac{g_{\mathrm{m2}}}{C_2}},\ Q = \sqrt{R_{\mathrm{m}}C_1\frac{g_{\mathrm{m2}}}{C_2}}. \tag{3}$$

Quality factor and the cutoff frequency depend on each other, which is a disadvantage. To make the design less complicated, we consider $C_1 = C_2 = C$. Then

$$f_{\mathrm{m}} = \frac{1}{2\pi C}\sqrt{\frac{g_{\mathrm{m2}}}{R_{\mathrm{m}}}},\ Q = \sqrt{R_{\mathrm{m}}g_{\mathrm{m2}}}. \tag{4}$$

Now the frequency filter can be changed independently on the quality factor, however, by the change of a capacitor, not electronically. An example design is presented in Table 1 and also simulated, as shown in Fig. 3,4,5 : $R_{\mathrm{m}} = 1\mathrm{k}\Omega,\ \mathrm{g_{m2}} = 1\mathrm{mS},\ \mathrm{g_{m1}} = \mathrm{G} = \frac{1}{\mathrm{R_m}} = 1\mathrm{mS},\ \mathrm{Q} = 1.$

f_m [MHz]	C [pF]
1	150
3	50
0.3	500

Table 1: Cut-off frequency depending on parameter C.

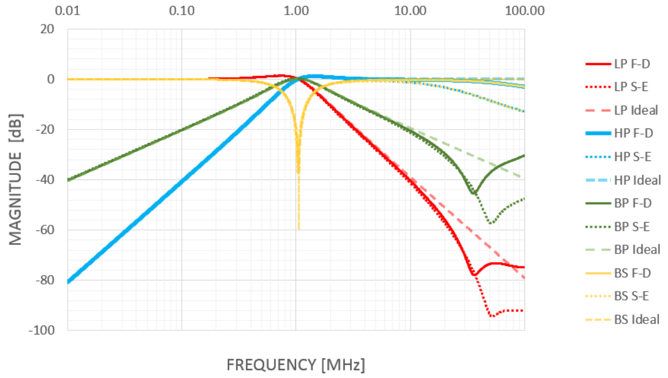
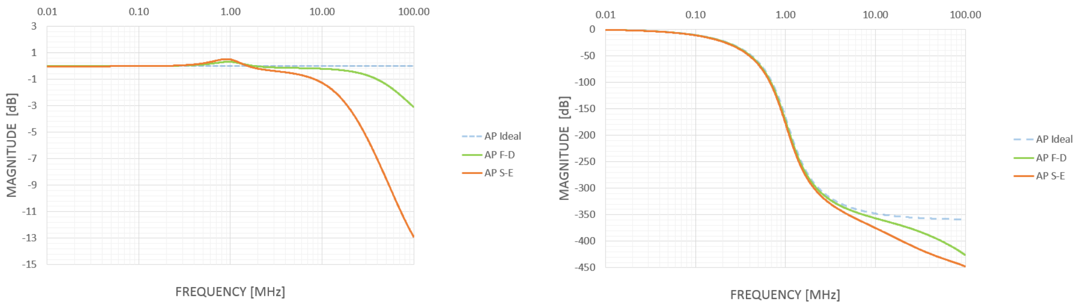


Figure 3: Results of the PSpice simulation using ideal and 3rd order models. Cut-off frequency of 1 MHz.



(a) (b)

Figure 4: Results of the PSpice simulation using 3rd order models. Cut-off frequency of 1 MHz. a) AP magnitude, b) phase frequency characteristic.

3 THE DISCUSSION OF THE RESULTS

The simulation proving the functionality of LP, BP, BS and HP is shown in Fig. 3. There is a result of the simulation with ideal models of the active devices referred to as Ideal in the legend. Results of the ideal simulation prove the design is correct. The ideal results of S-E and F-D simulation are identical.

The ideal 3rd order simulation models introduce parasitic zeros and parasitic poles. A parasitic zero causes the change of the attenuation at frequencies above 20 MHz for the F-D BP and LP and at around 40 MHz for the S-E. However, the results of the F-D HP and BS are more similar to the ideal simulation result compared to the S-E results. The parasitic zero depends on input impedance of the 3rd order models.

The AP simulation is shown in Fig. 4, proving the filter is causal and the phase characteristics of the LP, HP and iBP are correct. F-D version of AP is closer to the ideal filter at higher frequencies (above 3 MHz up to 20 MHz).

The tunability of the filter is verified in Fig. 5. The amplification of the BP increases with the frequency as an udesired side-effect. The F-D filter with behavioral models of the active devices is again closer to the ideal filter for frequencies below 10 MHz.

To achieve higher frequencies, the parasitic zeros and poles of the active devices should be shifted to the higher frequencies. This would require a different choice or settings of the active elements.

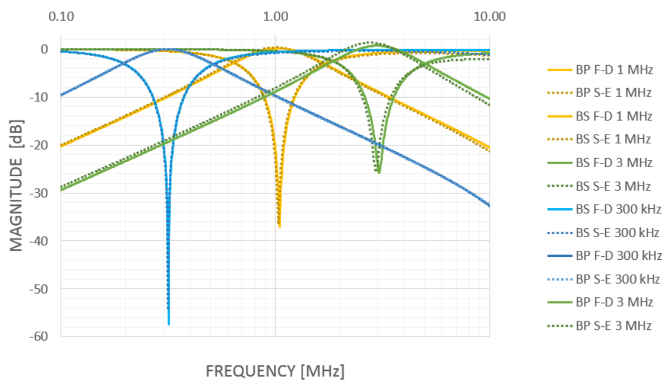


Figure 5: Tuning of the BS and BP filter, cut-off frequencies of 300 kHz, 1 MHz and 3 MHz. F-D (fair colors) and S-E (dark colors).

There is also a possibility to create poles and zeros within the filter architecture, which would cancel each other. However, that would require more capacitors and would make the design more complicated. Not to mention the parasitic side effects, which would again show themselves in the behavioral simulation.

4 CONCLUSION

The universal frequency filter using BOTA, CF and OTRA, providing transfer functions of LP, HP, BP, BS and AP is simulated in both S-E and F-D version using both behavioral and ideal models of the active devices. The transformation from S-E to F-D filter using SGF was successful.

The results of the simulation show that the F-D frequency characteristic resembles the ideal filter characteristic for HP, AP and BS better than S-E filter. The transfer function of the non-ideal filters is influenced by parasitic zero manifested at cca 20 MHz. The filter is not providing the right functionality for higher frequencies.

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