Design of an Asymmetrical Dual-Band WLAN Filter in Liquid Crystal Polymer (LCP) System-On-Package Technology

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***Abstract*—A single–input–single–output (SISO) dual-band filter operating at ISM 2.4–2.5 GHz and UNII 5.15–5.85 GHz frequency bands, using the novel "dual behavior resonators" technique has been developed. 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 insertion loss and return loss at the central frequency are −2.4 dB and −15 dB for the 2.4-GHz band, respectively, and −1.8 dB and −10 dB for the 5-GHz band, respectively. The filter has been fabricated using the novel liquid crystal polymer (LCP) based multilayer packaging technology, enabling a low cost SOP implementation.**

***Index Terms*—Dual-band filter, liquid crystal polymer (LCP), single-input-single-output (SISO), WLAN.**

I. Introduction

SEVERAL standards have been approved for operating in the ISM and UNII frequency bands, including Bluetooth, IEEE 802.11a/b/g [1]–[5]. The explosive expansion of the WLAN marketplace has been mostly enhanced by the introduction of dual-band wireless systems. Dual Band systems enable WLAN users with the freedom of using their preferred frequency whenever they need it, operating in the recent 802.11a 5 GHz for high speed data rate or the popular 802.11b and the new 802.11g 2.4 GHz for convenient access. Most of the products that can be found in the market offer a dual path architecture, one for the 5-GHz band, the other for the 2.4-GHz band. 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 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. On the basis of the previous considerations, a single–input–single–output (SISO) liquid crystal polymer (LCP) dual-band filter has been synthesized adopting the novel "dual behavior resonator" technique [6], [7].

LCP is a promising material because it has exceptional properties that make it well suited for use as a substrate material [8]. 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. The combination of polymeric specific properties together with properties specific to the liquid crystal phase has led to a multitude of new prospectives that are not possible for conventional materials. Exceptional barrier properties make LCPs well suited for the use in packaging applications and can replace materials such as ceramics, metals, composites and plastics due to the outstanding mechanical properties [9]. Moreover, LCP is quite flexible and significantly cheaper (comparable to FR4) than most of the other laminated materials, such as LTCC. Superior performance of integrated passives can therefore be achieved using this technology [10].

II. Dual-Band Filter Design

This section shows the novel "dual behavior resonators" method as the key enabling solution for SISO dual-band filter design. The Dual Behavior Resonators (DBR's) technique is based on the parallel association of two open-ended shunt stub resonators [6]. The open-ended shunt 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. In the preliminary case of the two-stub structure, if the stubs that form the filter are properly connected under constructive recombination criteria, the result is a band-pass response created between the lower and the upper rejection bands.

The same approach has been extended to obtain a dual-band narrow band-pass filter, by 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

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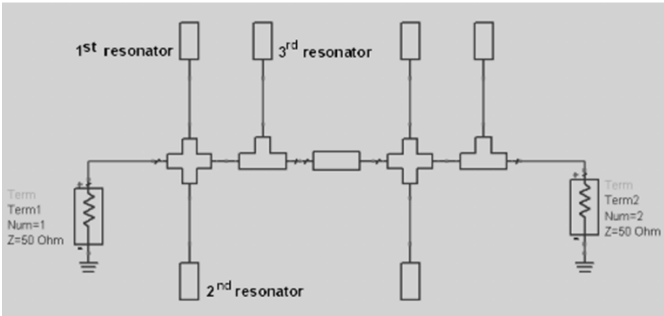
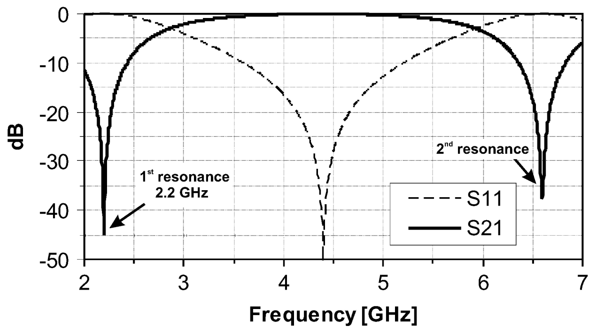
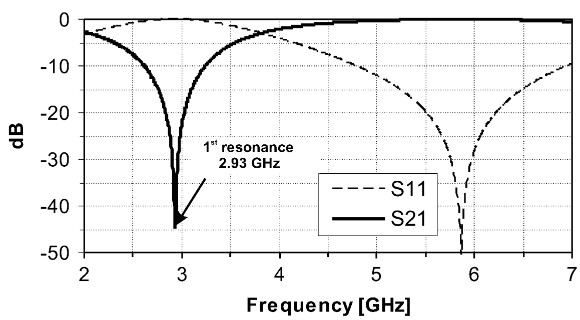


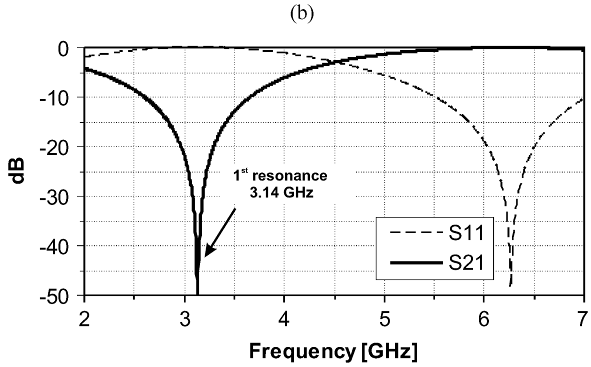
Fig. 1. Dual-band filter schematic.



(a)



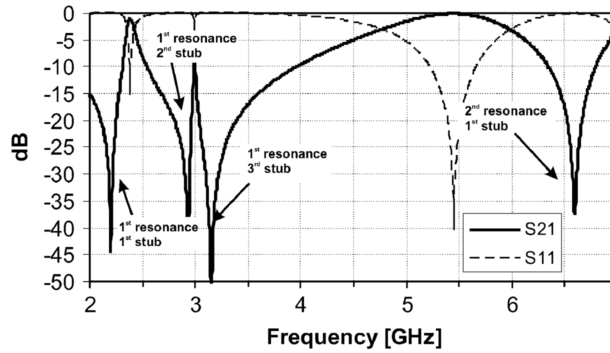
(b)



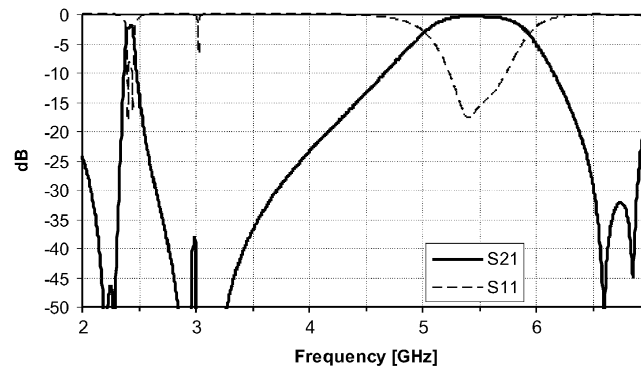
(c)

Fig. 2. (a) First resonator at 2.2 GHz. (b) Second resonator at 2.93 GHz. (c) Third resonator at 3.14 GHz.

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 in [7]. 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 simple version of the filter schematic is shown in Fig. 1.



(a)



(b)

Fig. 3. Design procedure. (a) First order filter. (b) Second order filter.

The two design passbands, 2.4–2.5 GHz and 5.15–5.85 GHz, are very different in terms of bandwidth (~4% at 2.4 GHz, ~12.7% at 5 GHz). Moreover the channel spacing is wide and a good rejection is difficult to achieve simply applying the technique described in [7]. To overcome this problem the location of the transmission zeros has been accurately chosen in order to control width and placement of the desired bands, successfully exploiting the second resonance frequency. Since the open stub resonates periodically, according to its length, the idea behind the project described here is to exploit the second resonance frequency to build the upper band-pass.

The design procedure followed the steps described in Figs. 2 and 3. 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 [see Fig. 2(a)], while the close transmission zeros at 2.93 and 3.14 GHz allows a better rejection in the inner stop band [see Fig. 3(a)]. A second order filter has been considered, to achieve better performance in terms of selectivity [Fig. 3(b)].

III. Results

The prototype, shown in Fig. 4, has been fabricated in LCP substrate, characterized by $\epsilon_r 2.9 \tan_\delta 0.002$, substrate thickness 275 μm, conductor thickness 9 μm. 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, resulting in a 8 mm $\times$ 15 mm of LCP area. Fig. 5 shows the

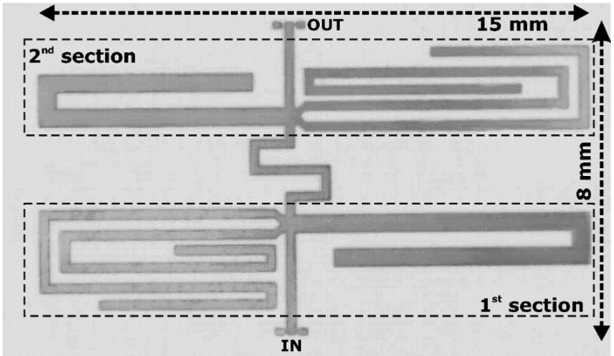


Fig. 4. WLAN dual-band filter prototype.

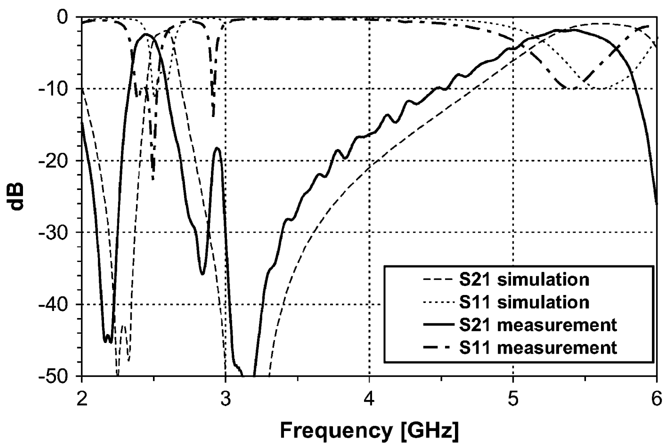


Fig. 5. Comparison between IE3D simulation results and measurements.

good agreement between IE3D simulation and measurement. The occurrence of a slight frequency shift has been detected: this is due to substrate dispersion, fabrication uncertainties and SMA connectors effects. Since no coupling phenomenon is used to synthesize the DBR filters, the radiation losses are negligible. The insertion loss and return loss at the central frequency are -2.4 dB and -15 dB for the 2.4 GHz band (6% around 2.45 GHz), respectively, and -1.8 dB and -10 dB for the 5-GHz band (12% around 5.45 GHz), 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.

It is worth noticing that using uniform open ended stubs is only an option; further degrees of freedom can be obtained using short-circuited and stepped-impedance stub resonators [11].

IV. Conclusion

A SISO dual-band filter with excellent loss performance for WLAN applications in ISM 2.4–2.5 GHz and UNII 5.15–5.85 GHz frequency bands (in-band insertion loss of 2.4 dB and 1.8 dB, respectively) has been reported. It is based on the novel "dual behavior resonators" technique and exploits the strong second resonant frequency of opend ended stub resonators to realize the asymmetric filtering response, achieving an out of band rejection of 45 dB. It has been fabricated using the LCP based multilayer packaging technology, which is proving to be an all-in-one solution for the heterogeneous SOP 3-D integration for multiband and reconfigurable RF modules.

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