Liquid Crystal Polymer (LCP): The Ultimate Solution for Low-Cost RF Flexible Electronics and Antennas

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Abstract: In this paper, solutions for developing low cost electronics for antenna transceivers that take advantage of the stable electrical properties of the organic substrate Liquid Crystal Polymer (LCP) has been presented. Three important ingredients in RF wireless transceivers namely embedded passives, a dual band filter and a RFid antenna have been designed and fabricated on LCP. Test results of all 3 of the structures show good agreement between the simulated and measured results over their respective bandwidths, demonstrating stable performance of the LCP substrate.

I. Introduction

Emerging wireless communication and sensor applications in the RF/microwave/millimeter (mm) wave regimes require miniaturization, portability, cost, and performance as key driving forces in the RF electronics evolution. In addition to its traditional use in communication, the use of RF in chemical and biomedical sensing and imaging also is promising, which is only expected to crowd the radio spectrum even further in the near future. Current trends have placed an ever-increasing demand on the materials, particularly dielectrics, used in the fabrication of RF devices.

As devices operate over ever widening bandwidths in the RF range, the substrate used should be able to change its polarization in response to propagating electromagnetic fields at even higher speeds (low permittivity) without exhibiting significant electric losses (loss tangent). Additionally, substrates should be able to demonstrate these electrical properties over a wide range of frequencies and external conditions such as temperature and pressure etc. This property becomes particularly useful in the design of broadband applications and in minimizing power leakage into adjacent bands, which is useful especially for communications devices operating in the crowded UWB range. Lastly, substrates used in RF devices should be able to withstand the rigors (e.g. humidity, gasing) of its operating environment and of the fabrication processes used in its packaging.

Liquid Crystal Polymer (LCP) is a fairly new and promising thermoplastic organic material [1]. It can be used as a low-cost dielectric material for high-volume large-area processing methods that provide very reliable high-performance circuits at low cost.
It has impressive electrical characteristics, which is indirectly related to its low and stable water absorption rate (<0.04%). It has a nearly constant dielectric constant of 3.1 over the entire RF range up to 110 GHz. In addition, LCP has a very low loss tangent of only 0.002, which increases to only 0.0045 at 110GHz, thereby making LCP very suitable in designing mm-wave applications [1]. Impressively low thermal expansion characteristics of LCP also make it ideal as a high frequency packaging material. The controllable coefficient of thermal expansion (CTE) of LCP can be engineered to match copper, silicon or GaAs, thereby making metallization on it easier. Multilayer circuits in LCP are also possible due to two types of LCP material with different melting temperatures making it ideal for System on Package Designs shown in fig 1. LCP is flexible,

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recyclable, impervious to most chemicals, and it is stable up to its high melting temperature making LCP an ideal choice for circuits operating in all kinds of environments.

This paper will present the designs of various RF passive structures, commonly in use in the wireless communication modules that have been fabricated using the LCP substrate at the Georgia Electronic Design Center (GEDC).

II. Thin Film Broadband Resistors on LCP

Embedded passives form an integral of all antenna based transceiver systems in attenuators or as tuning elements to alter the Q-factor of antennas. A cost effective method of creating embedded passive resistors on LCP for integration into LCP-based System on Package solutions is presented in this section. The resistors have been designed and characterized for broadband performance up to 40 GHz. The first step in this method involves laminating a sheet of copper foil with an integrated NiCrAlSi resistive layer onto a 4mil thick LCP substrate [2]. The film thickness can be chosen from between 100 to 400 Angstroms depending on the desired sheet resistance [2]. The next step involves using a two step selective etching process to selectively etch through the copper and the resistive layer followed by etching only the copper to expose the resistive layer, which forms the resistor shown in fig 3.Resistances ranging from 0 to 500 ohms can be fabricated using this technique [2]. The losses in the resistors are due to dielectric and conductor losses. However the contribution of the dielectric loss, a function of the loss tangent of the substrate, to the combined loss is significantly lower as shown in figure 2. The resistance measurements for DC resistance values of 12.5 ohms can be seen in figure 4. The resistances deviate from their respective DC values especially at higher frequencies due to parasitics introduced by the series inductances and shunt capacitance in the signal path. However, the simulated and measured results show good overall agreement over the measured frequency range.

III. SISO LCP Dual Band Filter

Passive filters often find use in the front-end modules of wireless transceivers to suppress undesired in-coming or outgoing signals and/or to increase isolation in duplexers. The presented Single-Input Single-Output (SISO) Dual band filter takes advantage of LCP's stable-with-frequency electrical characteristics to operate at two different frequencies with antennas in the UWB band. The SISO dual band filter uses the "dual behavior resonator" technique to operate at the WLAN operating frequency bands, ISM 2.4 GHz and UNII 5 GHz [3]. These bands have been targeted because of the ever growing number of services allocated in this part of the spectrum, including Bluetooth, IEEE 802.11a/b/g, and the introduction of dual-band wireless systems [3]. The dual behavior resonance technique is achieved through the use of 2 optimized open-ended stub resonators. The prototype dual band filter optimized to get the desired resonant frequencies was fabricated on a 2 mil thick LCP substrate of copper thickness 9um as shown in fig 5. Simulations and measurement show good agreement (fig 6). 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. It exhibits also an out-of-band rejection as high as 45 dB between the L and C band [3].

IV. RFID Tag Antennas

Requirements in automatic identification in several areas such as item level tracking, supply chain and retail applications has increased the demand for low-cost, flexible Radio Frequency Identification (RFID) tags. LCP substrate is considered one of the best candidates for RFID due to many reasons and RFID. Of the main required descriptions of most RFID tags is: conformal shape or flexibility in order to be placed on different shaped objects such as boxes, cylindrical bins, vehicles etc. Secondly, since most RFID tags contain no extra packaging and are exposed directly to their surroundings, RFID tags must be able to withstand harsh industrial environments such as water vapor/humidity. A third requirement is to have a low dielectric constant value with low dielectric loss for optimal RF power efficiency and transmissivity in embedded objects and optimum power performance, especially in passive RFID systems, where the only power to the tag is the RF power from the reader in the vicinity [4]. A typical passive RFID module is shown in fig.7. This antenna was fabricated on 4 mils thick LCP using 18um thick copper [4]. A tapered width dipole antenna was designed for high bandwidth operation. Two stubs: one inductive stub and one resistive stub are used for the matching of the antenna terminals to the IC which exhibits complex impedance as in most passive RFID ICs. The simulated and measured Return Loss is shown in fig. 8 to feature a bandwidth that covers the European (866MHz~868MHz) as well as North American (902MHz~928MHz) RFID UHF frequency bands.

V. Conclusion

The RF passive designs in this paper show good agreement between simulated and measured results over their respective bandwidths thus showcasing the impressively stable performance of LCP as a substrate. Also, LCP’s impressive tolerance to different chemicals and environmental conditions, combined with its low cost and increased flexibility makes it an ideal choice as a packaging material for RF wireless modules.

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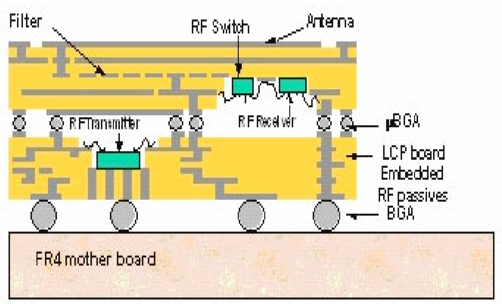

Figure 1. Side view of System on Package.

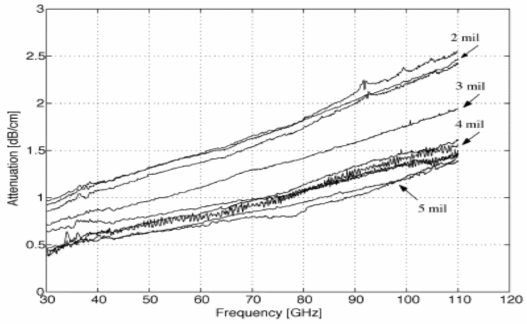

Figure 2. LCP dielectric loss.

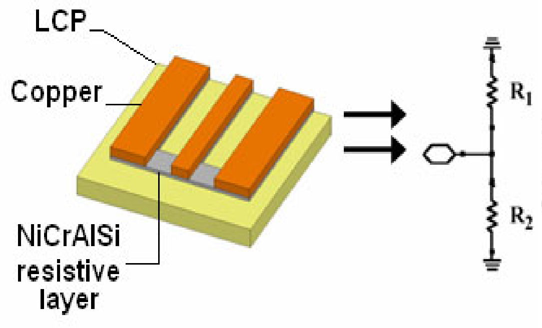

Figure 3. Resistor structure.

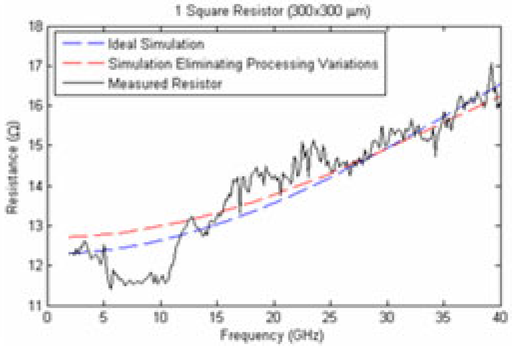

Figure 4. Resistance (DC value 12.5Ω).

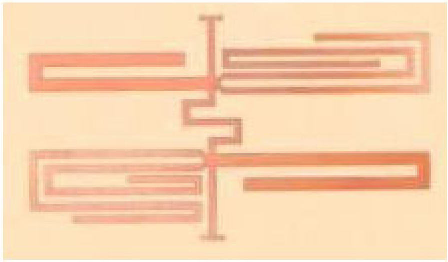

Figure 5. SISO LCP Dual band filter.

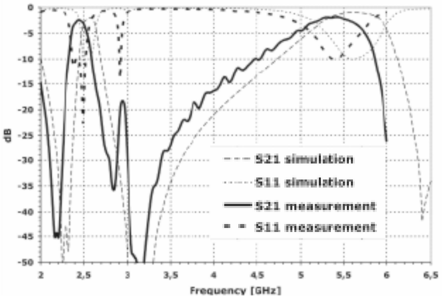

Figure 6. SISO LCP Filter results.

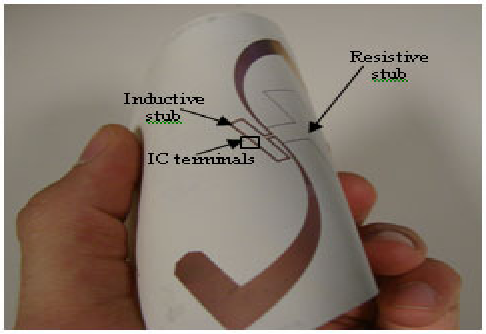

Figure 7. RFID tag on LCP.

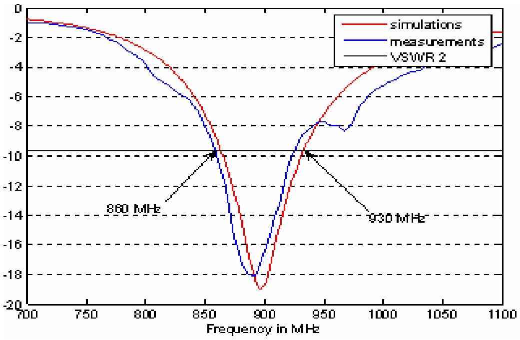

Figure 8. RFID tag Return Loss.