with low-insertion loss, compact size, high selectivity, and wide-fractional bandwidths.

4. CONCLUSION

Based on the combination of embedded double E-type SIR and open-loop resonators, a dual-band BPF with compact size and high selectivity for WiMax and WLAN applications is presented and illustrated. In this design, the proposed scheme provides sufficient isolation between the two specific passbands, thus each passband can be individually tuned. The embedded structure can further miniaturize the dimensions of the overall structure, furthermore, four transmission zeros are realized near the passband edges which result in a high-selectivity level. Good agreement between the simulated and measured results validates the correctness of the proposed design approach. The simple planar structure, compact size, passbands controllability, and high selectivity make the proposed BPF attractive for modern wireless communication systems.

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REFERENCES

1. L.C. Tsai and C.W. Huse, Dual-band bandpass filters using equal length coupled-serial-shunted lines and Z-transform techniques, IEEE Trans Microwave Theory Tech 52 (2004), 1111–1117.
2. X. Luo, H. Qian, J.G. Ma, K. Ma, and K.S. Yeo, Compact dual-band bandpass filters using novel embedded spiral resonator (ESR), IEEE Microwave Wirel Compon Lett 20 (2010), 435–437.
3. H.W. Deng, Y.J. Zhao, L. Zhang, X.S. Zhang, and W. Zhao, Dual-band BPF with DSIR and TSIR, Electron Lett 46 (2010), 1205–1206.
4. M. Sagawa, M. Makimoto, and S. Yamashita, Geometrical structures and fundamental characteristics of microwave stepped-impedance resonators, IEEE Trans Microwave Theory Tech 45 (1997), 1078–1085.
5. M.L. Chuang, M.T. Wu, and S.M. Tsai, Dual-band filter design using L-shaped stepped impedance resonators, IET Microwave Antennas Propag 4 (2010), 855–862.
6. R.Y. Yang, C.Y. Hung, and J.S. Lin, A dual-band bandpass filter with an enhanced second passband performance using modifiable coupling, J Electromagn Wave Appl 25 (2011), 305–314.
7. X.H. Guan, W. Fu, G.H. Li, S. Jiang, and H.W. Liu, Novel microstrip dual-band bandpass filter with wide stopband and high isolation, Microwave Opt Technol Lett 53 (2012), 803–806.
8. F. Wei, L. Chen, and X.W. Shi, Compact dual-mode dual-band bandpass filter with wide stopband, J Electromagn Wave Appl 26 (2012), 1441–1447.
9. J.S. Hong and M.J. Lancaster, Theory and experiment of novel microstrip slow-wave open-loop resonator filters, IEEE Trans Microwave Theory Tech 45 (1997), 2358–2365.
10. C.Y. Chen and C.Y. Hsu, A simple and effective method for microstrip dual-band filters design, IEEE Microwave Wirel Compon Lett 16 (2006), 246–248.
11. R.K. Maharjan, B. Shrestha, and N.Y. Kim, Compact microstrip square open-loop bandpass filter using open stub, Electron Lett 48 (2012), 333–334.
12. M. Hayati, L. Noori, and A. Adinehvand, Compact dual-band bandpass filter using open loop resonator for multimode WLANs, Electron Lett 48 (2012), 573–574.
13. D. Girbau, A.L. Lazaro, E. Martinez, D. Masone, and L. Pradell, Tunable dual-band bandpass filter for WLAN applications, Microwave Opt Technol Lett 51 (2009), 2025–2028.
14. L.Y. Feng, H.X. Zheng, C.G. Sun, and D. Cheng, Dual-band bandpass filter with tunable upper passband, Microwave Opt Technol Lett 53 (2010), 888–890.

COMPACT BANDSTOP FILTER FOR UHF IN MODIFIED MEANDER ARRANGEMENT WITH CAPACITORS

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ABSTRACT: *We present a novel bandstop microstrip filter with coupling capacitors. The microstrip is arranged in a meander-like pattern, with particular segments coupled by capacitors. This layout provides good results and reduced filter's size, with readily tunable transmittance that can be modified for notch-like operation or wide stop band.* © 2013 Wiley Periodicals, Inc. Microwave Opt Technol Lett 55:2110–2113, 2013; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.27756

Key words: *microstrip filter; notch filter; bandstop filter; meander line*

1. INTRODUCTION

Blocking of signals at different frequencies is a common task in design of radiocommunication equipment. Compatibility of coexisting radio systems requires them to be able to work simultaneously, without unintended degradation of their performance. Probably, the most classic example is the case of a receiver and a transmitter with antennas located in proximity but not meant to communicate with each other. For the receiver, the signal from the transmitter is just a distortion, which will likely dominate the signal to be received and makes the reception impossible. A way to alleviate this problem is to place after the receiver's antenna a filter to prevent the distorting signal from reaching the receiver. Such situation has been the motivation for development of the filter presented herein, which was meant to protect a receiver operating up to 822 MHz against a signal in 866–868 MHz band. It was assumed that losses in the received signal should not exceed 2 dB, and the distorting signal must be attenuated by at least 40 dB. These requirements made it necessary to look for a distributed filter solution, because lumped inductors, even those designed for use in RF circuits, introduce too high losses (i.e., do not offer sufficient Q-factor) to provide sharp enough transition from passband to stopband. Still, the filter had to be small enough to fit into limited space in the enclosure.

Limitations on dimensions are a common obstacle and in the literature, one can find reports on filters designed with compactness as the priority, for example, Refs. [1–4]; however, the presented results do not show that these filters are able to block a distortion in nearby spectrum. Filters capable of this task, like reported in Refs. [5–7], with quickly rising attenuation in their stopbands, to operate at subGHz frequencies would have to extend to significant size. Many filters are composed of a

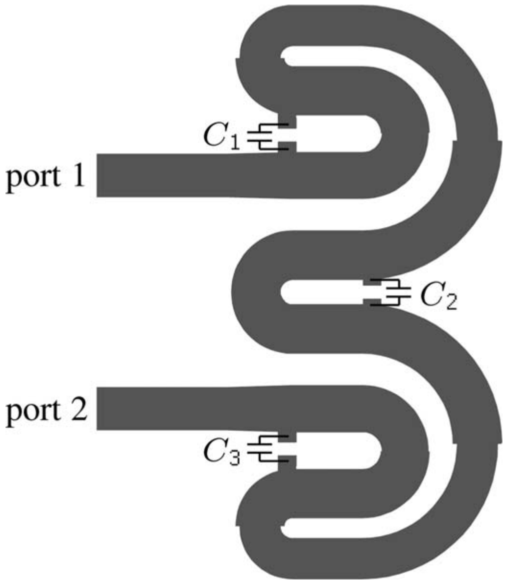

Figure 1 Structure of the filter trace and capacitors on the top layer

complicated structure and do not offer an easy way to tune them (e.g., with varicaps), what is necessary in practical application to compensate for various imperfections of materials and technology (like variation of dielectric constant of the substrate). Provision of such transmittance correction method was one of the goals in the design of the filter discussed in this article. It seems that the filter layout described here has not yet been introduced in the literature.

2. STRUCTURE OF THE FILTER

A frequently used arrangement that allows to fit a circuit on a small area is the meander line [8]. The presented filter is based on a modification of this pattern. The drawing of the structure of the filter is shown in Figure 1, the dimensions of the manufactured and measured one—in Figure 2, and a photograph of the assembled unit in Figure 3. Essentially, the filter comprises three resonators constituted by segments of microstrip line connected in parallel with capacitors, similar to parallel LC circuits,

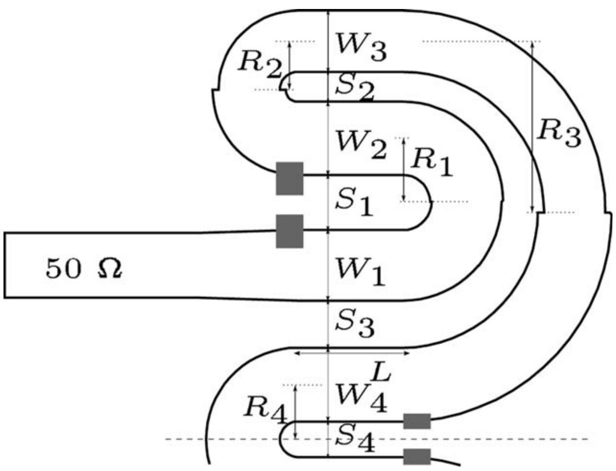

Figure 2 Dimensions of the manufactured structure: $L = 5.4$ mm, $W_1 = 3.58$ mm, $W_2 = 3.75$ mm, $W_3 = 3.14$ mm, $W_4 = 3.79$ mm, $S_1 = 2.83$ mm, $S_2 = 1.54$ mm, $S_3 = 2.42$ mm, $S_4 = 1.83$ mm, $R_1 = 3.25$ mm, $R_2 = 2.49$ mm, $R_3 = 8.79$ mm, and $R_4 = 2.81$ mm

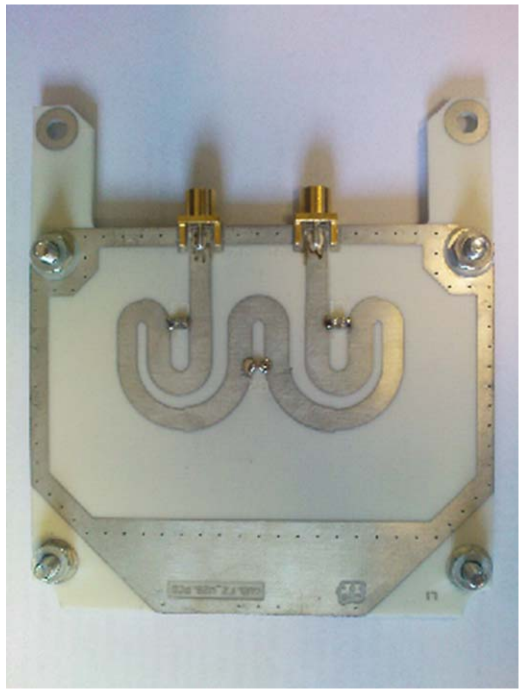

Figure 3 The manufactured filter used for measurements. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

introducing transmission zeros. The remaining parts of the microstrip line provide coupling of the resonators. The advantage over the usual LC circuit is that replacement of lumped inductors with microstrip segments allows to obtain a more selective response of the filter (i.e., steeper band edge). Further replacement of the capacitor with another microstrip line would lead to a filter with ring resonators, like discussed in Ref. [5], but it seems that capacitors perform much better than inductors, so that this replacement is not necessary, while it would expand the dimensions of resonators. Additionally, sliding the mounting positions of the capacitors allow to tune the resonant frequencies—proportionally to the change of the resonator's line length obtained this way.

In the described filter, the microstrip trace is arranged as a meander line bent outward in opposite directions to fit on a small area. It has been verified that simulation of the structure using a simplified circuit model with no coupling between the traces gives qualitatively the same results as an electromagnetic simulator. This means, that although the coupling of traces modifies characteristics of the filter, it does not change the principle of operation, which is explained above. The total length of the trace (excluding final "stub" sections, which have the same impedance as ports) is comparable with the wavelength of operation and thanks to its arrangement, the filter is rather compact. To allow for a greater flexibility of the filter design, the trace between ports has been divided into sections of different width (i.e., impedance), although the general properties of the structure seem not to depend on whether this division has been made or not. In the further part, there are presented results for the manufactured filter, with dimensions about 45 mm by 20 mm. The filter has been built on Rogers RO4003C substrate with S-series 0603 capacitors from Johanson technology, $C_1 = C_3 = 6.3$ pF (realized as 3.6 pF in parallel with 2.7 pF) and $C_2 = 4.7$ pF. The applied design procedure was optimization with the help of a simulator, which is the best choice if high accuracy is required.

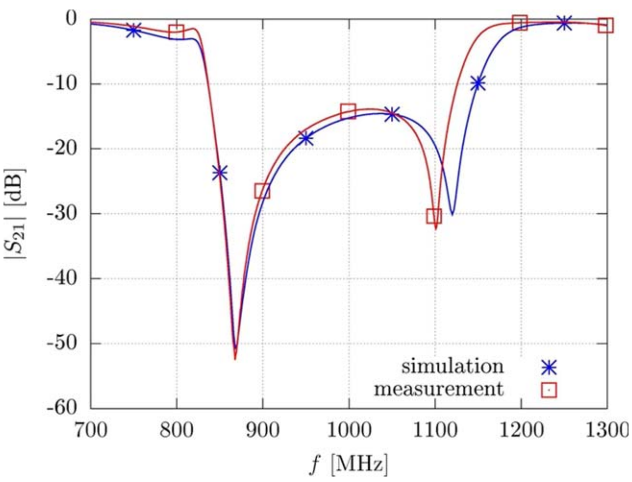

Figure 4 Filter transmittance—comparison of simulation and measurement. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

It is likely that there could be developed a synthesis method similar to Cauer algorithm for LC ladders, but it would be based on a simplified circuit model, which probably would not allow to reproduce the filter behavior so precisely. To make the filter more robust to proximity of other metallic objects, which could influence the transmittance, the filter has been equipped with conductive cover at 3 mm distance.

3. EXPERIMENTAL RESULTS AND TUNING POSSIBILITIES

The transmittance of the discussed filter is drawn in Figure 4 and its reflectance in Figure 5. The simulation has been performed in Microwave Office 2009 with planar three-dimensional simulator AXIEM, and the measurement data were captured with Rohde and Schwartz ZVL network analyzer. It can be seen that predictions of the simulation are reliable and match the experimental data very well. According to the measurement, the filter introduces attenuation as shown in Table 1. The transmittance S_{21} has a steep edge, decreasing by 47 dB with frequency change of 39 MHz, that is, with average of 1.2 dB/MHz. The reflectance S_{11} of the filter was not taken into account during design. It is on a satisfactory level of -6 to -10 dB or better

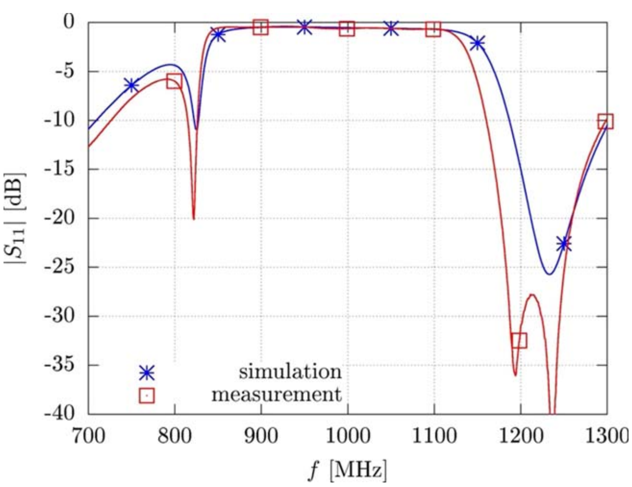

Figure 5 Filter reflectance comparison of simulation and measurement. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

TABLE 1 Measured Attenuation of the Filter

f [MHz]	Attenuation [dB]
786	2
818	1.5
827	3
866	50
868.5	52

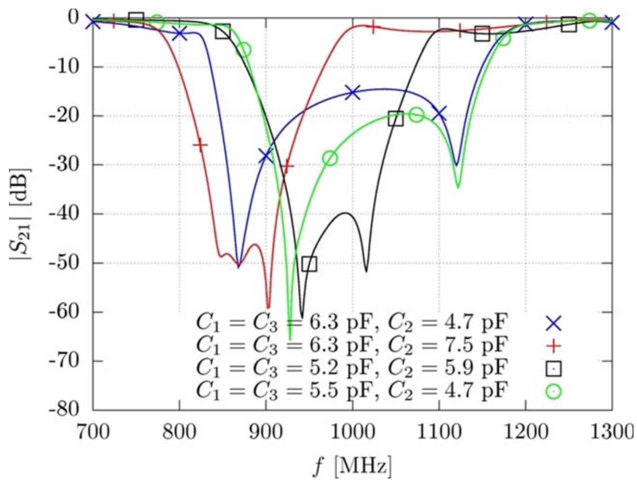

Figure 6 Filter transmittance for various capacitors simulation. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

in the lower passband and very good results have been observed in the upper passband. No signal deterioration by the filter has been observed in the target application.

For the application of the filter, it was important to obtain a sharp edge of the stopband at lowest frequencies, while the transmittance at higher frequencies was irrelevant. However, it is possible to modify the filter to adapt to circumstances requiring high attenuation in a wider band. Results of simulations depicted in Figure 6 show that it is possible to shift or shape the stopband simply by changing capacitances of capacitors. Reflectance is also modified and seems to be related to steepness of

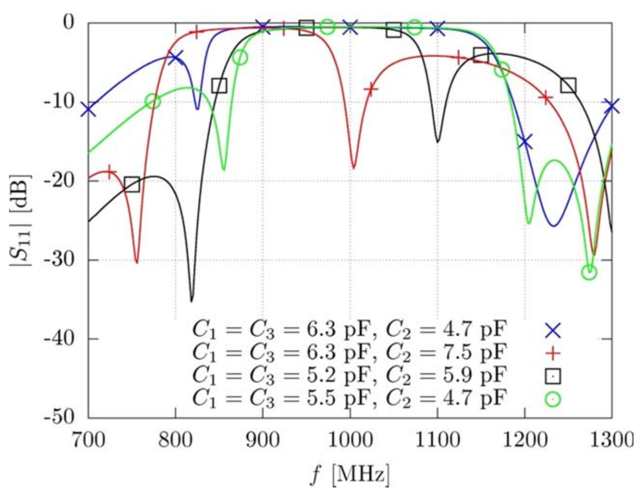

Figure 7 Filter reflectance for various capacitors simulation. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

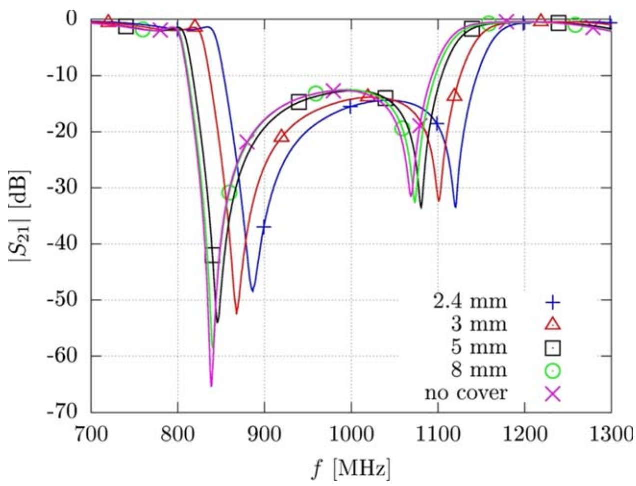

Figure 8 Filter transmittance for various distance to cover measurement. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

the passband edge—see Figure 7. For the cases of less-steeper transition, simulated reflectance in the passband could be even as good as −20 dB in maximum. Thus, the capacitors offer a way of tuning the filter and adaptation to specific requirements. With modern digitally tuned capacitors available, this creates a possibility to remotely modify the filter during its operation, what is a necessity, for example, in a fully software defined radio.

A second possibility of tuning the filter is through changing the height at which the cover is placed above the filter circuit. In Figure 8, there are shown measured transmittances for a few different heights. It can be seen that moving the cover further from the filter causes the stopband to shift to lower frequencies. This happens, because the electric length of a microstrip line increases with rising distance to the cover, thus the frequency of the wave experiencing the parallel resonance becomes smaller.

4. CONCLUSION

This article introduces a novel planar stopband filter, based on a modified meander microstrip line, with additional coupling capacitors, intended to operate at low frequencies from the UHF band. The filter is of compact size and is able to provide high attenuation of an undesired distorting signal with low-insertion loss in a nearby useful band. It is important, that the filter can be easily tuned and its stopband shaped, making it a good solution for equipment requiring high flexibility, and allowing to quickly compensate imperfections of technology or materials in produced units.

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REFERENCES

1. J.-H. Cho and J.-C. Lee, Microstrip stepped-impedance hairpin resonator low-pass filter with defected ground structure, Microwave Opt Technol Lett 48 (2006), 405–408.
2. G.Y. Su et al., Compact microstrip lowpass filter using a meander-line structure, Microwave Opt Technol Lett 48 (2006), 1339–1341.
3. J.G. Lee et al., Compact semilumped elliptic-function low-pass filter using microstrip meander line, Microwave Opt Technol Lett 49 (2007), 1777–1779.
4. D. Cui et al., A compact bandstop filter based on two meandered parallel-coupled lines, Prog Electromagn Res 121 (2011), 271–279.
5. R. Gómez-Garca and J.I. Alonso, Design of sharp-rejection and low-loss wide-band planar filters using signal-interference techniques, IEEE Microwave Wirel Compon Lett 15 (2005), 530–532.
6. H. Ishida and K. Araki, Coupled-line sharp notch filter with significant improvement of attenuation, In: Proceedings of Asia-Pacific Microwave Conference 2006, Yokohama, Japan, 2006, pp. 1264–1267.
7. R. Islam and G.V. Eleftheriades, Elliptic-type bandpass filter and bandstop notch filter inspired by metamaterial NRI-TL topology, Electron Lett. 44 (2008), 1470–1472.
8. A.R. Djordjević et al., On compact printed-circuit transmission lines, Microwave Opt Technol Lett 49 (2007), 2706–2709.

COMPACT CPW-FED UWB SLOT ANTENNA WITH TRIPLE BAND-NOTCHED CHARACTERISTICS

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ABSTRACT: *A novel compact coplanar waveguide-fed antenna is presented with triple band-notched characteristics. A C-slot is etched in a novel patch to avoid interference from WiMAX band. By using pair of CSRR slots and pair of L-shaped slits in ground plane, two notched bands for WLAN and ITU 8 GHz bands are obtained, respectively. The antenna has bandwidth of 2.8–11.2 GHz with three notched bands of 3.3–3.7 GHz, 5–6 GHz, and 8–8.4 GHz to avoid interference from WiMAX, WLAN, and ITU 8 GHz bands, respectively. The antenna has good impedance matching and stable radiation patterns. Good agreement is reached between measured and simulated results.* © 2013 Wiley Periodicals, Inc. Microwave Opt Technol Lett 55:2113–2117, 2013; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.27781

Key words: *VSWR; slot; radiation patterns; gain; group delay*

1. INTRODUCTION

Ultra-wideband (UWB) systems have gained attention in wireless world due to their advantages such as low cost and high data transfer rate. UWB antenna is an essential component of UWB system and it requires a bandwidth of 3.1–10.6 GHz for commercial UWB applications. Antennas with compact size are useful in microwave and radio frequency devices. Slot antennas [1–4] are popular in the design of UWB antennas because they are compact in size and produce large bandwidth. However, narrow band communication systems such as IEEE802.16 WiMAX band operating in 3.3–3.7 GHz, IEEE802.11a WLAN band operating in 5.15–5.825 GHz and ITU 8 GHz band operating in 8.025–8.4 GHz, exist inside UWB. As these bands generate electromagnetic interference in UWB, it is required to design UWB antennas with band-notched characteristics to avoid interference from them. For this purpose, UWB antennas can be designed with filters. However, design of UWB antennas with filters requires a complex process. Hence, several UWB antennas have been proposed in literature with band-notched characteristics such as embedding slots [6–10], attaching parasitic