COMPACT HIGH-ORDER PLANAR RING-RESONATOR FILTERS OPTIMIZED IN NOISE IN COPLANAR TECHNOLOGY

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ABSTRACT

This paper deals with technological considerations for the compact design of general planar ring-resonator structures that use active elements for frequency tuning and losses compensation. With our approach, noise performances optimization is simultaneously led by purely analytical means [1]. The technique is first applied to a one-pole tunable ring-resonator structure for which we discuss both microstrip and coplanar implementations. We underline the ease in implementing such structures in coplanar technologies and validate our approach with measured results of a two-pole version.

I. INTRODUCTION

With the rapid expansion of new applications, such as mobile communications, microwave engineers have found great advantage in using active filters. However, in the design of microwave active filters, researchers face problems with imperfect active devices and lossy passive components. The situation is similar to that encountered before the advent of high-performance op amps in the 1950s and 1960s, when audio-frequency active-RC filter designs were attempted. Although the physical constraints are different, the advantages of low frequency techniques carry over to microwave frequencies, thus showing an increasing interest in adapting these techniques for use in microwave systems. One of these techniques includes the design of recursive and transversal filters from which planar ring-resonator structures are derived. Nevertheless, the use of active elements introduces new design parameters and problems such as electrical stability, power handling behavior and noise performance. We use here a noise wave formalism to analytically evaluate the noise figure of ring-resonator multipole planar microwave active filters. After some theoretical points, we present the design of a one-pole filter and discuss the implementation both in microstrip and coplanar technologies. Advantages of coplanar technology are validated with the compact design of a hybrid tunable two-pole ring-resonator filter which noise performances have been optimized.

II. THEORETICAL BACKGROUND

Among all the possibilities for N-pole resonator structures, the topologies under consideration consist of N planar ring coupled resonators as shown in Fig. 1. They are developed in detail in [1].

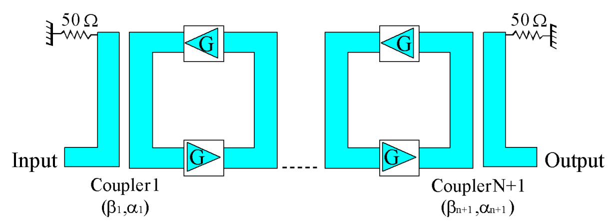

Fig. 1. General topology of ring-resonator filters

The general transfer function of these ring-resonator filters can be expressed as :

$$S_{21}(f) = \frac{K\, e^{-j\pi \frac{f}{f_0}}}{1 + \sum_{n=1}^{N} K_n\, e^{-2n\pi \frac{f}{f_0}}}$$

K and $\{K_n\}$ are functions of the coupling values and the amplifier gains. The response of these filters can be identified to N-pole bandpass recursive transfer functions [2]. Consequently, these filters can provide frequency tunable responses.

From the synthesis point of view, the objectives have been to find by purely analytical means (see [1]), the coupling values and the amplifier gains within the structure to ensure the following performances at the center frequency f_0 :

- amplification in the passband while keeping the electrical stability of the whole structure,
- input and output matching to 50 Ω ($|S_{11}| = |S_{22}| = 0$),
- optimum noise performances.

The noise performances of filters matched to 50Ω are characterized by a noise performance factor M defined as :

$$M = \frac{F - 1}{1 - \frac{1}{|S_{21}|^2}}$$

where F is the noise factor of the filter, $|S_{21}|$ is the transfer function of the filter. This parameter is more significant when cascading circuits than the noise factor F, because it also takes into account the gain of each sub-circuit within the cascade. For the noise analysis, we use a noise-wave formalism described in [2][3].

III. ONE-POLE FILTER DESIGN

An example of these structures is now presented in the first-order case. We apply our design considerations to the case of the topology of Fig. 2, as shown in [1]. The chosen topology is particularly interesting because a minimum noise is obtained for a maximum gain of the filter at the center frequency.

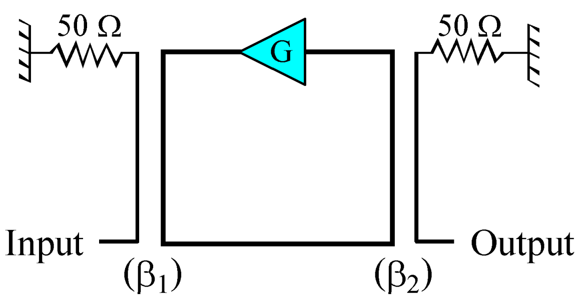

Fig. 2. First-order active ring-resonator filter

The transfer function is given by :

$$|S_{21}(f_0)| = \frac{\beta_1\beta_2}{1 - \alpha_1\alpha_2 G_0} = \frac{\beta_1\beta_2}{1 - V}$$

where V defines a given selectivity and the corresponding electrical stability of the filter [2].

For a given amplifier defined by its gain G_0 and noise factor F_A and for a given selectivity V, we derive β_2 as a function of G,V and β_1. It then remains one degree of freedom β_1 to analytically optimize the noise factor of the filter while maintaining the desired selectivity and response of the filter [1]. For a given selectivity, we notice that the noise factor M decreases when G_0 increases [1].

A. Design Parameters – Simulated Results

The amplifier/phase shifter chip used here for the filter implementation has already been developed in [4].

The chip includes two varactor diodes used as a voltage controlled element for the phase shift tuning. Dimensions of the chip are 1*3 mm^2. The measured maximum phase shift performed is 55° and the gain is near 7.5dB in the [3-5GHz] frequency band. The center frequency is f_0=4GHz and the noise factor is about 4.5dB. This amplifier module is very interesting for our filter because, as said earlier, the high gain and low noise factor are adequate conditions for a low noise filter design. The objective filtering performances are : f_0=4GHz and V=0.90 (Q=30). With $|G_0|$=2.2, F_A=4.5dB and M_A=2.29dB at f_0, we obtain $|S_{21}|$=9.1dB, F_{opt}=4.8dB and M_{opt}= M_A=2.29dB.

B. Implementation in Microstrip Technology

This filter has been first designed in microstrip technology and implemented on a 790µm-thick Duroïd substrate (ε_r=2.32). With this technology, many problems reside in via-holes and connections of the active chips which introduce a parasitic inductance that cannot be avoided. The complexity of the global circuit due to the connection of the active chips do not permit to take into account all the parameters during the simulation steps. Moreover, for high coupling values, the coupled lines are neither enough well-matched to 50Ω nor modeled precisely enough in terms of losses and equivalent electrical length, thus leading to a shift of the center frequency and a lower gain at this frequency. Measured performances of the filter are $|S_{21}|$=2.55dB and F=5.8 dB at f_0=4.72GHz. At center frequency, S_{11} and S_{22} are less than -7 dB.

C. Implementation in Coplanar Technology

Many studies have shown that, in most cases, coplanar waveguides can be a good alternative to microstrip lines because of more ease and flexibility in the design [5]. Because all conductors are located on the same plane, the ground connections for the active chips through via-holes or ground report are eliminated, thus leading in more ease for connecting the active parts and in more compact designs. Another advantage of coplanar technology is that each element characteristic can be adjusted and improved through additional geometrical parameters. According to this degree of freedom, high directivity couplers can then be easily achieved by minimizing the difference between the phase velocities of the two normal modes [6].

At the initial step, we have added matching network at the input of the chip to improve the global filter performances. Fig. 3 shows the layout of the active filter. The circuit is implemented on a 635µm-thick alumina substrate (ε_r=9.6). Dimensions of the filter are 40*25.4mm^2.

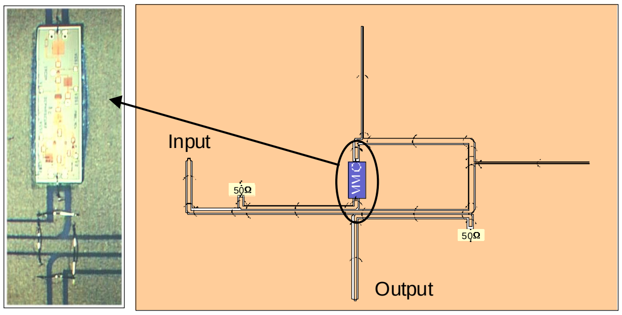

Fig. 3. One-pole filter layout in coplanar technology

Measured results in Fig. 4 are in perfect agreement with simulations. For V_d=-1.25V of the diodes, the gain of the filter $|S_{21}|$ is equal to 4.8dB at f_0=3.94GHz. Tuning frequency bandwidth is about 220 MHz. At center frequency, S_{11} and S_{22} are less than -8 dB for all the diodes biasing values. Corresponding simulated noise factor is F=5.2 dB. So, for an easiest implementation in coplanar technology, the results are obviously better than with the microstrip approach.

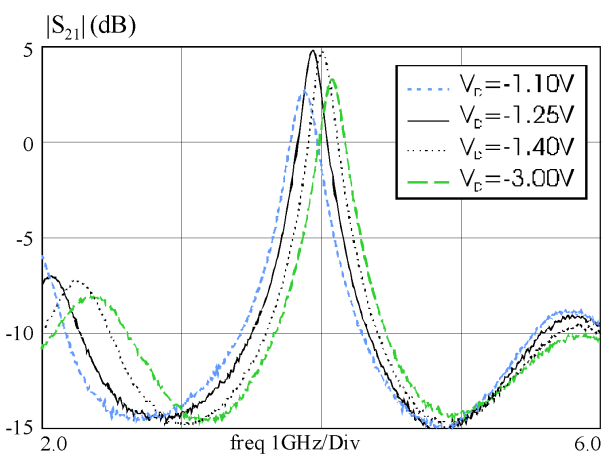

Fig. 4. Measured S_{21} of the first-order filter in coplanar technology

IV. TWO-POLE FILTER DESIGN

We now consider three pairs of parallel coupled lines with up to two amplifiers within each passive ring-resonator to achieve a second-order structure using the same approach in coplanar technology. Assuming that, there is the same number of phase shifter structures within each planar ring-resonator, these filters can also simply provide frequency tunable responses.

It can also be shown that the filter characteristics can be analytically parameterized with the objective bandwidth Δf and ripple δ within the passband.

We consider the topology in Fig. 5.

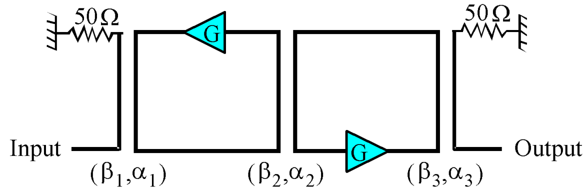

Fig. 5. Second-order active ring-resonator filter

In the same way than for the first-order case, for a given amplifier defined by its gain G_0 and noise factor F_A and for a given bandwidth Δf and ripple δ within the passband, we derive β_2 and β_3 as functions of G,V and β_1. It then remains one degree of freedom β_1 to analytically optimize the noise factor of the filter while maintaining the desired selectivity and response of the filter.

We use here the same amplifier/phase shifter than in the first-order case. The objective is to achieve an objective bandwidth Δf =120MHz and a ripple δ=0.2dB within the passband. With $|G_0|$=2.2, F_A=4.5dB at f_0, we obtain $|S_{21}|$=13.7dB, $|S_{ii}|$<-12dB and F_{opt}=6.5dB (see Fig. 6)

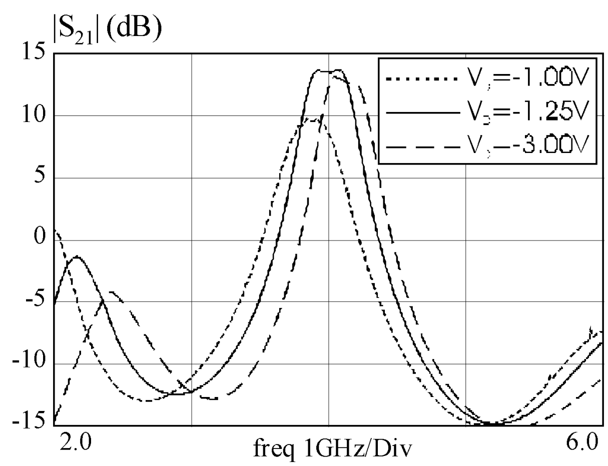

Fig. 6. Simulated S_{21} of the second-order filter

Fig. 7 shows the layout of the active filter. The circuit is implemented on a 635µm-thick alumina substrate (ε_r=9.6). Dimensions of the filter are 38*18mm^2. A photograph of the circuit on its test fixture is given in Fig. 8.

Measured results in Fig. 9 are in perfect agreement with simulations. For V_d=-1.25V of the diodes, the gain of the filter $|S_{21}|$ is equal to 13.6dB at f_0=4GHz. Tuning frequency bandwidth is about 200 MHz. At center frequency, S_{11} and S_{22} are less than -10 dB for all the diodes biasing values. Power consumption is about 24mW.

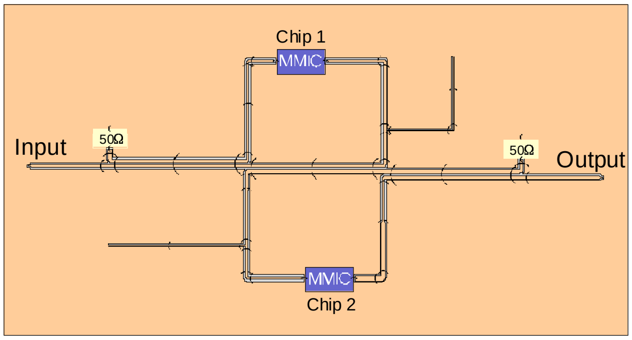

Fig. 7. Two-pole filter layout in coplanar technology

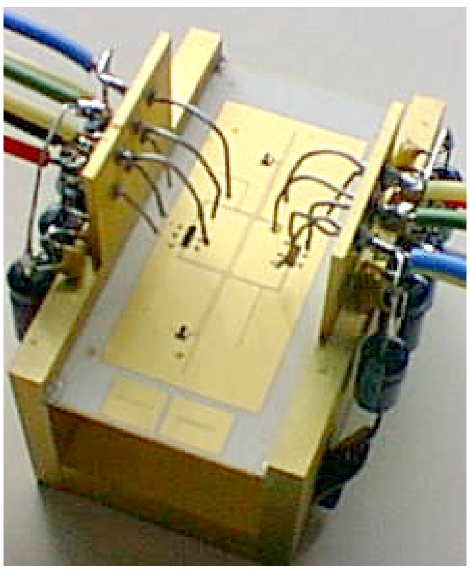

Fig. 8. Photograph of the two-pole filter

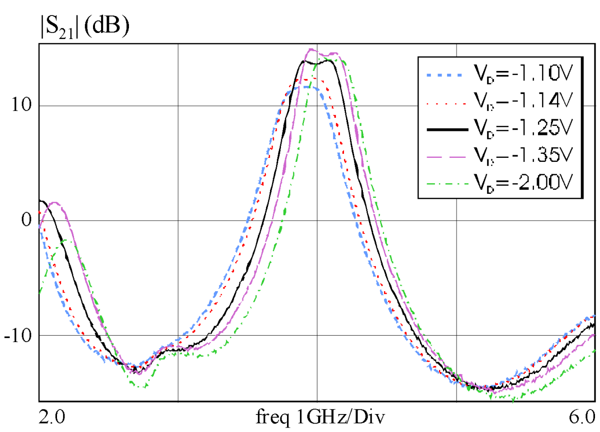

Fig. 9. Measured S_{21} of the two-pole filter

Fig. 10. shows a perfect agreement between simulated and experimental results for f_0=4GHz, thus validating our design approach.

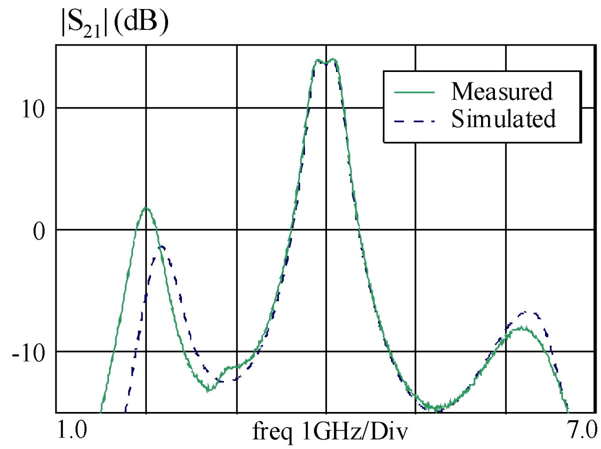

Fig. 10. Comparison between simulation and measurements of the second-order active ring-resonator filter

V. CONCLUSION

In this article, a first-order hybrid ring-resonator active filter using a MMIC amplifier/phase shifter is presented in microstrip and coplanar technologies. With our approach, gain in the passband, optimum noise performances and frequency tuning range can be optimized by purely analytical means. We have also demonstrated that coplanar technology is more adequate for the design of compact planar looped systems that use active elements for frequency tuning and losses compensation. Our approach is validated with the design of a 2nd-order filter which measurements are in total agreement with the simulations.

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