NOISE PERFORMANCE OF CMOS TRANSVERSAL BANDPASS FILTERS

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ABSTRACT

In this paper, the noise performance of the conventional MMIC transversal filter is studied. The in-band noise performance related to filter topology and circuit parameters are examined by a two-sections transversal filter. A noise figure approximation is also evaluated to characterize the filter noise performance. In order to show this approximation usefulness, a prototype MMIC filter centered @2.5GHz with about 10% 3dB BW is developed and it is implemented based on a 0.18μm CMOS technology. The simulation results show a good agreement with theoretical noise figure approximation.

1. INTRODUCTION

Conventional passive LC filters designed for modern communication transceiver either suffer the low Q problem or inductor implementation unavailability. As such, MMIC (Monolithic Microwave Integrated Circuit) active filters offer a unique solution to communication system, especially if the reduced weight and compact transceiver is of great concern [1]. But the main lingering doubts of this MMIC filter usage are the stability and non-linearity.

Referenced in chronological order, many new topologies have been proposed over years [2-6]. Recently, the transversal filtering technique has been proposed for use in MMIC active filters to relax the reliance on circuit elements with high Q-factors. In addition, this filter also offers high stability and selectivity. Even MMIC active filters provide the major advantages of small size and selectivity, the noise performance investigation is not yet received special attention [7-9]. As such, it is the objective of this work to investigate the noise behavior of CMOS MMIC active filter employing transversal filtering technique. For simplicity, the noise figure approximation is derived to account for the circuitry parameters' effect. Filter topological influence on noise behavior is also investigated so as to provide better understanding of the noise limitation for the active filter.

Besides this introductory section, Section 2 presents the noise analysis of the transversal filter and its noise figure approximation is also derived. Section 3, on the other hand, demonstrates the simulation results to illustrate the approximation usefulness. Finally, conclusion is then drawn in Section 4.

2. NOISE ANALYSIS OF MMIC TRANSVERSAL FILTERS

MMIC lumped and transversal filter, as shown in Fig. 1, relaxes the reliance on high Q element by the feedforward signal cancellation [1]. The lumped elements are used to achieve the basic bandpass response whilst the filter's band-edges are sharpened by the transversal elements [3]. Previous works report the filter transfer function as follows:

$$H(j\omega) = \sum_{k=1}^{N} A_k e^{-j2\omega k\tau_k} \quad (1)$$

where $H(j\omega)$ is the complex voltage transfer function of the transversal filter with N transversal elements

(A_k, k = 1...N), expressed in terms of the angular frequency ω. And τ_k is the sum of two time delays τ_{k1} and τ_{k2} introduced by sectional low-pass $L_{k1}C_{k1}$/high-pass $L_{k2}C_{k2}$ filters respectively. It is obvious that the larger number of transversal elements used, the higher selectivity the filter will obtain. But, to increase the number of transversal active elements may significantly affect the noise performance. As such, the filter investigated herein is based on two transversal elements sections.

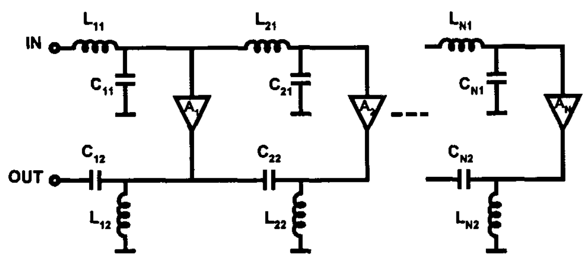

Fig. 1 Conventional Lumped and Transversal Filter.

2.1 Noise Performance subject to the Filter Structure Influence

In order to evaluate the noise performance of the transversal filter, the standard CMOS noise model is employed as depicted in Fig. 2 [10]. It is assumed that the dominant noise source in CMOS devices is channel thermal noise. Thus, the thermal noise current for a MOSFET operating in saturation is the dominant noise source and is as follows:

$$\overline{i_d^2} = 4kT\gamma g_{d0}\Delta f \qquad (2)$$

where g_{d0} is the zero-bias drain conductance
γ is a bias-dependent factor (2/3 < γ < 1)
k is the Boltzmann's contant
T = 290K
Δf is the bandwidth of the measuring system

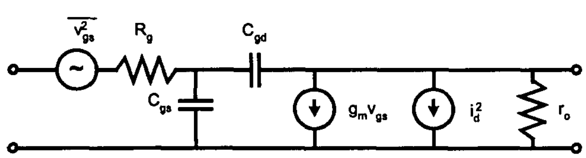

Fig. 2 Noise Model of CMOS Device.

In order to evaluate the filter structure influence on the noise performance, an additional amplifier FET_{1a} with the noise current governed by Eq.(2) is added to each transversal element respectively. As such, the noise current in each transversal element is increased and this indeed contaminates the noise figure. In fact, this noise figure influence is not significant if the amplifier FET_{1a} is added to left most transversal element as shown in Fig. 3. Simulation shows that there is only slight difference between the conventional filter's noise figure and the modified ones as shown in Fig. 4. Overall in-band noise behavior of these two filters is similar and both filters report a min. noise figure value of 6dB.

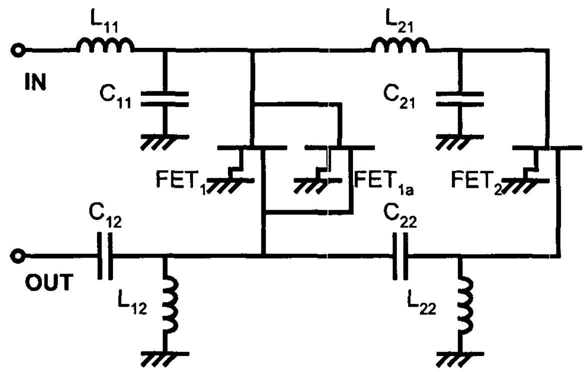

Fig. 3 Conventional Lumped and Transversal Filter with Additional Amplifier Configuration.

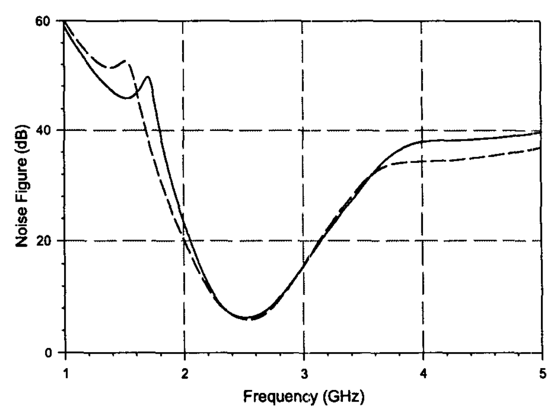

Fig. 4 Noise Figure Comparisons for the Conventional Lumped and Transversal Filter (--) vs. Lumped and Transversal Filter with Additional Amplifier Configuration (-).

In addition, it is clear from Fig. 5 that both the S_{21} and S_{11} transfer characteristics of the conventional lumped and transversal filter with additional amplifier configuration match the characteristics of that of the conventional lumped and transversal filter. The band edges' rejections of the filter with additional amplifier can be improved by moving the transmission zero closer to the mid band. Moreover, the input matching of the modified structure offers additional ~10dB improvement.

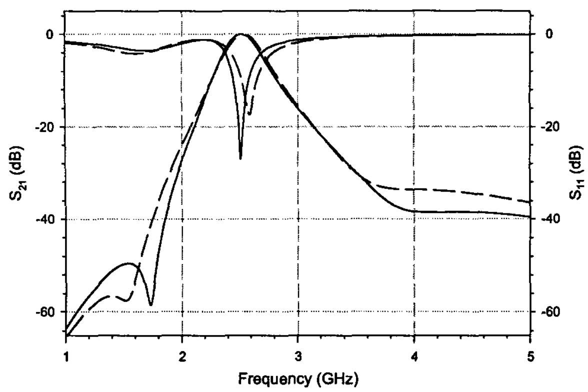

Fig. 5 Transfer Characteristics Comparisons for the Conventional Lumped and Transversal Filter (--) vs. Lumped and Transversal Filter with Additional Amplifier Configuration (-).

For the above conventional transversal filter under consideration, it can be assumed that the noise figure is mainly due to the right most transversal element as depicted in Fig. 3. As such, the filter's noise figure can be approximately determined by this transversal element alone.

2.2 Noise Figure Approximation

Assume the main contribution of the noise source is the transversal element FET2 under the above observation; the noise figure calculation can be simplified as a simple amplifier's noise figure determination. According to the noise model shown in Fig. 2, the approximation for the noise figure of the transversal element FET_2 can be written as [10]:

$$NF \approx 1 + \gamma \frac{1}{g_m R_s} + g_m \gamma R_s \omega \left(\frac{\omega - \omega_0}{BW} \right)^2 \qquad (3)$$

where ω_0 is center frequency
BW 3-dB bandwidth

3. SIMULATION RESULTS

In order to verify the above noise figure approximation, a conventional lumped and transversal filter with two sections is simulated in 0.18μm CMOS process. This filter is centered @2.5GHz with about ~10% 3dB BW. Using the noise figure approximation given in Eq.(3), ones can get the noise figure as shown in Fig. 6. For comparative purpose, both simulated and predicted noise figures are compared. It can be seen that there are some discrepancies between these two noise figures. Overall good noise figure performance in the level of 6dB @2.5GHz is achieved. The variations of the noise figures within the 3-dB BW range are in good agreement with the simulated ones. As such, this confirms the approximation correctness.

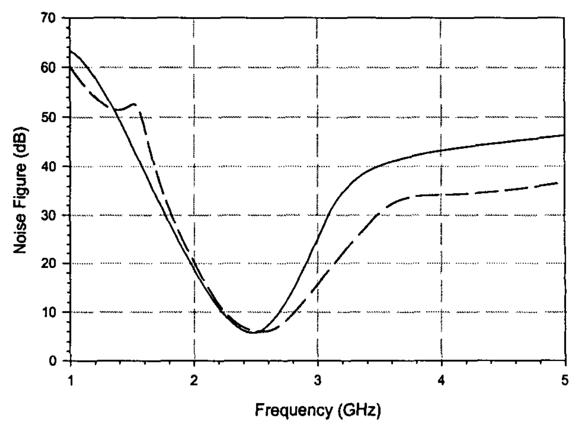

Fig. 6 Predicted (-) & Simulated (--) Noise Figure Comparison.

4. CONCLUSION

This paper has presented the noise performance study of CMOS MMIC lumped and transversal filter and its resemblance. The simulation result indicated that the designed lumped and tuned transversal filter offers a midband noise figure of 6dB @2.5GHz. In addition, an approximation for this filter is also presented and verified. It is envisaged that this approximation can be extended to large number of transversal element filter design.

ACKNOWLEDGMENT

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