Highly Integrated LTCC and LCP Millimeter Wave Functions For 3D-SOP High Data Rate Wireless Systems.

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Abstract—This paper presents the development of highly integrated millimeter waves function in multilayer LTCC and Liquid Crystal Polymer technology. Both ceramic and organic technologies are candidate of choice for the 3D integration, following the system-on-package concept, of compact, low cost, millimeter-wave high data rate wireless systems. Compact and easy-to-design passive functions such as directional filter and band pass filter have been demonstrated with excellent performances and high integration potential. Directional filter represents a fundamental device class enabling a compact hybrid passive mixer solution for millimeter wave direct modulator since they combine multiple filtering functions, reducing complexity while maintaining compactness. Easy implementation in standard LTCC technology has been demonstrated by using vertically coupling mechanism. Liquid Crystal Polymer (LCP) is a organic material that offers a unique combination of electrical, chemical and mechanical properties, enabling high frequency designs due to its ability to act as both the substrate and package for multilayer constructions. A band pass filter was designed to enable a low cost, very easy to design filtering solution to be integrated into a wireless millimeter-wave gigabit link system. The design exploits successfully the ripple of modified stepped impedance Tchebyscheff low pass filter combined with a rejection stub to create a wideband band-pass response center at 60 GHz. Insertion loss as low as 1.5 dB has been measured demonstrating the potential of LCP for millimeter-wave applications.

I. INTRODUCTION

Emerging high data rate wireless applications such as next generation WLAN systems and point-to-point systems requires more than ever low-cost manufacturing, excellent performances in millimeter wave and high level of integration. Unfortunately, cost, electrical performance, integration density, and packaging compatibility are variables that are often at odds with each other in RF designs. Few material technologies are able to address these considerations simultaneously. LTCC is a technology that has excellent electrical performance, very dense multilayer integration, and good barrier properties. It is a major candidate in millimeter wave systems integration [1,5], but due to its limitation in term of design rules (ie. minimum line width and spacing) compared to thin film technologies, the design at millimeter waves frequencies become challenging. Nevertheless, very mature multilayer construction capabilities of LTCC enable the replacement of broadside coupling by vertical coupling and make LTCC a competitive solution to meet millimeter wave design requirements.

On the other hand, most organic substrates and packaging materials do not have low loss (at least tan $\delta < 0.005$) and multilayer construction capabilities to be considered for vertical integration, in tandem with low water absorption properties and good mechanical properties. Liquid Crystal Polymer (LCP) is a organic material that offers a unique all-in-one solution for high frequency designs due to its ability to act as both a high performance substrate and a package for multilayer constructions [2-4]. LCP's very low water absorption (0.04%), low cost, and high performance (εr=2.9-3.0, tanδ=0.002-0.004) make it very appealing for many applications and will be situated as a prime technology for enabling system-on-package RF and millimeter waves designs [2].

In this paper presents the development of highly integrated millimeter waves function in both multilayer LTCC and Liquid Crystal Polymer technology. A compact and easy-to-design directional filter have been fabricated and excellent performances have been measured. Insertion loss of <3dB and a rejection of ~25dB have been measured at 38.5 GHz in the pass band section and in the rejection section respectively. Vertical coupling has been successfully used to overcome the design rules limitations of thick film technology and enable an easy implementation in standard LTCC technology. Also, a band pass filter was designed to enable a low cost, very easy to design filtering solution to be integrated into a wireless millimeter-wave gigabit link system. The ripple of modified stepped impedance Tchebyscheff low pass filter has been exploited and combined with a rejection stub to create a wideband band-pass response center at 60 GHz. Insertion loss as low as 1.5 dB has been measured demonstrating the potential of LCP for millimeter-wave applications.

II. Millimeter Waves LTCC Directional Filter

We developed a 40GHz 4 port directional filter with excellent performance on LTCC. The 3D topology of the device is described in Fig. 1 and Fig. 2. The device exhibits a band rejection characteristic between ports 1 and 2, and band pass characteristic between ports 1 and 4..The other port is isolated from input (port1)[6]. The whole structure is symmetric. It can be used in mixer applications to mix RF and LO signals with high isolation between them. Several directional filters can be cascaded to achieve frequency multiplexing as well as de-multiplexing due to frequency selective nature of one output along with rejection at other output. It has been realized using multilayer LTCC substrate. We choose microstrip transmission lines reduce the number of required layers as compared to stripline and hence increase simplicity while maintaining compactness..The high quality factor of the ring resonator assures narrowband operation and hence this can be used efficiently in frequency selective applications. In this single loop directional filter, the coupling between the ring resonator and the transmission lines has been achieved by vertically coupled structures reducing the need of very narrow broadside coupling distance which could not be realized in LTCC. The lengths of all the sides of the ring have been made quarter wavelength for their respective widths. 50Ω impedance levels are preserved throughout the complete circumference of the loop by optimizing the width of the sides of the ring for both coupled and uncoupled sides. At the working frequency band, the signal couples from the input transmission line to the embedded ring and hence required band pass and band reject characteristics are achieved. The dielectric thickness is 100um between each metal layers and it takes an area of 2mm×2mm. The measured performances of the filter are shown in figures 3. The band pass section shows an insertion loss of <3dB and the band reject section shows a rejection of ~25dB at around 38.5 GHz.

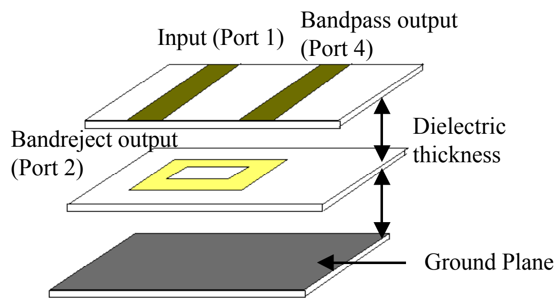


Fig. 1. schematic view of the multilayer millimeter waves LTCC directional filter.

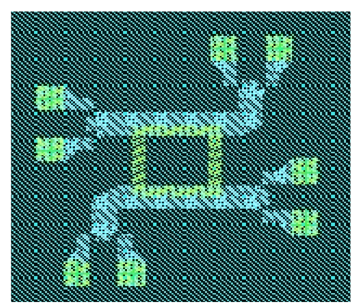


Fig. 2. Layout of the of the multilayer millimeter waves LTCC directional filter.

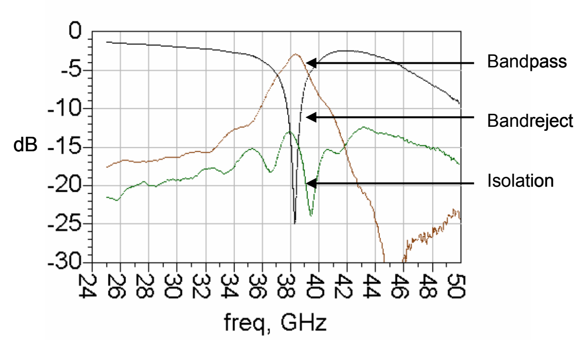
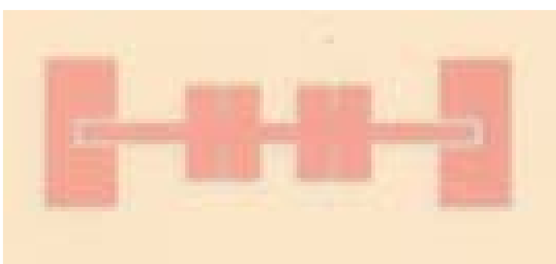


Fig. 3. Measured performances of the fabricated multilayer millimeter waves LTCC directional filter.

III. MILLIMETER WAVE COMPACT BAND PASS FILTER DESIGN ON LIQUID CRYSTAL POLYMER.

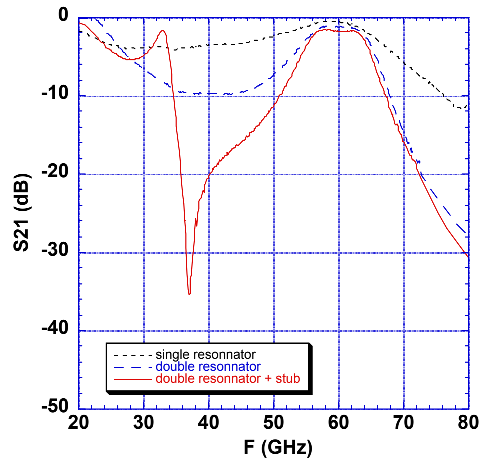
The design we developed exploits the ripple near the cut off frequency of a Tchebyscheff low pass filter to create a band pass response. The initial low pass filter has been implemented by cascading two low impedance sections [6]. Two slots have been added in each of these low impedance sections to enhance the ripple amplitude (cf. Fig 4a). Figure 5 shows that a ripple of 10 dB in amplitude has been measured. Then an open stub creating a transmission zero at 36 GHz has been added to enhance the rejection up to –35dB in the lower band (Fig 4b and Fig 5a). Capacitive feeding could be used to remove the low frequency pass band if it is required. This combination results in a pass-band response centered at 60 GHz and a relative 3dB bandwidth of 15%. Minimum insertion losses as low as –1.5 dB have been measured. A ripple of +/- 0.15 dB has been measured over a bandwidth of 6 GHz centered at 60 GHz (Fig.5). The design offers a very simple, low loss and low cost filtering solution for wideband millimeter waves applications such as 60 GHz WLAN gigabits wireless systems.



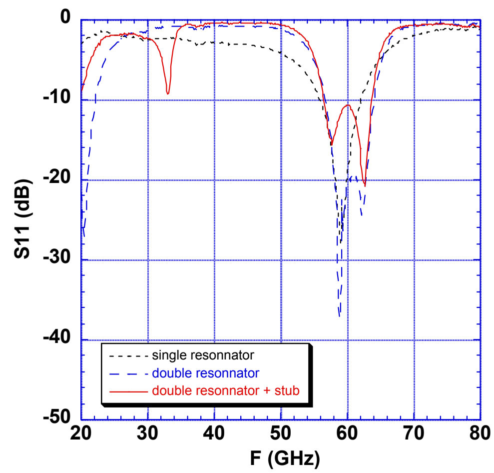
a)

b)

Fig. 4. Photograph of the fabricated millimeter waves LCP band pass filter with two “resonators” (a), two resonator and a rejection stub (b).



a)



b)

Fig. 5: Measured insertion loss (a) and return loss (b) of the LCP band pass filter.

V. CONCLUSION

We have presented the development of highly integrated millimeter waves function in both multilayer LTCC and Liquid Crystal Polymer technology. A compact and easy-to-design LTCC directional filter using vertical coupling has been fabricated to enable a compact hybrid passive mixer solution for millimeter wave direct modulator. Excellent performances have been measured. Insertion loss of <3dB and a rejection of ~25dB have been measured at 38.5 GHz in the pass band section and in the rejection section respectively. Also, a band pass filter exploiting the ripple of modified stepped impedance Tchebyscheff low pass filter combined with a rejection stub has been designed to enable a low cost, very easy to design filtering solution to be integrated. A minimum insertion losses as low as –1.5 dB have been measured. A ripple of +/- 0.15 dB has been measured over a bandwidth of 6 GHz centered at 60 GHz (Fig.4). The design offers a very simple, low loss and low cost filtering solution, ready to be integrated in wideband millimeter waves applications such as 60 GHz WLAN gigabits wireless systems.

ACKNOWLEGEMENTS

The authors wish to acknowledge the support of the Georgia Tech. Packaging Research Center, the GEDC Design Center, the NSF Career award, and the NSF Grant #ECS-0313951.

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