Design of WLAN Filters in LTCC and LCP System-On-Package Technologies

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CONFERENCE TOPIC ♯2: Filters and Multiplexers

***Abstract*— Electronics packaging evolution involves both architectural and technology considerations. In this paper, we present the design and measurements of Single-Input-Single-Output (SISO) dual-band filters operating at ISM 2.4-2.5 GHz and UNII 5.15-5.85 GHz frequency bands, using the novel "dual behavior resonators" technique. The filters have been fabricated using Low Temperature Co-fired Ceramic (LTCC) and Liquid Crystal Polymer (LCP) multi-layer packaging technologies, enabling a low cost system-on-package (SOP) implementation. Finally an LTCC low-pass filter have been measured and cascaded to the dual-band in order to suppress high-frequency spurious response.**

I. INTRODUCTION

SEVERAL standards have been approved for operating in the ISM and UNII frequency bands, including Bluetooth, IEEE 802.11a/b/g [1]-[3]. The explosive expansion of the WLAN marketplace has been mostly enhanced by the introduction of dual-band wireless systems. Most of the products that can be found in the market offer a dual path architecture. The reason behind this is to be found in the different power level characterizing the two operating bands and the different modulation scheme adopted with respect to the standard in use. Moreover, the services operating in the 5 GHz have a total available signal bandwidth of 300 MHz (5.15-5.35 and 5.725-5.825 GHz), as compared to the 85 MHz available for 2.4 GHz standards. One notices that the dual-band system is intrinsically asymmetrical. Therefore, this growing WLAN market has raised interest in novel architecture design and new technologies, in order to reduce complexity, costs and space. The goal is to exploit the same RF path providing support to multi-standards and multi-bands on a single platform, reducing the number of components, while maintaining effective performance and compactness.

Miniaturization, portability, cost and performance have been the driving force for the evolution of packaging and system-on-package (SOP) approach in RF, microwave and millimeter wave applications. Few material technologies are able address these considerations simultaneously. LTCC is a technology that has excellent electrical performance, dense multilayer integration, and good barrier properties, but it is relatively expensive compared to standard FR4. Most other substrate and packaging materials do not have low enough water absorption properties in tandem with multilayer construction capabilities to be considered for vertically integrated designs. Liquid crystal polymer (LCP) is a promising material because it has exceptional properties that make it well suited for use as a substrate material [4]. It is extremely attractive as a high frequency circuit substrate and package material due to its low loss ($tan_\delta < 0.004$) and low dielectric constant (2.9-3) up to mm-wave frequency range. Very good barrier properties make LCPs well suited for the use in packaging applications. Moreover, LCP is quite flexible and significantly cheaper (comparable to FR4) than most of the other laminated materials. Superior performance of integrated passives can therefore be achieved using this technology [5].

On the basis of the previous considerations, Single-Input-Single-Output (SISO) WLAN dual-band filters have been synthesized adopting the novel "dual behavior resonator" technique [6]. Exploiting the strong second resonant frequency of resonators to realize the filtering response, allows for achieving the asymmetric shape and the good rejection between the two bands. The filter has been fabricated both in LCP and LTCC and measured performances will be shown. Finally a low-pass filter, designed basing on the "m-derived" method" [7] will be cascaded to the dual-band filter to provide a good high frequency spurious response suppression.

II. THE DUAL-BAND FILTER DESIGN

SISO WLAN dual-band filters have been synthesized basing on the novel "dual behavior resonator" technique. The dual behavior resonators (DBRs) technique is based on the parallel association of two open-ended stub resonators [6]. The open-ended stub is, in fact, the simplest realization of a band-stop structure and shows a dual behavior in the band-pass and stop-band regions: using an open-ended shunt stub implies the introduction of a transmission zero (stop-band area), the resonance frequency of which can be easily controlled by adjusting the stub length, plus by playing with the several degrees of freedom that a microwave design offers. If the stubs are properly connected under constructive recombination criteria, the result is a band-pass response created between the lower and the upper rejected bands. The same approach has been extended to obtain a dual-band narrow band pass filter, simply adding a third resonator to create a third transmission zero. Choosing the transmission zero frequencies, one can first determine the length of the stubs which is equal to $\lambda/4$. The characteristic impedances of the three stubs are linked by the constructive recombination criterium. Once the central frequencies of band-pass regions are established, all impedances are determined and the full control of the pass-bands is possible, as demonstrated [8]. The values provided by the synthesis procedure, have been used to design an optimized planar compact structure by means of a full wave CAD tool. A second order filter has been considered, to achieve better performance in terms of selectivity. A simple version of the filter schematic is shown in figure 1.

In this case, the location of the transmission zeros has been accurately chosen in order to control the width and the location of the desired bands, successfully exploiting the second resonance frequency. The desired bands, 2.4-2.5 GHz and 5.15-5.85 GHz, are, in fact, very different in terms of width. Moreover the channel spacing is wide and a good rejection is difficult to achieve with the standard technique. On this basis, the stubs have been dimensioned in order to have transmission zeros at 2.2 GHz, 2.93 GHz and 3.14 GHz. To realize the pass-band in the 5 GHz range, the second resonance frequency of the first stub has been successfully exploited, while the close transmission zeros at 2.9 and 3.14 GHz allows a better rejection in the inner stop band.

III. Prototyping and Measurements Results

Multi-layer substrates have been and still are of great interest for research in the area of the 3D integration of RF and millimeter waves functions and module using the System-on-Package (SOP) approach. Our interest has been focused mainly on advanced multi-layer materials such as liquid crystal polymer (LCP) and Low Temperature Co-fired Ceramic (LTCC). LTCC has been widely used for RF and millimeter waves applications because of its process maturity and stability and its relatively low cost. Multi-layer capability up to 20 metal layer makes LTCC very attractive for 3D integrated embedded components such as filter and antenna in a very compact and cost effective manner [9]. LCP (Liquid Crystal Polymer) is a fairly new and promising thermoplastic material [10]. It can be used as a low cost dielectric material for high volume large area processing methods that provides very reliable high performances circuits at low cost. LCP have a unique combination of properties such as excellent electrical properties up to millimeter waves (low dielectric constant of 2.9 @ 20 GHz and low loss tangent of 0.002 @ 20 GHz comparable with ceramics), very good barrier properties, permeability comparable to that of glass and very close to that of ceramic, low coefficient of thermal expansion.

The prototype, shown in figure 2, has been fabricated in LCP and LTCC substrates. The size of the filter is mostly determined by the open-ended shunt stubs length. Folding the shunt stubs by the length of the open end in a sort of spiral shape, alleviates the effect of such excessive lengths and gives the structure a more compact and symmetric shape.

The LCP substrate is characterized by ϵ_r 2.9, tan_δ 0.002, substrate thickness 275 μm, conductor thickness 9μm. The prototype occupies a a 8mmx15mm of LCP area. Figure 3 shows the good agreement between IE3D simulation and measurement. The occurrence of a frequency shift, due to substrate dispersion and fabrication uncertainties, has been detected. The insertion loss and return loss at the central frequency are -2.4dB and -15dB for the 2.4 GHz band, respectively, and -1.8dB and -10dB for the 5 GHz band, respectively. Though the lower band is perfectly covered, the upper band is narrower than expected. Nevertheless this parameter can be easily recovered after a further optimization of the design. The filter exhibits also an out-of-band rejection as high as 45 dB between the bands.

The LTCC substrate is characterized by ϵ_r 5.4, tan_δ 0.0015, substrate thickness is 600 μm (stacking six layers of 100 μm each), conductor thickness 9μm. The prototype occupies a a 7mmx9mm of LTCC area. Figure 4 shows the comparison between IE3D simulation and measurement. The insertion loss and return loss at the central frequency are -5.8dB and -10dB for the 2.4 GHz band, respectively, and -2.5dB and -20dB for the 5 GHz band. The out-of-band rejection is as high as 45 dB between the bands. The results are poorer than in the LCP case: the occurrence of a frequency shift is present as well, and the lower band is

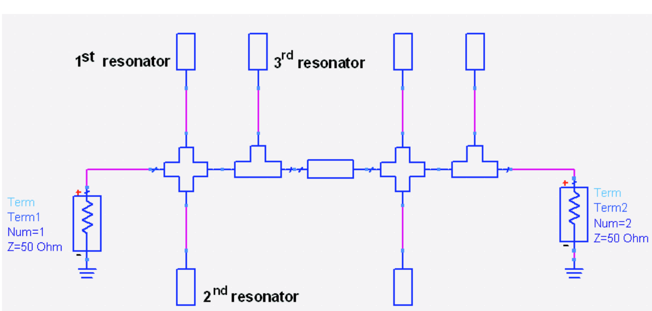

Fig. 1. Dual-band filter schematic

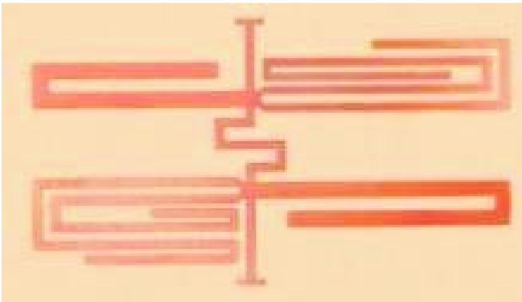

Fig. 2. WLAN Dual-band filter prototype

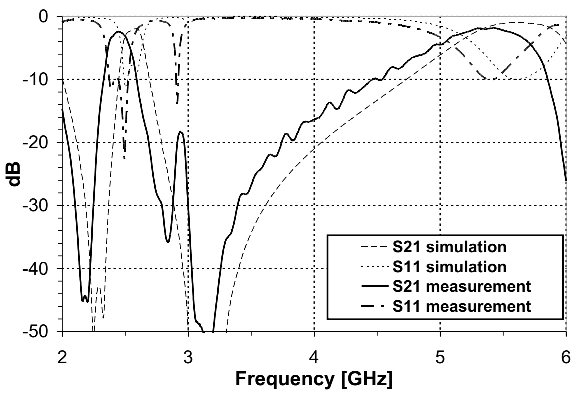

Fig. 3. Comparison between IE3D simulation results and measurements on the LCP prototype

characterized by a high insertion loss. Further optimization is required, but the results shows in both cases (LCP and LTCC) that these substrates are good candidates for microwave filters implementation.

In filter design based on the ”dual behavior resonators” technique, the constructive recombination is placed between the intrinsic resonance of each stub and causes the spurious resonances to be closer to the band-pass filter, allowing undesired low and high frequency signals to pass through. Capacitive feeding of the filter will remove the DC, and low pass filtering will remove the high frequency spurious response. This second aspect has been investigated in the case of the LTCC dual-band filter prototype.

A compact low-pass filter showing a cut-off frequency around 6 GHz has been designed basing on the ”m-derived” sharp cut-off method [7]. The presence of strong attenuation pole near the cutoff frequency provides a sharp attenuation response, while ensuring good matching properties in the pass-band, making this filter design very attractive for harmonic spurious response suppression. It has been fabricated

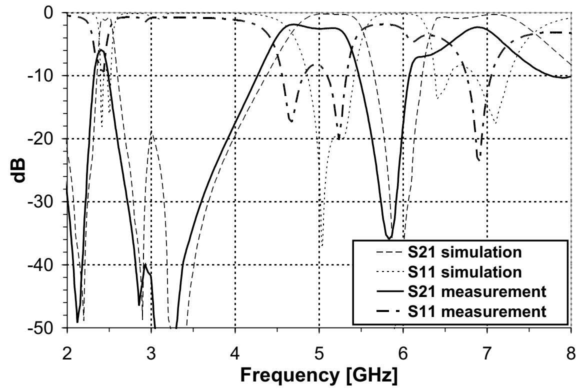

Fig. 4. Comparison between IE3D simulation results and measurements on the LTCC prototype

in LTCC, exploiting 8mmx4mm of substrate area (see figure 5), and measured. Figure 6 shows the comparison between IE3D simulations and experimental results. The agreement is quite satisfactory, despite of a slight frequency shift that has already been observed in the dual-band filters case. Measured performances exhibit rejection of the attenuated pole greater than 40dB while insuring insertion losses below 1 dB in the pass-band.

The low-pass filter has then been cascaded to the LTCC dual-band filter. As can be seen from figure 7 the high frequency spurious response is definitively removed and the return loss improved.

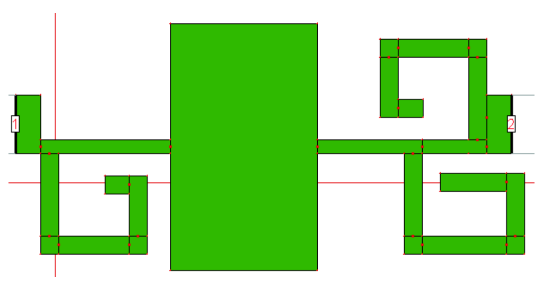

Fig. 5. ”m-derived” low-pass filter LTCC prototype

IV. Conclusion

In this paper SISO dual-band filters for WLAN applications in ISM 2.4-2.5 GHz and UNII 5.15-5.85 GHz frequency bands fabricated on LCP and LTCC have been shown. The design has been based on the novel ”dual behavior resonators” technique and exploits the strong second resonant frequency of resonators to realize the asymmetric filtering response. Moreover, a LTCC compact low-pass

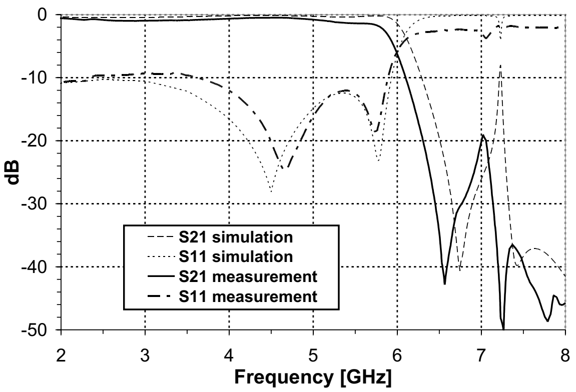

Fig. 6. Comparison between IE3D simulation results and measurements on the LTCC low-pass filter

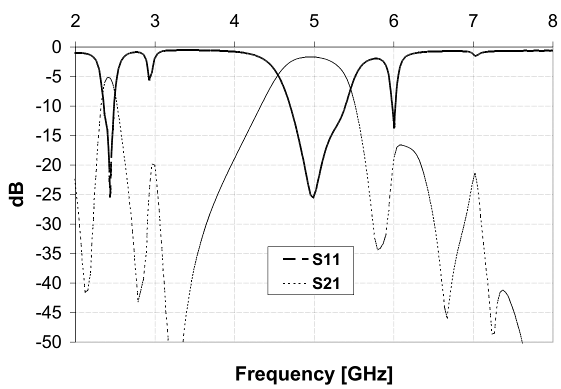

Fig. 7. Measurements results for the LTCC dual-band filter with low-pass filter

filter design for harmonic spurious response suppression at 6 GHz has been detailed.

In combination with innovative design this paper demonstrates LCP and LTCC potential for very low cost and high performances integrated circuits for RF and mm-wave applications.

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