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Development of compact cross-coupled filters for mobile communications

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Investigations on compact devices developed for the second (2G) and the third (3G) mobile communications systems are presented in this paper. Four-pole and six-pole filters were designed by cross-coupling new compact planar resonators. The coupling constants were investigated as functions of coupling gaps. Several models of the pass-band filters were manufactured and characterized. They exhibit steeper responses due to the cross-couplings, which introduce transmission zeros on each side of the pass-band. Moreover, due to their shapes, the resonators exhibit a first high order response at more than twice the fundamental frequency, therefore the filters show an enlarged rejection band. The measured filter responses are in a good agreement with the simulated responses. The developed filters are compact, cost-effective and suitable to be designed on high dielectric constant ceramic substrates, or for high temperature superconducting (HTS) circuits.

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Keywords: Mobile communications, Microwave filters, Coupling matrix, Microstrip devices

1. Introduction

The rapid evolution of the wireless communications systems requires cost-effective devices with improved parameters. For the mobile communications of the second (2G) and the third (3G) generations, the size reduction of the transmission-line devices is a major requirement. The device and circuit miniaturization could be provided by the substrates made of low-loss and high-dielectric constant ceramics [1,2]. Moreover, new types of planar resonators are very attractive for the development of compact devices with enhanced electrical characteristics.

Small resonators, as the stepped-impedance resonators, have been already proposed for planar circuits [3]. Furthermore, it was shown that a better compactness could be achieved by adding one [4] or two pairs of stubs [5] to the conventional stepped-impedance resonators. While appropriate positive and negative couplings are provided between resonators, filters with improved quasi-elliptic responses are obtained [6]. Investigations on compact cross-coupled filters with improved characteristics are presented in this paper.

2. Experimental

In order to prove the feasibility of new compact devices for base-stations of mobile communications systems, microstrip filters were developed on a Rogers substrate with a 10.8±0.25 dielectric constant. The devices were manufactured by using a standard photolithographic process and low-VSWR SMA connectors were mounted at the input and output ports.

The magnitude and phase of the scattering parameters, i.e. the transmission S_{21} and reflections S_{11} and S_{22} at the first and the second port, respectively, were measured in the 0.01 ÷ 3 GHz frequency range by using a Hewlett-Packard HP-8753C network vector analyzer, after a full two-port calibration was carried out.

3. Cross-coupled planar filters for UMTS applications

The 5.8 mm square size resonator, proposed for the Universal Mobile Telecommunications Systems (UMTS) standard of the third generation (3G), exhibits the fundamental mode resonance at f_0 = 1950.2 MHz. The first higher order resonance is at f_1 = 4524 MHz ~ 2.32 f_0. Therefore all devices based on this resonator will present an enlarged rejection band.

In order to design filters for UMTS applications, the coupling coefficients between the resonators and with the external circuit were investigated. The square geometry of the resonator allows three different types of couplings: electric, magnetic and mixed (partially electric and partially magnetic). The dependence of the coupling coefficients on the coupling gap for a zero offset is shown in Fig. 1. The magnetic coupling is the strongest, and the electric coupling is the weakest. As the external coupling, a direct (galvanic) coupling was preferred to a capacitive one. The external quality factor Q_{ext} increases when the coupling line approaches the middle point of the open-loop step-impedance resonator.

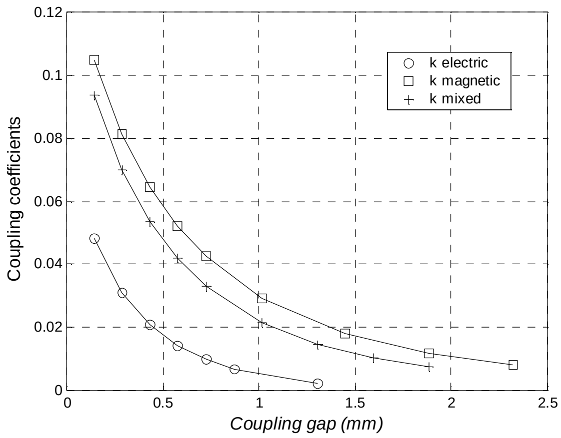

Fig. 1. The coupling coefficients versus the coupling gap for a zero offset.

Planar filters were designed for some determined coupling coefficients. A cross-coupled filter configuration was preferred to the direct-coupling configuration, in order to improve the filter response. The first model of cross-coupled filter shown in Fig. 2 was designed for a 96 MHz 3 dB-bandwidth, accordingly to the coupling matrix **M**:

$$\mathbf{M}_4 = \begin{bmatrix} 0 & 0.037678 & 0 & -0.00458 \\ 0.037678 & 0 & 0.029335 & 0 \\ 0 & 0.029335 & 0 & 0.037678 \\ -0.00458 & 0 & 0.037678 & 0 \end{bmatrix} \quad (1)$$

and with the external quality factor $Q_{ext} = 14.219$.

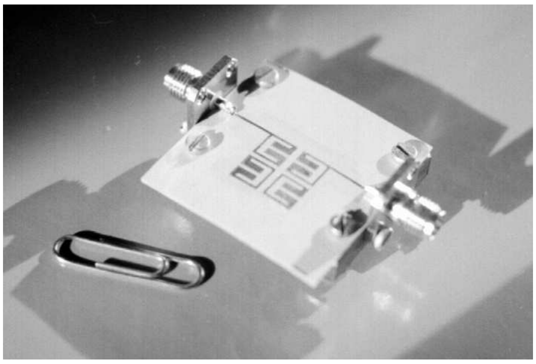

Fig. 2. The first model of the four-pole cross-coupled band-pass filter for UMTS systems.

The negative elements $M_{14} = M_{41}$ in the coupling matrix (1) involve a negative (electric) coupling. The quasi-elliptic filter response shown in Fig. 3 exhibits two attenuation poles on each side of the pass-band, as a result of the cross-couplings. This is a very useful effect for an improved rejection close to the band edges, hence for an improved selectivity. As shown in Fig. 3, the cross-coupled filter exhibits a steeper response than the Chebyshev response of a conventional direct-coupled filter. The measured group delay of the filter, shown in Fig. 4, is flat in the pass-band. Moreover, the filter exhibits a wider rejection band than the devices based on usual half-wavelength resonators, as shown in Fig. 5.

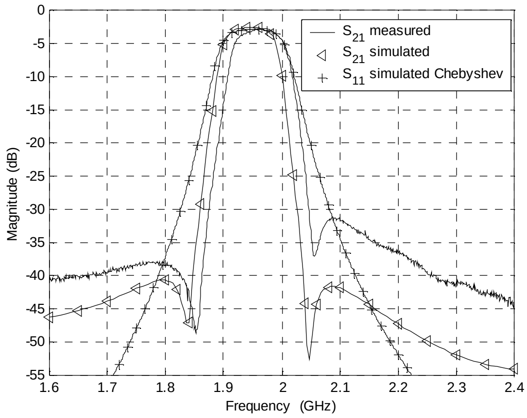

Fig. 3. Measured and simulated frequency response of the first filter model shown in Fig. 2.

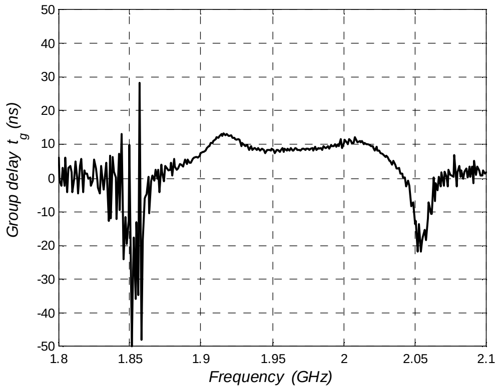

Fig. 4. Measured group delay of the first filter model shown in Fig. 2.

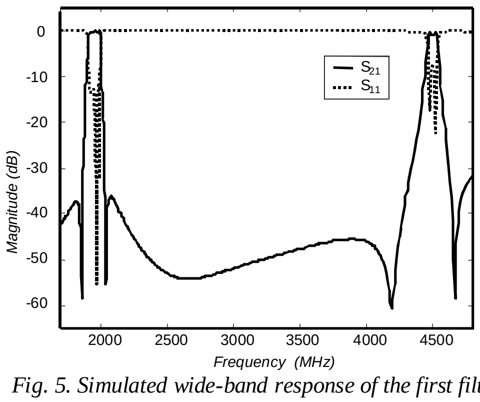

Fig. 5. Simulated wide-band response of the first filter model shown in Fig. 2.

In order to prove the feasibility of filters with different bandwidths, a second filter model was developed for a 140 MHz 3dB-bandwidth. This second model of the UMTS filter is shown in Fig. 6. The couplings are stronger and the Q_{ext} is smaller than in the previous case. Due to the narrower coupling-gaps, second-order cross-couplings appear ($M_{13} = M_{24} \neq 0$) and they result in some deterioration of the simulated $\boldsymbol{S_{11}}$ response compared with the expected $\boldsymbol{S_{11}}$ response of the prototype filter, as shown in Fig. 7. However, the measured response of the filter follows closely the simulated response. Moreover, as for the previous case, the measured group delay depicted in Fig. 8 is flat in the pass-band.

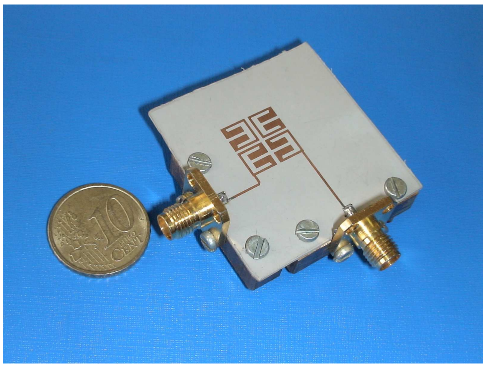

Fig. 6. The second model of the band-pass filter for UMTS systems.

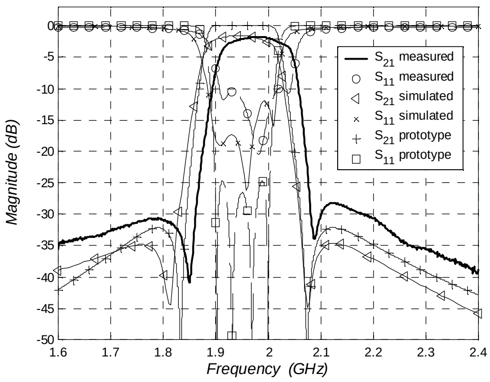

Fig. 7. The comparison between the measured, simulated and prototype responses of the second UMTS filter model.

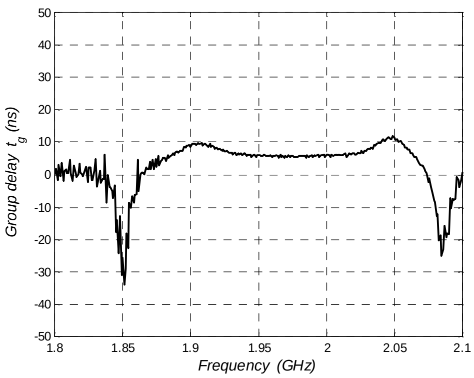

Fig. 8. Measured group delay of the second UMTS band-pass filter model.

A third model of the UMTS filter with a narrow 3 dB band of 32 MHz was also investigated. The picture of this filter is shown in Fig. 9. The distances between resonators are larger than those in the first and second UMTS filter models because of the required lower coupling coefficients.

Due to the finite value of the intrinsic quality factor Q_0 of the microstrip resonator, the narrow-band filter response shown in Fig. 10 exhibits an increased in-band insertion loss, as predicted by the simulations. Furthermore, while the attenuation poles on each side of the pass can easily be observed in Fig. 3 and Fig. 7 for the previous filters, the measured and the simulated responses shown in Fig. 10 of the narrow-band filter practically do not show the attenuation poles on each side of the pass-band. Instead of these poles, two points, where the attenuation rate suddenly changes, can be observed.

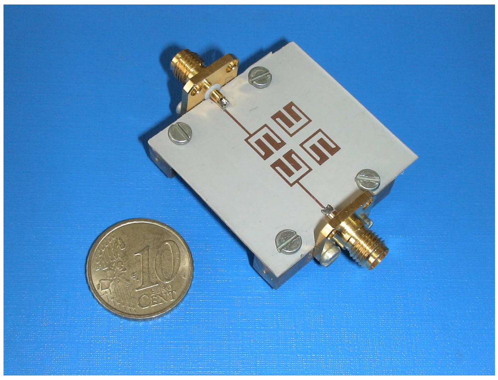

Fig. 9. The third model of the UMTS filter with a narrow pass-band.

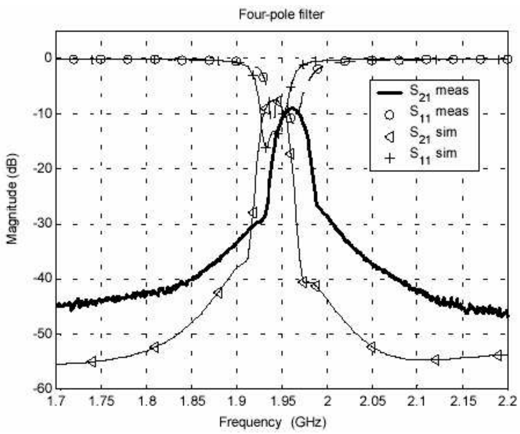

Fig. 10. The measured and simulated frequency responses of the third model of the UMTS cross-coupled filter.

4. Compact filters for GSM / GPRS applications

The issue of size-reduction is even more important for low frequency bands such as the 900 MHz frequency band of the GSM / GPRS mobile communications systems of the second generation (2G). A design method to reduce the surface area occupied by a single resonator down to 32% of the area of a square loop half wavelength resonator was developed [4]. As for the devices discussed above, the resonators' square shape allows cross-couplings between them for an improved quasi-elliptic filter response.

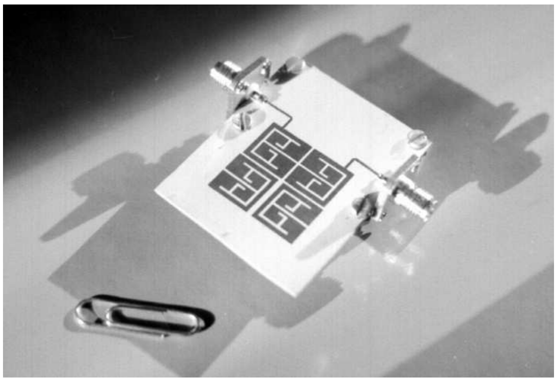

Fig. 11. A four-pole band-pass filter with compact cross-coupled resonators for 900 MHz GSM/GPRS systems.

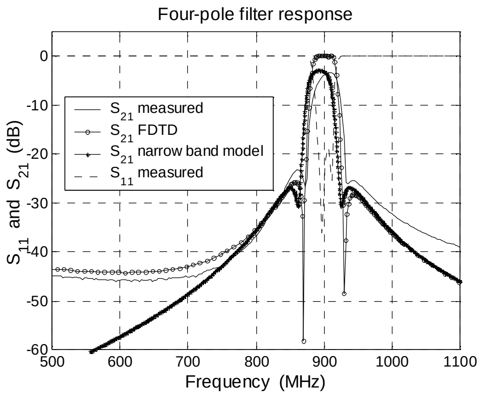

Fig. 12. The frequency response of the four-pole GSM / GPRS filter.

In the case of these filters, the step-impedance resonators have been modified by adding symmetric stubs in order to reduce the resonance frequency of the fundamental mode and to increase the resonance frequency of the first higher-mode for an enlarged rejection band. An example of four-pole cross-coupled pass-band filter for GSM / GPRS applications is shown in Fig. 11. In Fig. 12, the measured response of this filter is compared with the simulated response by using a Finite-Difference Time-Domain (FDTD) method, and with the response of a prototype circuit, which includes the losses. The FDTD response follows closely the measured response. However, at this stage, the in-house developed FDTD method does not include the losses, therefore the FDTD response does not predict the in-band insertion loss. On the other hand, the prototype response accurately estimates the in-band insertion loss but does not precisely estimates the filter response at frequencies far from the filter central frequency, because the prototype is a narrow-band model.

In order to improve the out-of-band rejection, a six-pole cross-coupled filter was designed and manufactured for GSM / GPRS. The same compact planar resonators were employed as for the previous four-pole filter. The external quality factor is Q_{ext}=19.69 and the coupling matrix of the filter is given by:

$$\mathbf{M}_6 = \begin{bmatrix} 0 & 0.0342 & 0 & 0 & 0 & 0 \\ 0.0342 & 0 & 0.01917 & 0 & -0.0078 & 0 \\ 0 & 0.01917 & 0 & 0.0245 & 0 & 0 \\ 0 & 0 & 0.0245 & 0 & 0.01917 & 0 \\ 0 & -0.0078 & 0 & 0.01917 & 0 & 0.0342 \\ 0 & 0 & 0 & 0 & 0.0342 & 0 \end{bmatrix} \qquad (2)$$

The negative couplings are in this case the electric couplings between the second and the fifth resonators, i.e. $M_{25} = M_{52}$ = -0.0078 from (2). The picture of the six-pole filter is shown in Fig. 13. The filter was designed by adding resonators to the input and output ports of a four-pole cross-coupled filter shown in Fig. 11. The frequency response on a wide-band range is given in Fig. 14. An out-of-band rejection better than the dynamic range of the network analyzer of 55 dB was achieved on a very wide band.

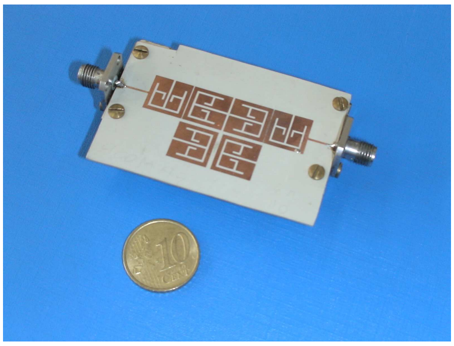

Fig. 13. A six-pole band-pass filter for 900 MHz GSM / GPRS systems.

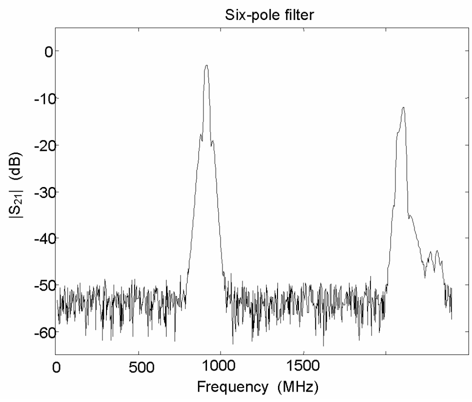

Fig. 14. The measured frequency response of the six-pole GSM / GPRS filter.

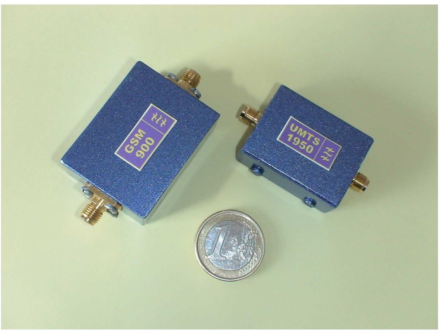

Fig. 15. Encapsulated filters for GSM / GPRS and for UMTS systems, respectively.

The proposed filters allow for a very easy integration with the other components of a microwave planar circuit. However, the case influence on the filter response was investigated and encapsulated versions pf the GSM 900 and UMTS 1950 filters were developed as shown in Fig. 15. The filter design can be easily extended to the high temperature superconducting (HTS) devices, in order to take advantage of a significantly increased unloaded quality factor for an improved in-band insertion loss [7].

5. Conclusions

Four-pole filters with small-size planar resonators were developed for 1950 MHz frequency band of the UMTS system and for the 900 MHz band of the GSM / GPRS applications. The resonators were obtained by folding the stepped-impedance resonators, which provide both size-reduction and widening of the rejection band. The measured filter responses are in a good agreement with the simulated responses. The cross-couplings provide an improved quasi-elliptic response, for a better filter selectivity. The six-pole cross-coupled filter developed for GSM / GPRS system exhibits an improved out–of–band rejection.

The developed filters are compact and cost-effective. The required technology is simple, without any via holes, air-bridges or lumped elements. The same design method is appropriate to the design of other devices, working at other frequency bands. Besides, the designs can be easily extended to miniaturized devices on high-dielectric constant substrates or for high-temperature superconducting (HTS) devices for improved in-band insertion losses.

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References

[1] A. Ioachim, M. G. Banciu, M. I. Toacsan, L. Nedelcu, D. Ghetu, H. V. Alexandru, G. Stoica, G. Annino, M. Cassettari, M. Martinelli, Materials Science and Engineering B **118**, 205 (2005).
[2] A. Ioachim, M. I. Toacsan, M. G. Banciu, L. Nedelcu, H. Alexandru, C. Berbecaru, D. Ghetu, G. Stoica, Materials Science and Engineering B **109**, 182 (2004).
[3] M. Sagawa, M. Makimoto, S. Yamashima, IEEE Trans. Microwave Theory Tech. **MTT-45**, 1078 (1997).
[4] M. G. Banciu, R. Ramer, A. Ioachim, IEEE Microw. Wireless Comp. Lett. **13**, 175 (2003).
[5] M. G. Banciu, R. Ramer, A. Ioachim, Electron. Lett. **38**, 228 (2002).
[6] G. Lojewski, Telecomunicații, No. 2, 43 (2003).
[7] J.-S. Hong, M. J. Lancaster, R. B. Greed, D. Jedamzik, J.-C. Mage, H. J. Chaloupka, IEEE Trans. Microwave Theory Tech. **MTT-48**, 1336 (2000).

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