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A chip-on-board packaged bandpass filter using cross-coupled topological optimised hairpin resonators for X-band radar application

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ABSTRACT

Devices that are compact in design and fabrication continue to draw attention for specific applications that require high performance. A compact elliptic bandpass filter using a cross-coupled topological structure with a hairpin resonator optimised for radar applications is presented in this paper. This work presents the design theory and corresponding semiconductor fabrication processes and describes the chip-on-board packaging method in detail. The proposed design of the bandpass filter can not only reduce the size of the device and result in good RF performance, but the accurate semiconductor fabrication process can also ensure high performance further. In addition, the presented chip-on-board packaging method can greatly enhance the reliability and long-term stability of a microwave device, which rarely introduces RF characteristic interference. The simulated, bare-chip measured and final chip-on-board measured results agreed well, which validated the correctness of the proposed approach.

1. Introduction

The compactness of devices with excellent RF performance is of critical importance to ensure low cost and integrated wireless communication systems. Bandpass filters (BPFs) are indispensable devices in the RF front-ends of both the receiver and transmitter circuits. Therefore, research on BPF has become an important issue for the rapid technological progress of wireless communication systems. Planar BPFs are preferred because they can be fabricated using printed circuit technology or semiconductor technology at low cost and high performances. In [1–3], BPFs are realised by coupled half-wave-length resonators; however, this type of BPF suffers from a large circuit size for the modern system. Clearly, size compaction has become an important issue in developing new microwave filters. Currently, open-loop resonators [4–6], slow-wave resonators [7–9], spiral resonators [10], and hairpin resonators [11–13] have been extensively investigated to overcome this difficult issue due to their compact size and attractive features. In particular, hairpin filters are fabricated by folding an open-line $\lambda/2$ microstrip resonator into a U-shaped resonator, which reduces the circuit size relative to the parallel-coupled line structure. Further progress in size reduction has been made by miniaturising hairpin resonator filters [14]; the two arms of the U-shaped microstrip are further folded to form a pair of closely coupled lines that enhance the capacitive nature of the open-end arms. The area of this type of resonator is less than half of that of a U-shaped resonator. Therefore, this miniaturised hairpin resonator is much smaller than a conventional hairpin resonator.

On the other side, RF devices and systems have to bear harsh outdoors weather conditions, and therefore, they have to be shielded. A packaging method determines the reliability and long-term stability of a RF device; in addition, packaging has become increasingly important in terms of isolation and interference suppression. If some not properly controlling happened, the interference can cause each device or system to malfunction and even fail. Therefore, good packaging is essential for the commercial success of these devices [15–17]. As a result, the packaging must be considered from the very beginning of the filter development. In this research, a chip-on-board (COB) attachment of our presented BPF to a printed circuit board (PCB) is demonstrated. The COB method is a direct chip assembly technology wherein the chip die is directly mounted on and electrically interconnected to its final circuit board instead of undergoing a traditional packaging process as an individual IC. The COB assembly technology can simplify the overall process of designing and manufacturing a BPF, as well as improve its performance as a result of the shorter interconnection paths due to the elimination of conventional device packaging [18–20]. It also places the wire-bonds nearer to a ground plane to further reduce the emissions and provide a higher reliability due to the improved heat distribution and a lower number of solder joints.

In our previous work [21], a miniaturised bandpass filter packaged by COB method was presented, however, that work did

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not give a detailed analysis of filter, description of fabrication and COB-packaging. And the unsatisfactory metal surface roughness affects the performance of the proposed filter seriously. Based on the above mentioned issues, this paper deeply presents explanations on filter design, fabrication and COB-packaging. In addition, the power handling capability of the whole chip is also presented in details. In this paper, a compact elliptic BPF using a cross-coupled topological structure with a hairpin resonator optimised for radar applications is presented. It was fabricated using a semiconductor process and packaged using the COB method. Each resonator requires approximately 3/4 of the area of a square open-loop resonator. Moreover, the method of COB packaging has been applied to the fabricated BPF to increase the performance and reduce the cost and space requirements. This optimised work improved the metal surface roughness to ensure the realisation of good performance. The measurement results show that the filter's performance can meet the specified design goals; they correspond very well to the electromagnetic (EM) simulation results. The dimensions of the fabricated and packaged BPF are very compact. The paper is organised as follows. Section 2 gives a detailed description of the design theory for the proposed BPF. Section 3 investigates the semiconductor fabrication process and COB packaging method. The measured BPF responses with wire-bonding and final measured BPF responses are presented, and the discussion is presented in Section 4. Section 5 presents this paper's conclusions.

2. X-band filter design and mechanism analysis

The configuration of the optimised hairpin resonators with cross-coupled topological structure is shown in Fig. 1, which evolved from sections of $\lambda/2$ open microstrips. Therefore, the fundamental resonance of each resonator occurs in the odd mode. As such, the electric field distribution at the central valley of the folded microstrip is maximised during resonance, and the electric field distribution at both ends of the coupled lines are minimised with opposite signs [22]. The following discussion describes the procedure used to design the elliptic function BPF. The width of the microstrip was determined by setting its characteristic impedance to 50 Ω with the goal of compacting the entire structure. The transfer function of the elliptic type of filter is [1]

$$|S_{21}(\Omega)|^2 = \frac{1}{1+F_n^2(\Omega)\varepsilon^2} \tag{1}$$

$$\varepsilon = \frac{1}{\sqrt{10^{-\frac{L_R}{10}}-1}} \tag{2}$$

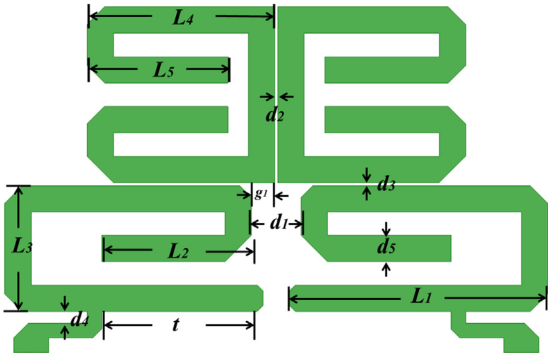

Fig. 1. The geometrical structure of the proposed elliptic BPF

$$F_n(\Omega) = \cos\text{h}\left[(n-2)\cos\text{h}^{-1}(\Omega) + \cosh^{-1}\left(\frac{\Omega_z\Omega-1}{\Omega_z-\Omega}\right) + \cosh^{-1}\left(\frac{\Omega_z\Omega+1}{\Omega_z+\Omega}\right)\right] \tag{3}$$

where Ω is the frequency variable that is normalised to the passband cut-off frequency of the lowpass prototype filter, $\Omega = 1/\text{FBW}\cdot(\omega/\omega_0 - \omega_0/\omega)$, in which ω is the frequency variable of the bandpass filter, ω_0 is the midband frequency, and FBW is the fractional bandwidth. ε is a ripple constant related to a given return loss, $L_R = 20\ \text{Log}\ |S_{11}|$, and n is the degree of the filter. $\Omega = \pm\ \Omega_z\ (\Omega_z > 1)$ clearly gives the frequency locations of a pair of transmission zeros. The locations of two finite frequency transmission zeros of the bandpass filter are given by

$$\omega_{z1} = \omega_0\frac{-\Omega_z\text{FBW} + \sqrt{(\Omega_z\text{FBW})^2+4}}{2} \tag{4}$$

$$\omega_{z2} = \omega_0\frac{\Omega_z\text{FBW} + \sqrt{(\Omega_z\text{FBW})^2+4}}{2} \tag{5}$$

In the design of the desired four-pole function X-band BPF, the cross-coupled topological structures are applied to generate finite transmission zeros, which can greatly improve the selectivity of the proposed BPF.

In this work, the cross-coupled filter was designed by using the above transfer function. The degree of the filter was $n=4$. The specification of the elliptic response was $F_c = 11.25$ GHz and 3 db-FBW=20%; the coupling coefficients and input/output external quality factors can be determined using the following formulas [1]:

$$\text{Q}_{\text{er}} = \text{Q}_{\text{el}} = \frac{g_1}{\text{FBW}} \tag{6}$$

$$M_{i,i+1} = M_{n-i,n-i+1} = \frac{\text{FBW}}{\sqrt{g_i g_{i+1}}} \quad \text{for } i = 1 \text{ to } m-1 \tag{7}$$

$$M_{m,m+1} = \frac{\text{FBW}\cdot J_m}{g_m} \tag{8}$$

$$M_{m-1,m+2} = \frac{\text{FBW}\cdot J_{m-1}}{g_{m-1}} \tag{9}$$

The values g_1, g_2, J_1, and J_2 were obtained from the tables provided by Hong and Lancaster [1]. Finally, the external quality factors and the coupling coefficient matrixes can be derived:

$$Q_{er} = Q_{el} = 4.862$$

$$M = \begin{bmatrix} 0 & -0.0108 & 0.1614 & 0 \\ -0.0108 & 0 & 0 & 0.1614 \\ 0.1614 & 0 & 0 & 0.1285 \\ 0 & 0.1614 & 0.1285 & 0 \end{bmatrix}$$

In this study, the full wave simulators Advanced Design System (ADS) 2011 tool was used for the extraction process. Once the physical dimensions of each resonator were determined, the dimensions associated with the tap position t of I/O resonators and the gaps between adjacent resonators could be obtained using the design curves shown in Fig. 2. The coupling spacing d_1 and d_2 for the required $M_{1,2}$ and $M_{3,4}$ can be determined from Fig. 2(a)-green dash dot line for the electric coupling and Fig. 2 (b)-green solid line for the magnetic coupling, respectively. The mix coupling spacing d_3 for $M_{1,3}$ can be found from Fig. 2(b)-red dash dot line. The tapped line position for the required Q is determined from Fig. 2(a)-red solid line.