Military Technical College
Kobry El-Kobbah,
Cairo, Egypt

9th International Conference
on Electrical Engineering
ICEENG 2014

Design of Compact Dual-Band BPF Based on SIR using LTCC Technology

By

A. M. Elelimy *   A. M. El-Tager *   A. G. Sobih *

Abstract:

This paper presents a compact size dual-band BPF embedded in a low temperature co-fired ceramics (LTCC) designed to produce two passbands for WiMAX applications. The dual-band BPF center frequencies are 3.5 GHz and 5.8 GHz. A design methodology as well as design guidelines are proposed based on stepped-impedance coupled resonators to produce dual-band response. This dual-band BPF is simulated, optimized and verified. The proposed filter provides better size reduction and at the same time performs superior enhancement in insertion losses and keeps adequate passbands compared to other published dual-band packaged filters.

Keywords:

Bandpass filter (BPF), dual-band BPF, stepped-impedance resonators (SIR), low temperature co-fired ceramics (LTCC).

---

* Egyptian Armed Forces

1. Introduction:

In recent years, the demand for dual-band wireless communication systems is increased to enable user access to various services. Dual-band filters are common in dual-band transceivers, to reject unwanted interfering signals, and pass the main signal in the desired passband. Compact wireless modules fabricated with a low-temperature co-fired ceramic (LTCC) substrate are widely used for recent wireless systems such as Universal Mobile Telecommunication System (UMTS), IEEE 802.11 wireless local area networks (WLANs), and IEEE 802.16 worldwide interoperability for microwave access (WiMAX) systems. These modules consist of chip components, integrated circuits, the LTCC substrate, and passive components embedded in the LTCC substrate [1], [2]. The embedded passive components (bandpass filter, coupler, and balun) are basically fabricated by using the multilayer structures of thin ceramic sheets and conductor patterns.

In [3], dual passbands is obtained with a mixed topology, using a shunt-stub bandpass filter and a shunt serial LC bandstop filter. While in [4], a multilayer two bandpass filters and matching circuits has been adopted to build a packaged dual-band BPF but it suffers from high insertion losses. In addition, [5] proposed a method to construct compact sized dual-band filters using stepped-impedance-stub resonators with vertically folded structure to obtain the dual-band BPF. One of the interesting techniques is found in [6]. Its dual-band response is realized using coupling stepped-impedance resonators. Therefore, a closer but better technique is adopted throughout this paper to enhance insertion losses as well as filter size.

In this paper, we present a dual-band BPF embedded in an LTCC based on the method of filtering using coupled stepped-impedance resonators, so that this type of multiband filter would be more suitable for a small separation between adjacent bands. The proposed circuit is designed using **DuPont 9*k*7** LTCC package substrate to verify the idea. Moreover, the design is verified using multi-layer model library (IMST **multi-lib** Design Kit), and simulations show good agreement with the required specifications. This paper is organized in four sections. Section II discusses the proposed design procedure of the structure. Section III shows simulations and comparisons to recent publications. Finally, Section IV concludes the main ideas of this work.

2. Design Procedure:

The main advantage of coupled striplines is that even- and odd-mode phase velocities are equal in a stripline structure. This stems from: due to its homogenous dielectric, the fundamental propagation mode is TEM in striplines (although higher-order modes can be excited if the frequency is high enough) [7]. Practical implication of this structure is that it yields very good isolation compared to the microstrip case. In addition, for small

metallization thickness, one can obtain exact, closed-form expressions for even- and odd-mode characteristic impedance through conformal mapping technique.
Two coupled lines and two transmission lines are proposed for the packaged dual-band BPF. For this structure shown in Figure (1), a transmission zero appears in the middle of two equally separated passbands. The input admittance Y_i , the area surrounded by the dashed line in Figure (1) can be then expressed as [8]:

$$Y_i = j\tan\theta * \left[\frac{Z + Z_L}{Z(Z_L - Z\tan^2\theta)} + \frac{1}{Z_L} \right] \tag{1}$$

where, Z and Z_L are respectively the characteristic impedance of the wider and narrower sections of the SIR and the characteristic impedance of the coupled striplines, given as:

$$Z_L = \sqrt{Z_{0e} Z_{0o}} \tag{2}$$

The resonance condition is achieved at $Y_i = 0$. In addition, let K equals Z_L / Z. Then the electrical length θ can be computed as:

$$\theta = \tan^{-1}\sqrt{K^2 + 2K} \tag{3}$$

On the other hand, K can be computed from the relationship between f_1 and f_2, the center frequencies of each passband, as follows:

$$\frac{f_1}{f_2} = \frac{\tan^{-1}\sqrt{K^2 + 2K}}{\pi - \tan^{-1}\sqrt{K^2 + 2K}} \tag{4}$$

Next, the choice of Z_L and Z is to be determined. This has a degree of freedom which is related to the resolution of the available fabrication process governing the coupled lines separation [9]. Therefore, a design curve is generated to relate the impedances Z , Z_{0e} , Z_{0o} to the second passband's fractional bandwidth FBW2 (%) with 10 dB return loss as shown in Figure (2). A fractional bandwidth is to be chosen to give a $K = Z_L / Z$ ratio similar to that obtained from equation (4). Therefore, designers have some freedom to choose impedances with realizable values based on their fabrication limits.

The case study of this paper has passband center frequencies located at: 3.5 GHz and 5.8 GHz for (WiMAX). According to the latest WiMAX standards announced in 2012 (802.16e) , the proposed filter is required to have a very good filter port isolation, a return loss value more than 10 dB and an insertion loss less than 1.5 dB.

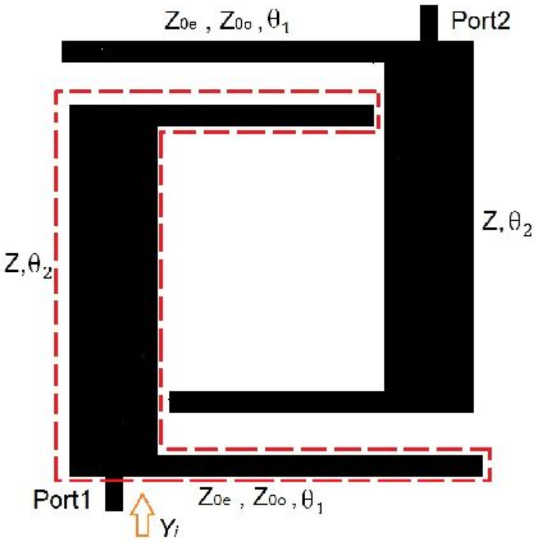

Figure (1): *Architecture of the dual-band BPF*

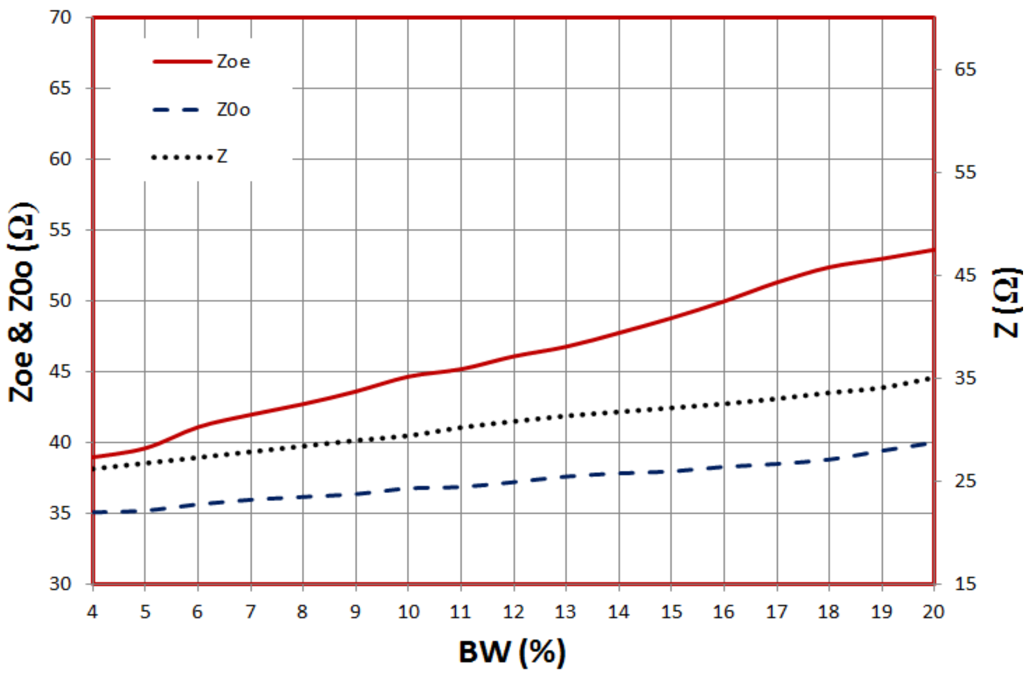

Figure (2): *Relation between impedances Z_L, Z_{0e}, Z_{0o} and the first passband absolute bandwidth with 10 dB the return loss for striplines*

When 12 % is chosen for two passbands' absolute bandwidth BW, according to Figure (2), the impedances Z , Z_{0e} , Z_{0o} are 30.85 Ω, 46.11 Ω and 37.24 Ω respectively. The electrical length θ can be then obtained from equation (3) as 74º. The dual-band filter is designed using Agilent Advanced Design System (Tlines Multi-layer lib.).

The design is verified using another model library (IMST **multi-lib** Design Kit), which includes all standard elements for multi-layered circuit designs. As an add-on to Agilent‘s ADS, multi-lib library is very easy to use for simulation, design, and layout of multi-layered RF circuits. The modeling approach is based on a full 3D-EM-field simulation (FDTD) of the respective elements and a smart cache allows fast and interactive simulation of RF circuits and modules. The final optimized circuit design is shown in Figure (3).

3. Results and Discussions:

The proposed filters is designed using the **DuPont 9*k*7** Low-Temperature Co-fired Ceramic process with ε_r = 7.1 and tanδ= 0.001 [10]. Each LTCC tape layer has a post-fired thickness of 50 μm and uses silver metallization with t = 10 μm and σ= 5.5 x 10^7 S/m. Figure (4) shows the 3D model of the dual-band BPF, while Figure (5) shows the comparison between the multi-layer circuit simulation and the IMST **multi-lib** kit design simulation.

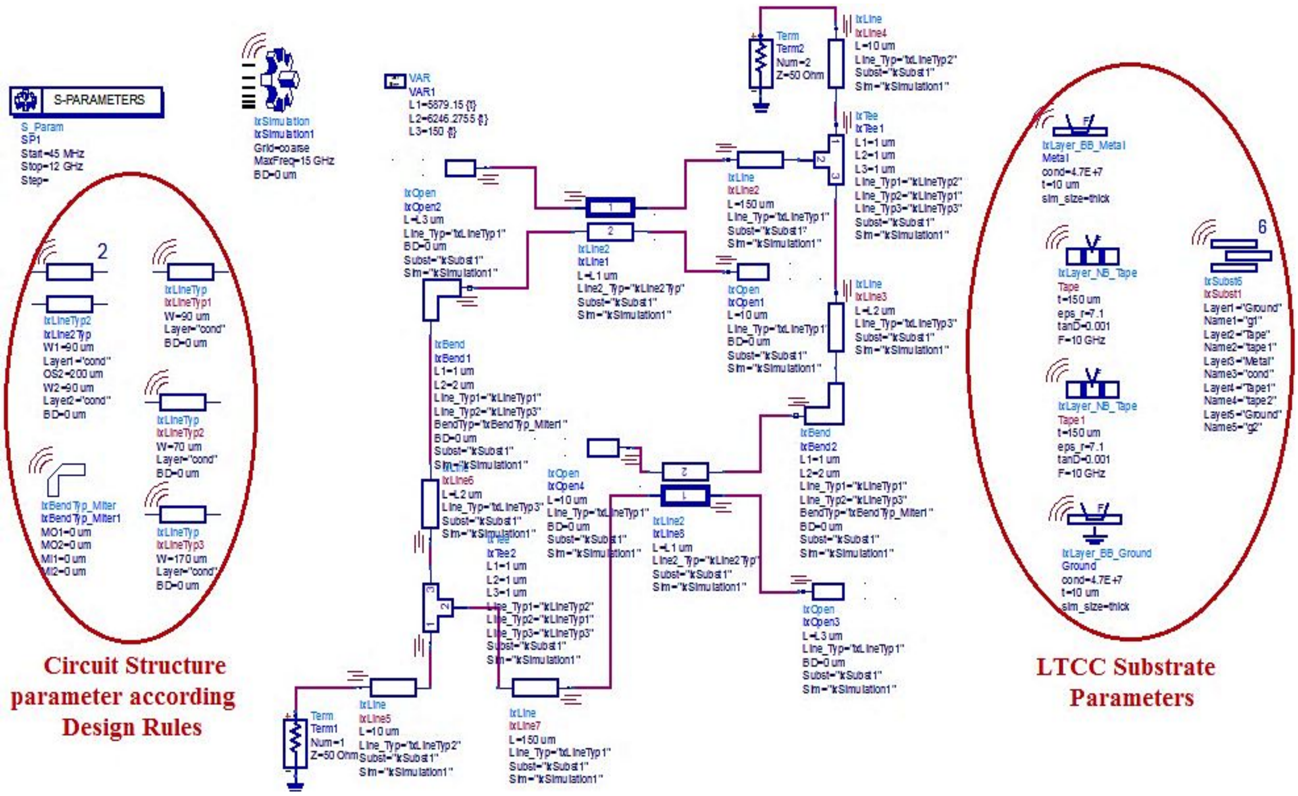

***Figure (3):** The designed circuit of a LTCC dual-band BPF*

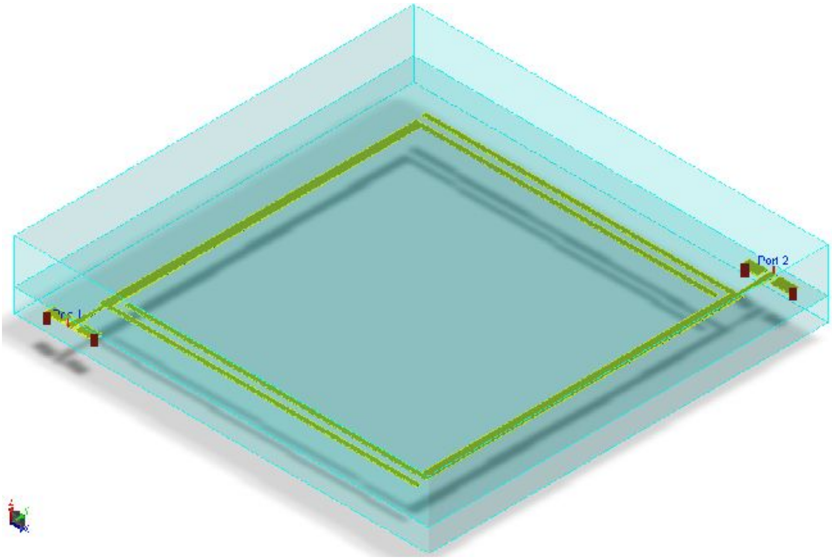

Figure (4): *ADS 3D model of LTCC dual-band BPF embedded in a packaged*

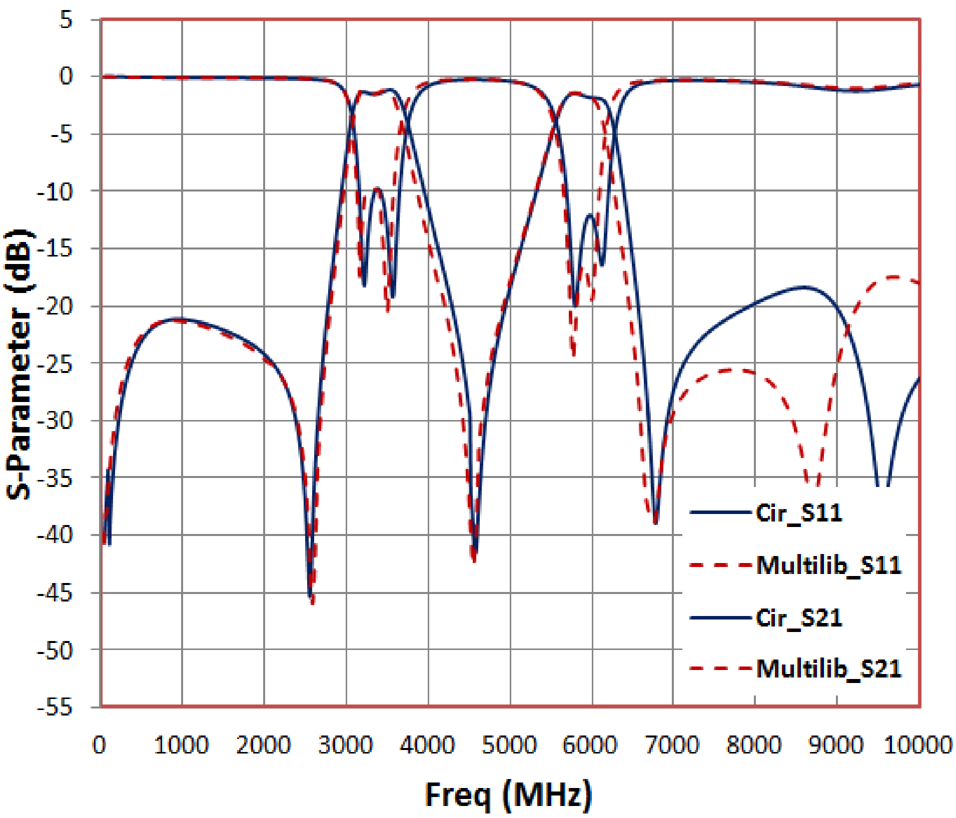

Figure (5): *Simulated responses of the LTCC dual-band BPF*

The proposed filter is with size of (6.33 x 6.53 mm^2). The maximum return loss at the pass bands is about 15 dB, while the insertion loss at the passband is better than 1.5 dB. Table (1) shows the performance of the dual-band BPF.

Table (2) summarizes comparison of dual-band BPF embedded in LTCC Package with other recently published designs from the point of view of simulated performance parameters as well as filter size. One can conclude that the proposed filter provides size reduction over that of other publications; namely about 13% better than [4], the smallest filter in the table. In addition, the proposed filter features insertion loss enhancement; namely it provides the best simulated IL by 9 % better than [5] for the first band and 6 % better than [4] and [6] for the second band.

Table (1): *Performance of the Dual-Band BPF*

	Parameters	**Simulated Results**
-	**Size**	6.33 x 6.53 mm^2
3.5 GHz Band	IL.(dB)	1
	RL. (dB)	20
5.8 GHz Band	IL.(dB)	1.4
	RL. (dB)	18

Table (2): *Performance of the Dual-Band BPF*

Ref.	**1st Frequency**			**2nd Frequency**			**Size (@ f_1)**
	f_o (GHz)	**IL. (dB)**	**RL. (dB)**	**f_o (GHz)**	**IL. (dB)**	**RL. (dB)**	
[4]	4	2	15	7.5	1.5	18	**λg/3 x λg/5**
[5]	2.4	1.1	22	5.8	1.4	21	**λg/2 x λg/2**
[6]	2.4	1.2	29	5.2	1.5	40	**λg/3 x λg/4**
This Work	3.5	1	20	5.8	1.4	18	**λg/4 x λg/5**

4. Conclusions:

In this paper, a structure for a dual-band BPF embedded in an LTCC Package is proposed. The dual-band BPF consists of: two SIR coupled lines which are proposed in a structure tuned at f_1 and f_2. A proposed prototype is designed and simulated so that center frequencies of the passbands are located at: 3.5 GHz and 5.8 GHz for (WiMAX). The validity of the proposed structure was confirmed using multi-layer model library (IMST **multi-lib** Design Kit) and simulations show good agreement with the required specifications. The prototype of the bandpass filter achieved the insertion loss of 1 dB and 1.87 dB, return loss of 20 dB and 18 dB at 3.5 GHz and 5.8 GHz, respectively. Not only does the proposed filter provide size reduction over other published packaged dual-band BPF, but also superior insertion loss is achieved.

Acknowledgment:

The authors wish to thank IMST GmbH in Kamp-Lintfort, Germany for providing a free trial license of their product tool for multi-layered circuits (**multi-lib** kit).

References:

[1] G. Wang, M. Van, F. Barlow, and A. Elshabini, "*An Interdigital Bandpass Filter Embedded in LTCC for 5-GHz Wireless LAN Applications*," IEEE Microw. Wireless Compon. Lett., vol. 15, Issue: 5, pp. 357–359, May 2005.

[2] Y. Lin, C.-C. Liu, K.-M. Li, and C. H. Chen, "*Design of an LTCC Triband Transceiver Module for GPRS Mobile Applications*," IEEE Transactions on Microwave Theory and Techniques, vol. 52, Issue: 12, pp. 2718–2724, December 2004.

[3] Y. Liu and W. Dou, "*A Dual-band Filter Realized by Alternately Connecting the Main Transmission-Line with Shunt Stubs and Shunt Serial Resonators*," IEEE Microwave and Wireless Components Letters, vol.19, Issue: 5, pp. 296 – 298, May 2009.

[4] S. Oshima, et al., "*Multilayer Dual-Band Bandpass Filter in Low-Temperature Co-Fired Ceramic Substrate for Ultra-Wideband Applications*," IEEE Transactions on Microwave Theory and Techniques, vol. 58, Issue: 3, pp. 614–623, March 2010.

[5] K. Chin, et al., "*LTCC Dual-band Stepped-Impedance-Stub Filter Constructed with Vertically Folded Structure*," IET Electronics Letters, vol.46, Issue: 23, pp. 1554 – 1556, November 2010.

[6] Y. Ping Zhang and M. Sun, "*Dual-Band Microstrip Bandpass Filter Using Stepped-Impedance Resonators With New Coupling Schemes*," IEEE Transactions on Microwave Theory and Techniques, vol. 54, Issue: 10, pp. 3779–3785, October 2006.

[7] S. Tsitsos, et al., "*Higher Order Modes in Coupled Striplines: Prediction and Measurement*," IEEE Transactions on Microwave Theory and Techniques, vol. 42, Issue: 11, pp. 2071–2077, November 1994.

[8] T. Ching-Wen and W. Po-Hsien, "*Design of a planar dual-band bandpass filter*," IEEE Microwave and Wireless Components Letters, vol.21, Issue: 7, pp. 362 – 364, July 2011.

[9] A. Elelimy, A. El-Tager, A. Sobih, M. Abdel-Azeem, "*Novel Compact Dual-Mode Tri-Band Bandpass Filter for WiMAX & GSM Applications*," in Proc. 42nd European Microwave Conference, pp. 1119-1122, October 2012.

[10] DuPont, GreenTape 9*k*7, 2009 [Online]. Available: http://www2.dupont.com/MCM/en_US/assets/downloads/prodinfo/GreenTape9*k*7 Datasheet.pdf, DuPont..

Nomenclatures:

dB	Decibel
K	Stepped-impedance resonators impedance ratio Acceleration
f_o	Center frequency of the band pass filter
Z_0	Characteristic impedance of transmition line
Z_{0e}	Even characteristic impedance
Z_{0o}	Odd characteristic impedance
ε_r	Relative permittivity of the medium
θ	Electrical length of a transmition line
$\tan\delta$	Loss tangent of the material
σ	Conductivity
λ_g	Guide wavelength of a plane wave in the material