Approaching Ideal Polyphase Filter Response in 65-nm CMOS

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Abstract

This work analyzes the effect of the most critical non-idealities on a passive polyphase filter implemented in a 65-nm CMOS technology, to attain single-sideband transmission in a 5 GHz Wi-Fi alike communication system. Non-idealities impact on this kind of passive complex filter have not been thoroughly analyzed in literature.

Introduction

Multiplying two sinusoidal signals produces two tones placed in the sum and difference of original frequencies, the desired and image signals. This is used in heterodyne transmitters to increase signal frequency up to RF band by multiplying an IF signal by the signal generated by a local oscillator (LO). However, image signal must be sufficiently reduced to accomplish Wi-Fi standard [1].

A well-known method to avoid image generation is to include a polyphase filter (PPF) for mixing in-phase (I) and quadrature (Q) signals (see Fig. 1). Still, in a real approach, cancellation is not perfect because non-idealities of PPF, imperfect quadrature of LO signal and imbalance of mixers, reducing the image rejection ratio (IRR) [2]. This brief will focus on the effect and mitigation of PPF non-idealities, so perfect LO signal and ideal mixers are assumed.

Passive polyphase filter

A polyphase filter is a passive network compound exclusively of resistors and capacitors [3], compatible with a standard CMOS technology. In this work, MIM capacitors and poly resistors of a-65-nm CMOS process have been used.

Due to Wi-Fi standard was selected as reference, an IRR above 40 dB is required in a whole 20-MHz bandwidth and f_{LO} and f_{IF} were defined to a nominal values of 5 GHz and 100 MHz, respectively, leading to a transmission channel operating between 4.89 and 4.91 GHz and image between 5.09 and 5.11 GHz. To achieve these specifications, a three-stage filter is mandatory, defining three RC poles with infinite IRR, as shown solid line in Fig. 2. Its non-idealities have been evaluated [4] and the most critical ones will be presented next.

Temperature and process variations

Both effects cause a shifting in frequency of the filter response without altering its shape. Thus, the worst cases, which are the critical ones to be analyzed, are when their effects are correlated.

In order to avoid the impact of both non-idealities, PPF should achieve the required IRR not only in signal bandwidth but also with possible displacement, so pole splitting must be in concordance with that. In Fig. 2, the effect of these variations on IRR is shown.

Mismatch

Mismatch alters the internal balance of each stage, modifying position and magnitude of the poles and setting a maximum guaranteed level of IRR. Fig. 3 summarizes all of this showing the results of four 600-iteration Monte Carlo analyses (green zone covers 70% percentile and yellow 25%). According to the simulations, the impact is much more significant in the last stage than in previous ones, and the mismatch of the resistors is the main cause.

Parasitics

All parasitic elements of a PPF could be summarized in a single grounded capacitor in each node of the circuit. It is well known that if all parasitic capacitances of each stage are the same, just signal losses are affected. IRR worsens if they are different, especially when Q and I phases do not match. However, differences between path parasitics of opposite phases cause little reduction in IRR. This is shown in Fig. 4.

Conclusions

Non-idealities could have a strong impact on IRR as consequence of an imbalance among phases that should be mitigated to achieve a good performance. Thus, an adequate symmetry in layout design is the key of a good performance of a PPF. Besides, it should be highly recommendable to pay special attention to last stage, due to its critical relevance to IRR.

It has been demonstrated the potential to achieve an IRR of 40 dB in 65-nm CMOS technology despite non-idealities. Moreover, the results obtained in this work could be easily extrapolated to other nanometer CMOS technologies and different number of stages of PPF and RF bands.

Acknowledgements

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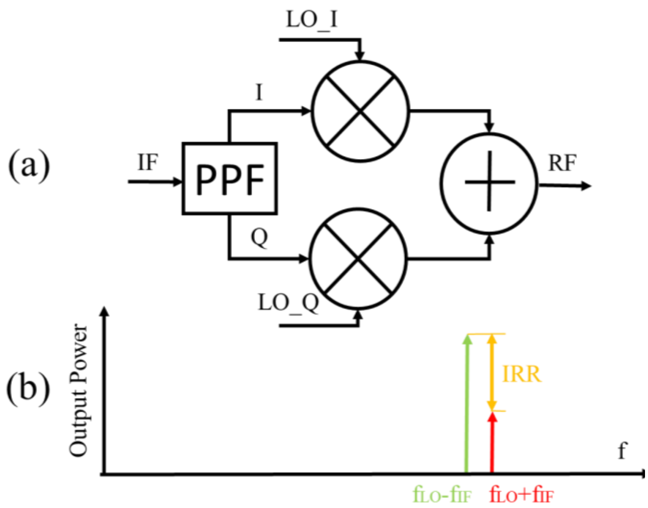

Fig. 1 (a) Heterodyne transmitter with quadrature architecture and (b) output spectrum.

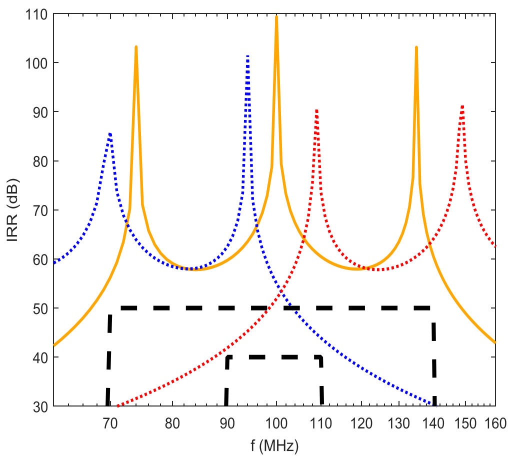

Fig. 2 Process and temperature effect. In orange, PPF in nominal corner. Dotted lines show filter response in worst-case corners. Dashed lines define IRR and bandwidth target.

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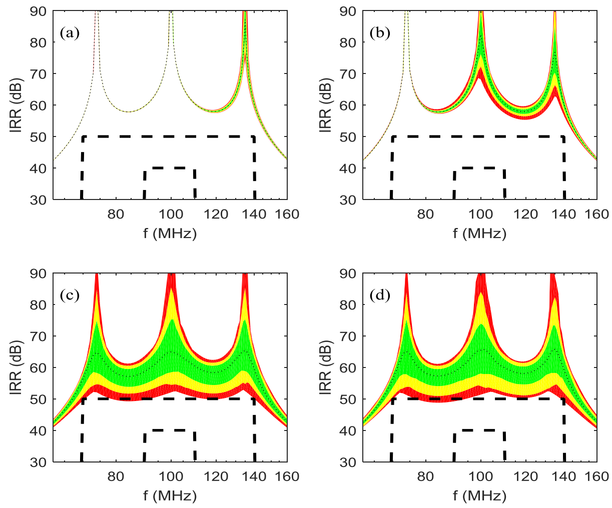

Fig. 3 IRR with mismatch only in (a) first stage, (b) second stage and (c) last stage. In (d) all stages with mismatch..

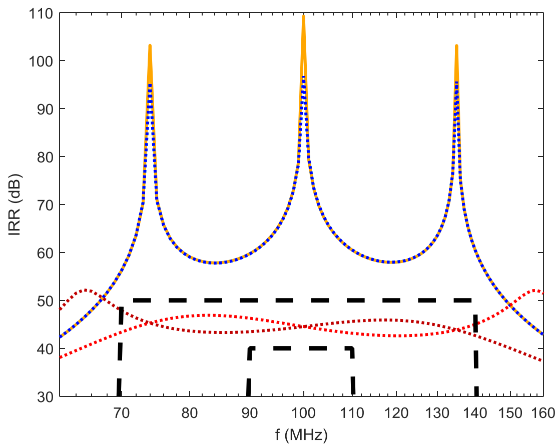

Fig. 4 Impact of imbalance of last stage parasitic capacitors between differential signals (blue) and quadrature signals (red). Perfect balance is shown in orange.