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Miniaturized loop-filter with high out-of-band rejection for future UMTS mobile terminals

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Abstract - This paper deals about the implementation of miniaturized band-pass filters operating on a very narrow bandwidth. An original synthesis technique is proposed for achieving high out-of-band rejection by means of a loop resonator where transmission zeros are introduced through mutual coupling effects. Quite good performances are obtained regarding losses, size and spurious resonances for the proposed topology, which can be considered as a good solution for mobile equipments.

I. INTRODUCTION

With the emergence of new telecommunication services and architectures, specific and drastic requirements are involved today concerning on-board electronic equipments, especially about filters and multiplexers. The transmission losses within the operating Tx and Rx bandwidths, usually less than 3%, as well as the out-of-band responses and the isolation between channels, remain critical parameters for both base stations and mobile terminals.

Among the numerous possible configurations, new generations of band-pass filters, like SAW filters or coaxial ceramic modules, have been developed and extensively used, mainly for mobile devices for size and cost motivations. Nevertheless, many difficulties are encountered when implementing such filters, considering either reliability or interconnection constraints with common electronic functions integrated in RF front ends.

In this way, microstrip filters remain really attractive. Significant efforts have been done in order to improve the electrical performances and the dimensions of such elements. Then, alternative but efficient solutions can now be proposed for substituting the conventional hybrid configurations (SAW or ceramic filters mounted on PCB) used up to this time [1] [2] [3].

The figure 1 describes various types of band-pass filters which can be considered as well-suited solutions for improving both the size and the performances of microstrip topologies. In this paper, we consider a basic

open loop resonator, derived from the well-known hair-pin filter, which is modified and optimised in terms of size, loss and rejection thanks to an original combination of synthesis and implementation approaches. We first discuss about the possibility of reducing the transmission losses. We emphasise on an original synthesis technique for improving the out of band rejection of these reduced-order filters by introducing low and high adjacent coupling phenomena and controlling resonance effects. The agreement between simulations and measurements underlines the good control of the design methodology and modelisation task.

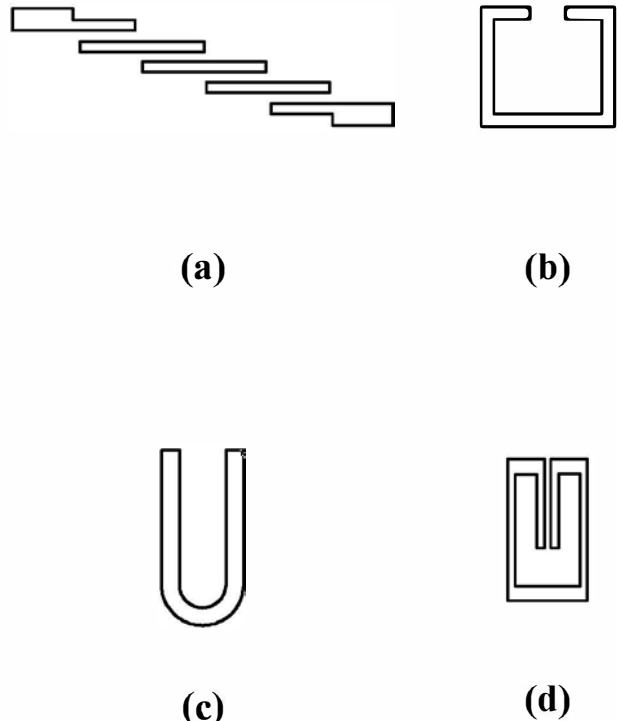


Fig.1 : Microstrip filters architectures based upon resonant structures
(a) filter with $\lambda_g/2$ open-end resonators, (b) open loop $\lambda_g/2$ resonator, (c)-(d) hair-pin resonators

II. FILTERS FOR MOBILE APPLICATIONS : MAIN REQUIREMENTS AND DIFFICULTIES

Typical limitations and specifications are required about the integration of filters for present and future telecommunication mobile systems. They can be summarized under the following fundamental points :

- Transmission losses must be as low as possible, requiring basic resonant structures with high Q factor
- The size is a critical parameter for integration constraints. This is generally achieved by limiting the number of resonators (1st or 2nd order filters).
- Relative operating bandwidths do not exceed 2 or 3%. This results in very low coupling levels between adjacent resonators, which contributes to significantly increase radiating losses.
- The cost has to be reduced, by choosing appropriate materials and interconnecting techniques.

The loop-resonator used for designing hair-pin filters can be considered as one of the basic topology which can meet the previous points.

III. DESIGN METHODOLOGY FOR IMPROVING MICROSTRIP FILTER PERFORMANCES

As mentioned before, one of the main preoccupation consists in ensuring quite a good isolation between Rx and Tx channels, and simultaneously maintaining low insertion losses in both operating bandwidths, especially for the receiver.

The losses can be fundamentally minimised by using a single filtering resonator (1st order filter). This solution is also suitable for minimizing the filter area, but involves severe conditions on the resonator Q factor for achieving simultaneously quite a high out-of-band rejection and low insertion losses. The Q factor of microstrip resonators is basically low (about 250) but can be improved by using wide conductive resonant lines.

In addition, despite the small bandwidth usually required, the radiation and dielectric losses inherent to the microstrip structure have to be reduced by overcoupling the resonator to its feeding lines. We have investigated on such a solution, and proposed an original approach for controlling the out-of-band rejection by inserting transmission zeros.

A. Introducing input and output high coupling levels

In order to control the radiation and dielectric losses, we investigate on basic loop-resonators strongly coupled to their microstrip feeding lines. This can be achieved at once by reducing the spacing between the input/output lines and the resonator, but limitations are quickly encountered because of technological limitations.

Another solution consists in extending the coupling length, but this leads to oversize the structure and may introduce spurious resonances.

We propose an alternative solution by introducing interdigitated coupling areas instead of homogeneous coupled lines. This is obviously the best solution to meet loss and size requirements. Figure 2 shows a comparison between the simulated responses of a basic open-loop resonator coupled to its feeding lines through conventional or interdigitated coupled topologies. The coupling phenomena is significantly increased by way of the fringing fields between the resonator and the lines.

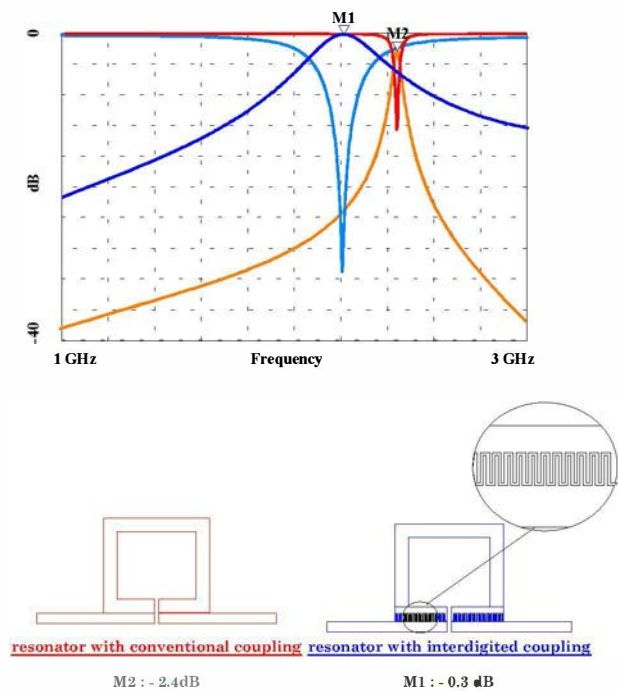


Fig. 2 : Simulated responses of a loop resonator with conventional and interdigitated coupling

For an optimal coupling level, which corresponds here to a $\lambda/6$ coupling length, insertion losses are quite small (0.3dB at 2.2 GHz). In comparison, with the conventional coupling technique, a small operating bandwidth is achieved, in accordance with the Q factor of the resonator, but the overall losses are strongly degraded by the external Q factor (2.4dB at 2.35 GHz). However, it is now necessary to introduce transmission zeros each apart the operating bandwidth for improving the out-of-band rejection level. The strong coupling effect also modifies the centre frequency of the resonator to a lower value, but this effect is compatible with miniaturisation considerations.

B. Ensuring a high out-of-band rejection

In order to achieve high rejection levels in the lower and upper cut bands, we introduce transmission zeros in the filter responses. Despite transmission zeros are usually obtained by means of mutual interactions between non-adjacent resonators, we rather prefer to work with a single resonator filter for size motivations. A first transmission zero can be introduced by coupling the open-ends of the feeding lines. Additional coupling effects are produced inside the previous described loop resonator, by modifying its shape.

Such modifications induce multiple paths for the resonant mode, and therefore numerous resonant conditions. Then, it becomes possible, through an appropriate decomposition of the resonator shape, to generate destructive resonance conditions which result in transmission zeros.

C. Final filter topology : Design and experimental results

The modified loop-resonator is presented on figure 3. A high coupling region is now located inside the resonant structure, while low coupling effects are still maintained at the feeding lines extremities. The combination of these two constructive effects is used to introduce a transmission zero nearby the filter operating bandwidth. The design procedure is performed on HP-MoMentum software. A 1.5 % band-pass filter has been realised at $f_0=1.9$ GHz (30 MHz bandwidth), with a transmission zero at 2.07 GHz ($1.09 f_0$). The dimensions remain quite small despite this low operating frequency (7 mm*5 mm), in accordance with the original synthesis technique involved, and thanks to an appropriate substrate selection ($\epsilon_r=10/h=635 \mu\text{m}$).

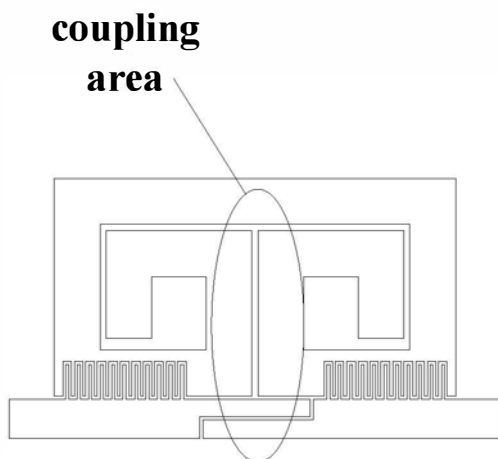


Fig. 3 : Configuration of the new loop band-pass filter



Fig. 4 : Photography of the new loop band-pass filter

Experimental results are provided on figure 4, in comparison with simulated ones. Insertion losses are quite small (less than 1.6dB) for a -10dB return-loss bandwidth of about 2%. A -30 dB rejection level is obtained on a 30MHz band centred at 2.06 GHz, which corresponds in our application to the TX channel. Quite a fair agreement is obtained between 2.5D simulations and experiment.

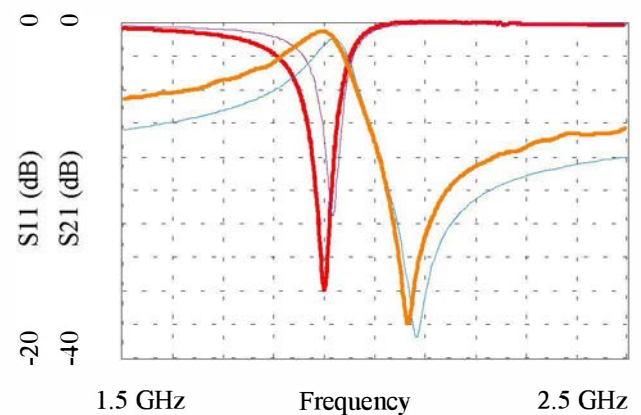


Fig.5 : Measurement (thick line) – Simulation (fine line)

Notes that the transmission zero can only be placed at higher frequencies with respect to the centre resonance of the structure. This is due to the path length of the additional coupled section within the loop resonator which is consequently resonating at a frequency greater than f_0 . The introduction of transmission zeros at lower frequencies should require at least 2nd order topology with multiple non-adjacent coupling.

IV. CONCLUSION

A new loop-filtering resonator is presented in this paper. A single resonator is employed in order to minimize the dimensions and the insertion losses. Additional tuning parameters are introduced by modifying the shape of the resonator in order to improve the out-of-band rejection and the transmission losses. Despite only one resonator is considered (1st order filter), the different coupling phenomena and resonant paths produced by the particular resonator geometry are efficiently used to ensure very high rejection levels. This modified loop-filter is consequently really attractive for wireless applications regarding its performances (loss, rejection, size) and becomes a good candidate for the future third generation of UMTS terminals.

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