MOS-Only Polyphase Filter

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Abstract

In this paper, a design methodology that can be used to implement first-order MOS-only polyphase filter is proposed. The proposed MOS-only polyphase filter can be used as an image-reject filter in low-IF circuits where key filter parameters are electronically controllable. Moreover, the approach allows substantial reduction in the circuit's chip area by avoiding the use of bulky passive components. In order to verify the usefulness of the theoretical approach, simulation results of the filter are obtained by using SPECTRE in the CADENCE design tool.

1. Introduction

The low-If receiver is an introduced alternative receiver topology which address some important issues related to zero-IF receiver [1]. One major problem with IF receiver is in-band image signal problem which superimpose the desired signal and may severely affect the overall system performance. A possible approach to overcome this problem is using an image reject filter to suppress the image signal.

Polyphase filters, known as complex filters, are widely used for image rejection [2,3]. The first introduced polyphase filters in the literature are based on using only resistors and capacitors [4-6]. In the last decade, many kind of active components with passive elements are utilized to design polyphase filters called as active polyphase filter [7-13]. One important restriction of this type of filters is that passive elements occupy too much space on chip area.

From the other side, filters called as MOS-only filters which employ only the intrinsic capacitors of the MOS transistors have attracted some interest in recent years [14-16]. This kind of filters provide low occupied chip area, because of using as reactive component MOS capacitances with higher capacitance density compared to on-chip capacitors. Thus MOS-only filters feature very useful advantages from IC realization viewpoint [17-19].

In order to alleviate above mentioned restriction of the polyphase filters, an area effective implementation of this type of filters is proposed in this paper. This filter is based on the parallel RC cells using equivalent MOS only circuits, therefore provides an area effective filter implementation.

Simulation results are obtained using Spectre simulator in Cadence design environment and verify the proper operation of proposed active-only filter circuit.

2. Image Problem and Polyphase filters for image rejection

The superheterodyne radio receiver is one of the most widely used types of receiver in a wide variety of radio communications applications. One of the important specifications associated with the operation of the superheterodyne radio is its image response or image rejection.

In superheterodyne receiver, it is possible for two signals to enter the intermediate frequency (IF) amplifier as shown in Fig. 1. The image rejection of a receiver will be specified as the ratio between the wanted and image signals expressed in decibels (dB) at a certain operating frequency. An important feature of today's receiver is to provide a substantial image rejection.

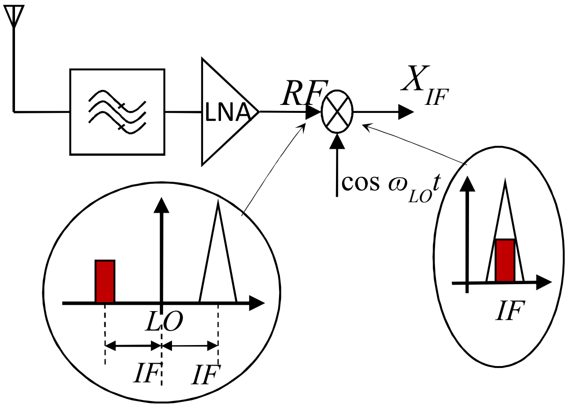


Fig.1. Image problem in conventional RF receivers

The image interference problem becomes very challenging for low-IF receivers.

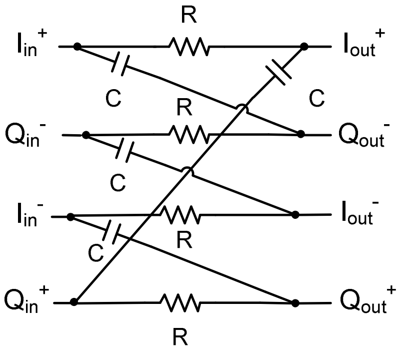


Fig.2. The first-order RC polyphase filter

A possible solution is to use a complex polyphase filter. The general polyphase filter which is realized by using passive elements is given in Fig. 2.

Assuming that the complex transfer function is defined as,

$$H(\omega) = \frac{I_{out} + jQ_{out}}{I_{in} + jQ_{in}}$$

the analysis of the circuit in Fig. 2 yields

$$H(\omega) = \frac{1+\omega RC}{1+j\omega RC} \quad (1)$$

Note that the filter provides unsymmetrical characteristics, i.e. $H(\omega) \neq H(-\omega)$.

Note that the filter magnitude can be expressed as follows:

$$|H(\omega)|^2 = 1 + \frac{2\omega RC}{1+(\omega RC)^2} \quad (2)$$

which shows that for positive frequencies, its magnitude remains between 0dB and 3dB, while for negative frequencies, the magnitude function has a zero at $\omega = -1/RC$. Therefore, the circuit in Fig. 2 can be used as an image reject filter.

3. Realization of MOS-only Polyphase Filter

A. Synthesis Procedure

The passive polyphase circuit mentioned above consists of two parts, the phase and the quadrature phase. In order to obtain the active-only equivalent of the passive polyphase filter, the subcircuit shown in Fig.3 is first considered.

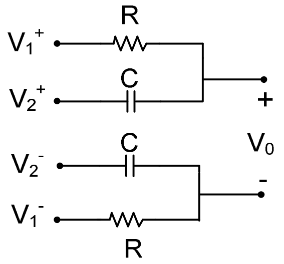


Fig. 3. Basic RC subcircuit

The transfer function of this subcircuit is determined as follows:

$$V_0 = \frac{1}{1+sRC}(V_1^+ - V_1^-) + \frac{sRC}{1+sRC}(V_2^+ - V_2^-) \quad (3)$$

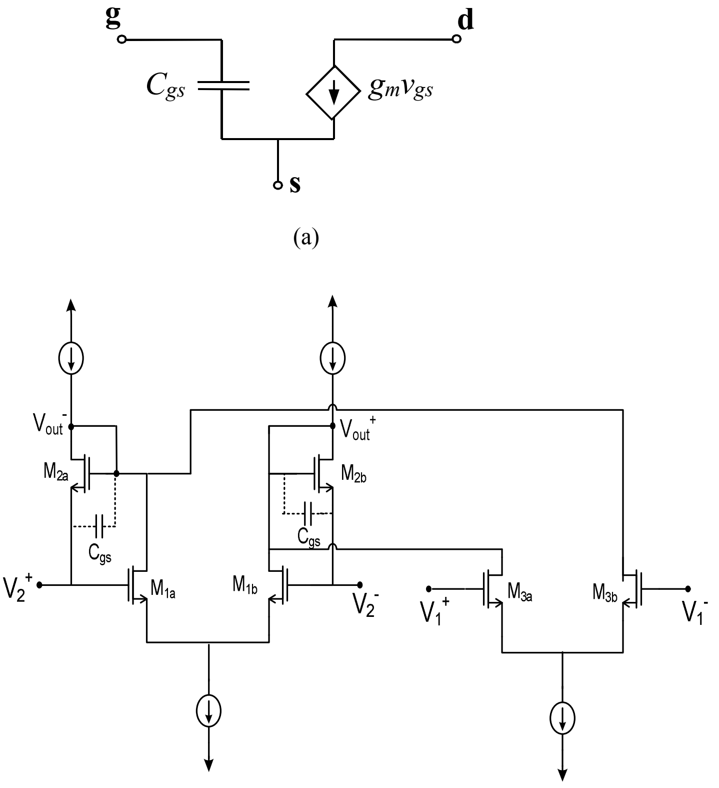
Note that in case of $V_1^+ - V_1^- = V_{in}$ and $V_2^+ - V_2^- = -jV_{in}$, , i.e. quadrature signals are applied to the filter, we obtain the function in (1). This also shows that: The desired signal with positive frequency falls in the filter's passband while the image signal at negative frequency is suppressed.

In low IF circuits, the low frequency RC circuit occupies too much space on the chip. Since capacitance and resistance are not used in MOS-only circuits, this kind of filters provides substantial area advantage.

The MOS small-signal model shown in Fig. 4a is used in the synthesis prosedure of the proposed active-only polyphase filter. The small-signal transfer function is obtained by:

$$V_0 = \frac{g_{m3}/g_{m2}}{1+sC_{gs}/g_{m2}}(V_1^+ - V_1^-) + \left(1 - \frac{g_{m1}/g_{m2}}{1+sC_{gs}/g_{m2}}\right)(V_2^+ - V_2^-) \quad (4)$$

where C_{gs} is the intrinsic gate capacitance and g_{m2} is the small-signal transconductance of the transistors. Provided that all transistors' transconductances are equal, the expressions in (3) and (4) are identical and the MOS-only circuit in Fig.4b simulates the RC subcircuit in Fig.3.



(a)

(b)

Fig.4. a) Simplified small-signal device model used in the filter synthesis. b) Proposed MOS-only circuit realizing the RC subcircuit in Fig.3.

B. Implementation of Image-Reject Polyphase Filter

By inspecting how two of the subcircuits in Fig. 3 are interconnected to compose the RC polyphase filter in Fig. 2, the active-only polyphase filter can be obtained accordingly by interconnecting two of the subcircuits in Fig. 4b. The circuit thus obtained is shown in Fig. 5.

It is clear that, the center frequency of the complex bandpass filter is obtained such as: $\omega_0 = g_{m2}/C_{gs}$. Note that in this implementation, not only substantial reduction in the chip area is achieved, but also a filter with all key parameters are electronically controllable, is obtained.

It should be noted that, in application where high-order filters are required, the proposed first-order polyphase filter can be used in cascade configuration to provide necessary image rejection.

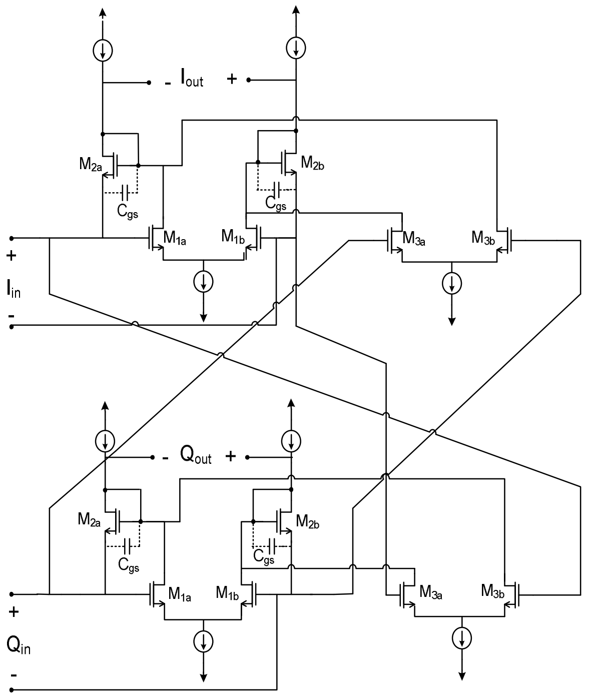


Fig.5. Implementation of the MOS-only polyphase filter.

4. Simulation Results

In order to realize a complex bandpass filter with a center frequency of 15MHz, we have designed the filter in Fig. 5 and obtained simulation results using Spectre simulation tools in Cadence design environment using model parameter of a 0.35µm CMOS process. The filter is biased with ±1.65V DC power supply and all biasing currents are 20µA except for the tail currents which are 40µA. In simulations, all current sources in Fig.5 are realized using simple current mirrors. Note that transconductances of all transistors should be choosen equal. The dimensions of MOS transistors are given in Table. 1. Simulated filter magnitude characteristic is shown in Fig. 6. From these results, the complex filter's center frequency is found as 15MHz and the image rejection ratio is also found as 32 dB.

Table.1 Dimensions of MOS transistors

$M_{1a,b}$	12µm/1 µm
$M_{2a,b}$	48µm/4 µm
$M_{3a,b}$	12µm/1 µm
NMOS current mirrors	12 µm /1 µm
PMOS current mirrors	30 µm /1 µm

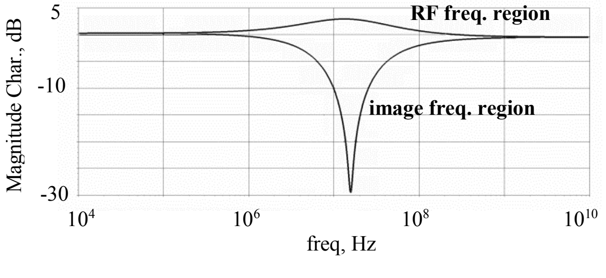


Fig.6. Simulation result of first order MOS-only polyphase filter

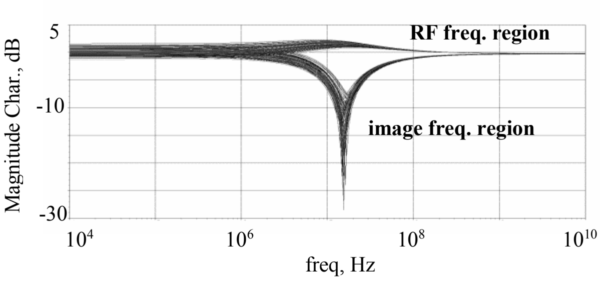


Fig.7. Monte-Carlo simulation results

In order to show the effect of mismatches on the filter performance, we have performed Monte-Carlo analysis of the circuit using the foundry provided models of process deviations. The proposed poylphase filter is simulated 100 times and the obtained magnitude characteristics are shown in Fig.7. Although the effect of mismatching can be alleviated by using larger and equal transistors, the filter has large sensitivities at low frequencies. Nevertheless, it can be clearly seen that image rejection ratio is no less than 18 dB. These results verify feasibility of the filter.

5. Conclusions

In this paper, a MOS-only polyphase filter with electronically adjustable filter parameters is presented. In order to verify the usefulness and feasibilities of the circuit, Cadence Spectre simulation results are provided. The proposed circuit is expected to provide substantial advantage over to the compared to passive polyphase filter in terms of the occupied chip area.

6. References

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