Compact Microstrip Loop Resonator Based Bandstop Filters for Sub-GHz Channels

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Abstract. *This paper presents two microwave bandstop filters based on microstrip loop resonators with capacitors. The filters have steep band edges, are compact and easy to fabricate. They are applicable for protection against strong signals in nearby channels. Construction of filters, capabilities of band shift compensation and tuning are discussed.*

Keywords

Microstrip filters, microwave filters, loop resonators, channel protection, sub-GHz band.

1. Introduction

Filters are one of important devices necessary in most radio communication equipment. They are realized in many different forms and various technologies, depending on requirements of particular applications. These can be, for example: attainable attenuation, limited insertion loss, affordable cost or allowed dimensions and weight of the filter. Fulfilling all of these requirements can be especially challenging for systems working with strong signals in nearby channels and utilizing equipment with restricted dimensions, which are nowadays ubiquitous.

This paper presents two radio frequency filters, which can be used for filtering channels at UHF frequencies below 1 GHz. For this band it is possible to use filters composed of discrete components: capacitors and inductors, but inductors are generally characterized by low quality factors, limiting capabilities of filters. Other possibilities include filters built of coupled cavities, like helical resonators, but they are of significant dimensions and weight, or introduce high losses. They are not easy to fabricate, either. Much easier to fabricate are filters employing microstrip resonators on printed circuit boards (PCBs), which do not require advanced, expensive machinery for prototyping and can be delivered by one of many PCB manufacturers. Still, these filters can meet requirements of many demanding applications. Among such microstrip structures there are filters composed of open loop resonators, to which class belong also the filters reported in this paper. This kind of filters has been extensively investigated theoretically [1,2] and the literature contains many examples of realized and measured filters based on open loop resonators themselves or used as an essential portion [1–9]. Such structures seem to be rather predictable and reliable. They offer good performance, allowing to obtain small or reasonably limited insertion loss (like 3 dB in [2], 1.5 dB to 3 dB in [3], 2 dB in [4]) and relatively high attenuation (like reaching 60 dB in [2]), while keeping small dimensions of the filter circuit. Many variations for improvement or adaptation are possible, e.g. covering individual resonators with metallic plates to modify their frequency responses [4], nesting smaller loops inside bigger ones and switching of coupling [5] or implementing loop resonators as defects in the ground plane (so-called defected ground structure) [6].

However, as it can be seen in many papers, e.g. [2,7,8], the real filter can be shifted in frequency in relation to the design by 10 MHz or more. This can be not a problem for filters with wide bands, but is not acceptable if the filter has to operate on precisely defined and closely located channels in frequency domain. For this reason, the loops of the filters reported herein have been closed with capacitors, what, as shown in [8] or [9], allows to adjust resonant frequencies of individual resonators and hence correct imperfections or effects not accounted for in the design. Additionally, this enhances applicability of the structure, enabling tuning of the filter's transmittance.

The filters presented in this paper have been designed to protect receivers against strong signals in preset nearby channels. Thus, they are primarily bandstop filters, although attention was paid no to make the received channel ("passband") suffer high insertion loss. The filters are compact and have been built on PCBs manufactured with standard prototyping tolerances and commercially available components (capacitors and connectors).

2. Designed filters

In this paper there are presented two examples of filters based on microstrip loop resonators with capacitors. It can be noted, that the signal traces of the developed structures contain no vias. This simplifies simulation, and even more fabrication, eliminating the need of drilling and plat-

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ing. The only mounted discrete components are capacitors. As discussed, their use allows to tune transmittances of filters, thus extending their potential application range without redesigning PCBs, and makes it possible to compensate material spreads and fabrication or design inaccuracy. The selected capacitors were size 0603 ceramic S-series capacitors produced by Johanson Technology [10], because of their high quality factors. Also, the producer supplies measured data, in particular equivalent circuits with values of parasitic components, in form of computer program MLCSOFT. The program is able to calculate effective capacitance and quality factor, needed for simulation. Printed circuit boards were manufactured by Satland Prototype on Rogers RO4003C substrate [11] with thickness 1.5 mm. The filters have been equipped with metallic covers, which act twofold: they allow to shift the bands of filters and protect the filters against proximity of other metallic objects, which could disturb their operation.

Simulations and optimizations were performed in Microwave Office 2009 with AXIEM electromagnetic simulator. The final corrections of the filter were done by mounting additional capacitors with small values, based on behavior observed in the simulator, or by changing the height of the cover. The adopted rule was, that changes of capacitance were mainly meant to improve the shape of the filter's transmittance, while the cover was used to shift the bands to desired frequencies. The measurements were performed with Agilent PNAX network analyzer.

The presented filters, schematically shown in Fig. 1, named FZ835 (Figs. 2 and 3) and FPP794 (Figs. 4 and 5), employ loop resonators closed with capacitors, but with different locations of taps and capacitor in each resonator. There are four resonators, both the first pair and the last pair of them is coupled by a capacitor (thus, in total there are six capacitors used in each of the filters). The filters have been equipped with metallic covers, obtaining final form as shown in Fig. 6.

Filter FZ835 was designed to block WLAN network signals in channel with central frequency 835 MHz and bandwidth 20 MHz, while passing signals of WLAN network, using channel with central frequency 794 MHz and bandwidth 12 MHz. The filter FPP794 was intended to posses two stopbands, and in addition to the same operation on WLAN networks' signals, it was designed to block signals of WiMAX network transmitted in the range 690 MHz to 730 MHz or narrower.

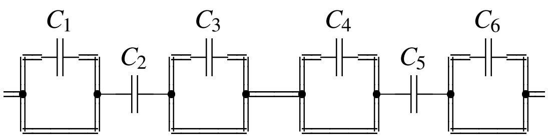


Fig. 1. Schematical representation of filters FZ835 and FPP794.

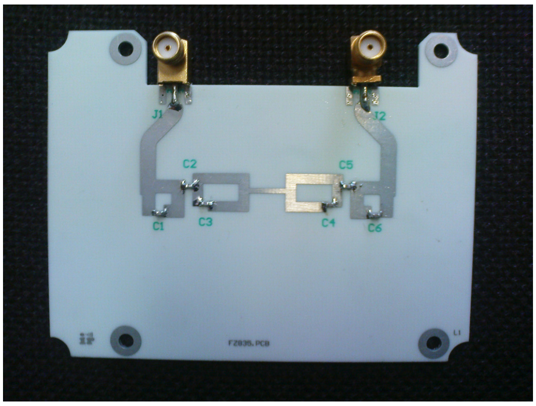
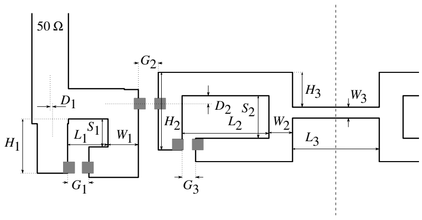


Fig. 2. Printed circuit board of filter FZ835.



$W_1 = 2.75$ mm	$W_2 = 2.15$ mm	$W_3 = 1$ mm
$L_1 = 3.65$ mm	$L_2 = 7.85$ mm	$L_3 = 7.85$ mm
$H_1 = 4.925$ mm	$H_2 = 7.075$ mm	$H_3 = 3.175$ mm
$G_1 = 1.925$ mm	$G_2 = 1.8$ mm	$G_3 = 1.225$ mm
$S_1 = 2.55$ mm	$D_1 = 0.2$ mm	$D_2 = 0.725$ mm
$S_2 = 3.85$ mm		

Fig. 3. Dimensions of designed filter FZ835.

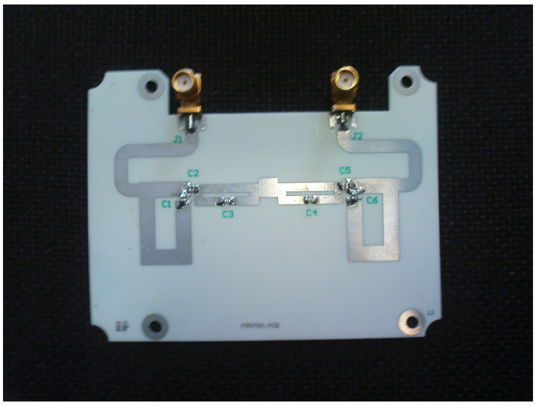
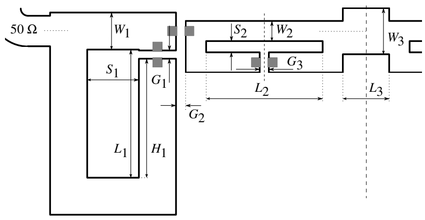


Fig. 4. Printed circuit board of filter FPP794.



$W_1 = 4$ mm	$W_2 = 2.2$ mm	$W_3 = 5$ mm
$L_1 = 13.9$ mm	$L_2 = 12.6$ mm	$L_3 = 5$ mm
$G_1 = 0.9$ mm	$G_2 = 1.05$ mm	$G_3 = 1$ mm
$S_1 = 5.6$ mm	$S_2 = 1.2$ mm	$H_1 = 12.9$ mm

Fig. 5. Dimensions of designed filter FPP794.

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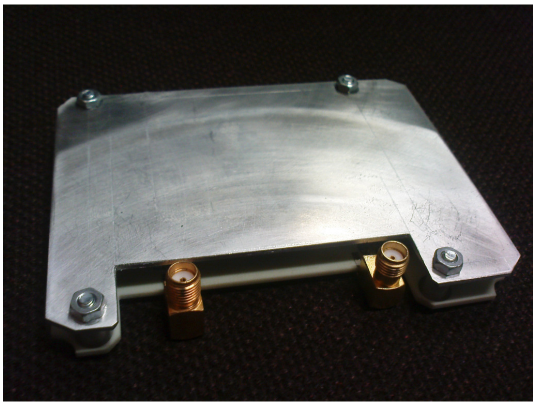

Fig. 6. Fully assembled filter FZ835 or FPP794.

The transmittance and reflectance of filter FZ835 are plotted in Fig. 7. Insertion loss in the 794 MHz channel is 1.6 dB to 1.8 dB and attenuation in the 835 MHz channel is 28 dB to 50 dB. This filter comprises capacitors with the following (nominal) values: $C_1 = C_6 = 6.6$ pF (obtained from 3.9 pF in parallel with 2.7 pF), $C_2 = C_5 = 5.6$ pF and $C_3 = C_4 = 3.9$ pF. The cover was placed at height of 6 mm above the surface of filter's board. For this filter C_1 and C_6 were increased with respect to design by additional 1 pF, while C_3 and C_4 were increased by additional 0.3 pF, to correct the shape of the stopband edge. The corrected stopband edge is still not monotonical, but more steep than predicted by simulation, falling at the rate of ca. 1.5 dB/MHz from the 3 dB attenuation level to the first dip, and ca. 1.15 dB/MHz from the 3 dB attenuation level to the maximal attenuation. The area occupied by the filter circuit is very small: 55 mm by 10 mm, and twice as many resonators could be placed easily on the same PCB, if necessary. As depicted in Fig. 8, it is possible to shift the edge of the stopband to higher frequencies by moving the cover towards the filter's PCB.

In the filter FPP794 there were mounted capacitors (nominal values): $C_1 = C_6 = 3$ pF (two 1.5 pF in parallel), $C_2 = C_5 = 11.2$ pF (two 5.6 pF in parallel), and $C_3 = C_4 = 3.9$ pF. To correct the transmittance of the fabricated filter capacitances C_1, C_3, C_4 and C_6 were increased by 0.3 pF. The filter's cover was located 4 mm above its PCB. Fig. 9 presents the transmittance and reflectance of this filter. The measured insertion loss of 794 MHz WLAN channel is 1.2 dB to 1.9 dB, while attenuation in the second WLAN channel, at 835 MHz, reaches 35 dB to 47 dB and attenuation of the assumed WiMAX band 690 MHz to 730 MHz is 19 dB to 62 dB, depending on the channel. The steepness of the stopband edges can be estimated as: 1.7 dB/MHz for WLAN and 1.8 dB/MHz for WiMAX, measuring from the level of attenuation by 3 dB to the first maximum of attenuation. On the PCB the filter occupies an area of 69 mm by 23 mm. The transmittance of FPP794 can be shifted upwards in frequency by moving the cover closer to PCB of the filter – see Fig. 10.

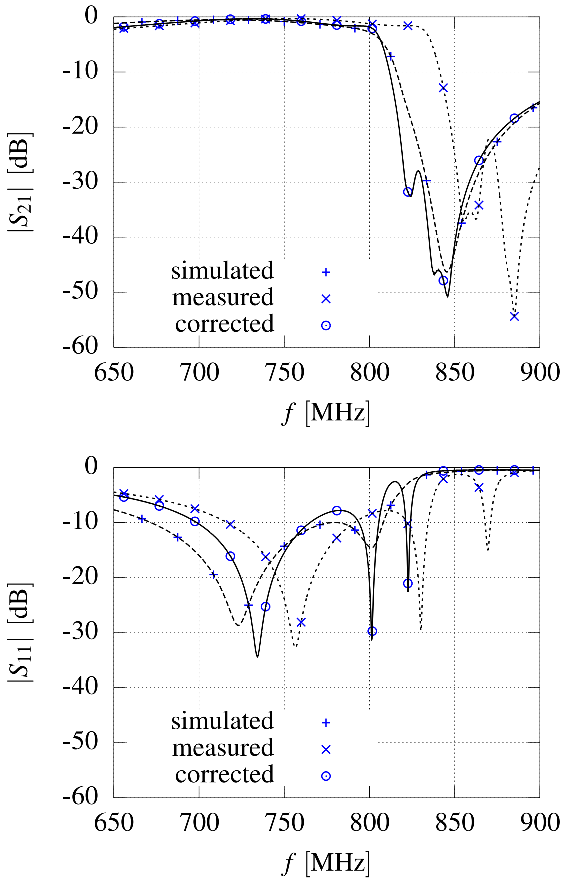

Fig. 7. Transmittance and reflectance of filter FZ835 for blocking signals occupying bandwidth 825 MHz to 845 MHz.

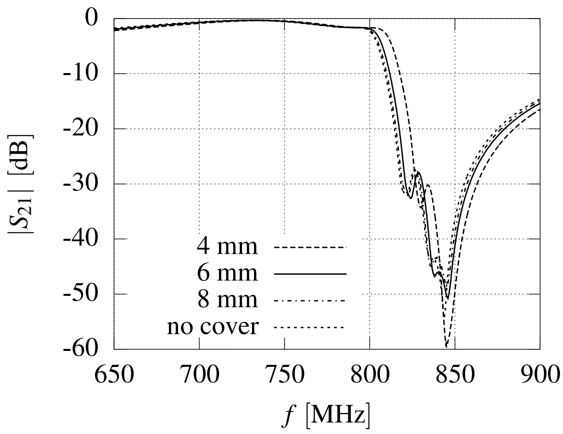

Fig. 8. Transmittance of filter FZ835 tuned by changing the height of cover's mounting – measured data.

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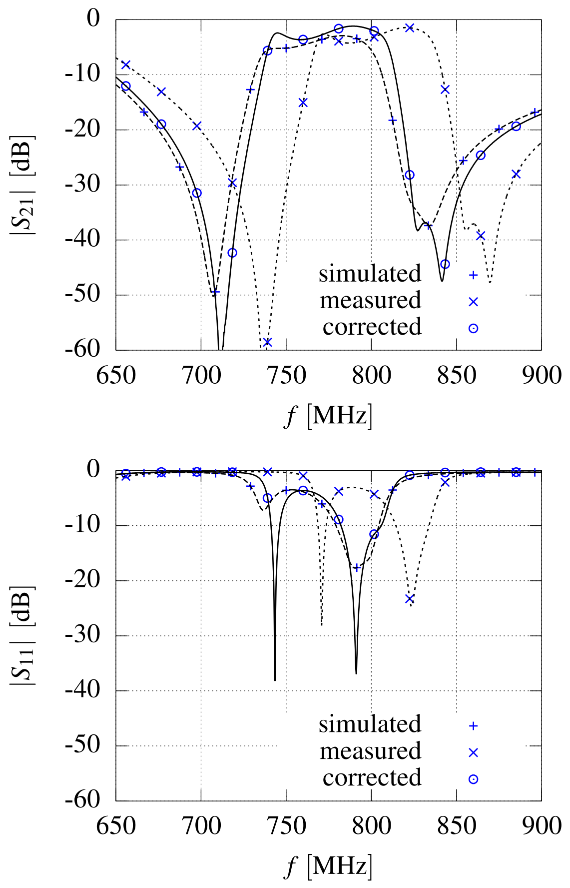

Fig. 9. Transmittance and reflectance of filter FPP794 for blocking signals in the ranges 825 MHz to 845 MHz and 690 MHz to 730 MHz.

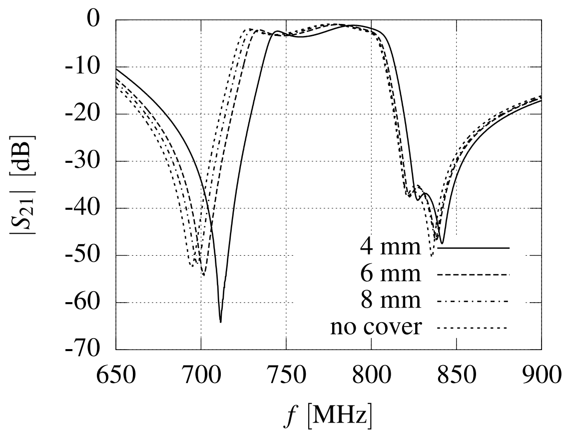

Fig. 10. Transmittance of filter FPP794 tuned by changing the height of cover's mounting – measured data.

3. Summary

In this paper there are presented two microstrip filters based on loop resonators, capable of blocking signals in channels near the received one. To make them suitable for such applications with strictly defined and narrow bands of operation, the filters are equipped with capacitors, allowing to correct or tune their transmittances. The filters provide an alternative with lower cost, smaller dimensions and weight, and easier fabrication for filters based on coupled resonant cavities in metallic blocks and are applicable especially in devices with limited space.

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