Liquid Crystal Polymer-based Integrated Passive Development for RF Applications

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Abstract — **A Liquid Crystal Polymer (LCP) based multilayer packaging process is presented for RF/microwave applications. LCP is gaining increasing interest as a choice technology in the packaging community due to its superior thermal and electrical properties including low loss, low dielectric constant and low CTE characteristics. For the first time, we present a thorough study of the design, model, and measurement of integrated passives using LCP. A coplanar waveguide transmission line test structure demonstrates an insertion loss of .35dB at 23 GHz and a return loss better than 15dB to 30GHz. Quality factors (Q) in excess of 70 and a self resonance frequency (SRF) to 29GHz have been achieved. A bandpass filter implementation is also demonstrated to realize a c band module. Advantages of passive integration using built up LCP as opposed to multilayer organic are discussed.**

I. INTRODCTION

System on Package (SOP) technology is gaining wide attention due to its potential in addressing issues such as: system volume, cost reduction, electrical performance, and design flexibility. The high wiring density nature of SOP technology requires thin film materials with low dielectric constants. Organic and polymer dielectrics have a low dielectric constant between 2.0-4.0 and high-wiring density, which makes it more attractive than thick film LTCC processes. Focus has been on organic in the form of multilayer SOP technologies. However, organic has limitations due to high coefficient of thermal expansion, low thermal conductivity and higher loss tangent. LCP is extremely attractive as a high frequency circuit substrate and package material due to its low loss and low dielectric constant over a wide frequency range, near hermitic plasing sealing as a result of superior moisture barrier properties, flex circuits and microvia laminates for high density interconnection[1,2]. Superior performance of integrated passives can therefore be achieved using this technology. We show examples of this here as well as comparison to a similar multilayer organic process.

II. LCP PROCESS TECHNOLOGY

LCP is a fairly new material that can be used as a single sheeted or laminated dielectric or as a substrate. It has superior loss, δ=.002 and CTE, (8-17) ppm/°K characteristics compared to a comparable organic process with δ=.026 and CTE, (15-20) ppm/°K. The cross-section of a LCP process is shown in Fig. 1. It uses a 1mm thick FR-4 organic substrate, with 12-18μm copper metal layers and 25μm (1mil) thick dielectric layers.

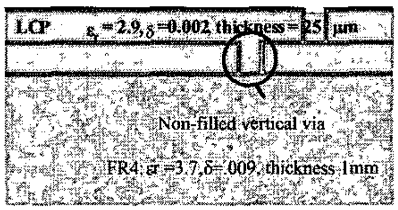

Fig. 1. Cross-section of LCP process technology.

III. LOSS PERFORMANCE

We have fabricated coplanar waveguide (CPW) transmission line test structures to assess the loss performance of this technology. Fig. 2 shows the measured S-parameters of a 100 mil CPW line. A maximum insertion loss of .35dB at 23 GHz is demonstrated. In addition, the CPW exhibits a good match demonstrated by a minimum of 15dB return loss to 30 GHz. This result is better than a CPW fabricated on a similar organic process [3]. For all S-parameter measurements in this paper, a HP8510C network analyzer was calibrated using the LRRM technique up to 30GHz. Cascade Microtech coplanar ground-signal-ground probes were used.

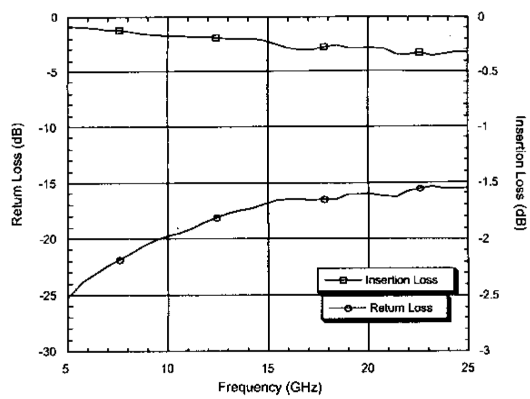

Fig. 2. Measured result of 100 mil LCP CPW line

IV. Inductor Design

Basic 1-port, 5 mil width rectangular spiral inductors were implemented with design variations that include spiral radius (inductor size) and ground plane spacing, Fig. 3. The spiral radius was varied at 26, 29, 36 and 43 mil. Each of them was implemented with ground plane spacing of 10, 15, and 20 mil. Q_{max} in excess of 70 in c-band have been measured. The ground plane effects due to ground plane size are also studied. For this study, 4 mil width, 1-turn circular spiral inductors with 8 mil radius and 8 mil ground plane spacing were designed. Ground plane width was varied at 4, 8, and 12 mil, respectively. Q_{max} of 52 and SRF to 29 GHz were achieved for a 1nH inductance, which is higher than SRF reported in a multilayer organic process for a similar inductance value [4,5].

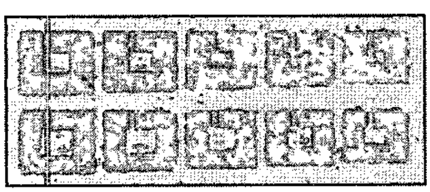

Fig. 3. Photograph of coplanar LCP spiral inductors with radius and ground plane spacing variations.

V. Experimental Results

A. Inductor Radius

As the radius of the CPW inductor increases in increments of 7 mil from 22 to 43 mil, respectively, the measured results are represented in Fig. 4. These graphs demonstrate the effects of radius variation as it impacts quality factor, inductance, and self-resonance frequency. This set of inductors were designed with ground plane spacing of 20, 15, 10, 5 mil, respectively. The highest Q_{max} of 80 was achieved by a 22 mil inductor with a ground plane spacing of 10 mil shown by table 1. Q and SRF decreases as the radius of the coil increases due to the increased series resistance and substrate parasitics as a result of a larger inductor area. The inductance increases as it is proportional to the coil length.

B. Ground Plane Spacing

Fig. 4 also demonstrates that as the spacing between the inductor and ground decreases from 20 to10 mil, maximum Q and SRF increase slightly as a result of the reduction of loss due to parasitic resistance. L decreases due to the increase in eddy current effect.

TABLE 1
SUMMARY OF MEASURED LCP INDUCTOR PERFORMANCE WITH VARIED RADIUS AND GROUND PLANE SPACING

Radius (mil)	GPS (mil)	Q	L (nH)	SRF (GHz)
22	20	72	2.9	11
43	20	63	1.8	15
22	10	80	2.6	11
43	10	67	1.7	16

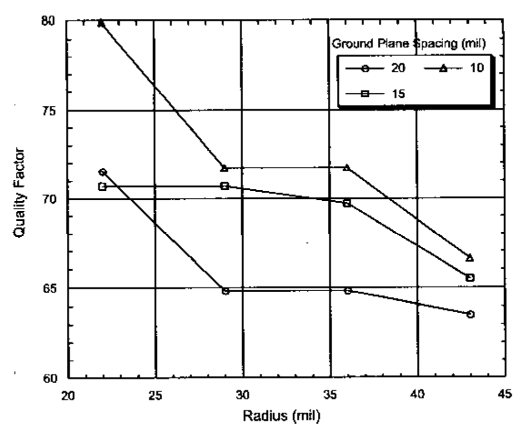

Fig. 4a. Maximum quality factor versus inductor radius.

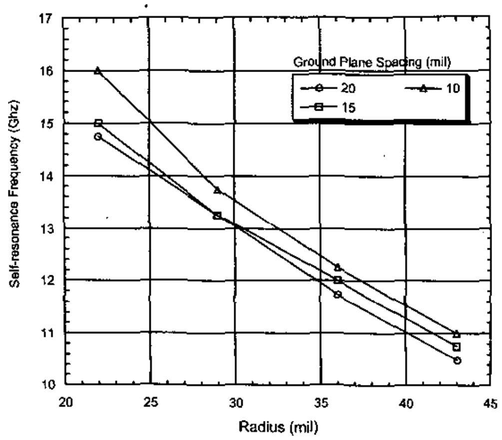

Fig. 4b. Inductance versus inductor radius.

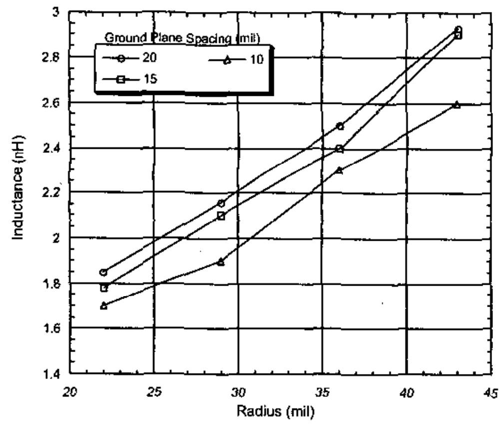

Fig. 4c. SRF versus inductor radius

C. *Ground Plane Width*

While keeping the same spiral footprint, ground plane width was varied at 4, 8, and 12 mils. Q_{max} of 42, 46, and 55 was achieved, respectively, as can bee seen in Fig. 5. SRF to 29 GHz is also achieved for the inductor with 4 mil ground plane spacing. As the size of the ground plane increases, resistive losses decrease, which improves Q shown in table 2. Inductance values remain constant due to the fixed spacing between the inductor and ground plane.

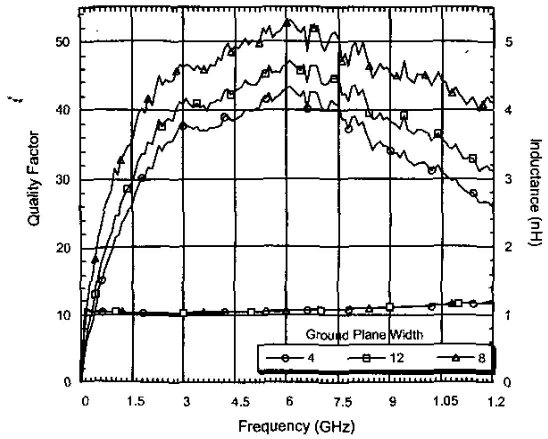

Fig. 5 Measured Q of circular spiral inductor

TABLE 2
SUMMARY OF MEASURED LCP INDUCTOR PERFORMANCE WITH VARIED GROUND PLANE WIDTH

Radius (mil)	GPW (mil)	Q	L (nH)	SRF (GHz)
8	4	43	1	29
8	8	46	1	28.5
8	12	52	1	28

VI. Inductor Modeling

Fig. 6 shows agreement between measured and modeled results of a 22 mil radius inductor with 10 mil ground spacing. The 2.6 nH inductor shows a Q_{max} of 80 with a SRF of 11 GHz. A one-port lumped element electrical model was used for the inductor to understand the parasitics and their effects. L and Rs represent the inductance and resistance, respectively, directly related to the coil. The mutual coupling between the turns are insignificant due to the configuration and relatively large spacing between them. The coupling capacitance and substrate capacitance can be combined in parallel to a single capacitor, Ceq. Rp represents the substrate resistance. It is verified that as the size of the inductor increases Rs and Ceq increases. Rp, which is inversely proportional to the size, decreases, which results in decrease of Q and SRF and increase in L.

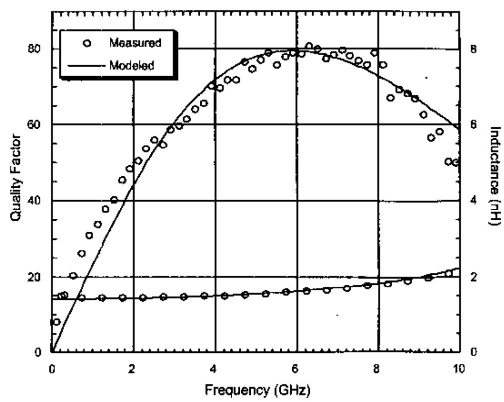

Fig. 6. Measured and modeled Q factor or 22 mil radius inductor with 10 mil ground plane spacing.

VII. BANDPASS FILTER IMPLEMENTATION

Fig. 7 shows a bandpass filter (BPF) implemented in LCP technology. This CPW topology BPF uses a broadside-coupled dual-mode square ring resonator. Performance indicates a center frequency of 5.8 GHz, bandwidth of 1GHz, minimum insertion loss of 1dB and 17dB return loss, Fig. 8. It is designed specifically to realize a compact c-band module suitable for IEEE802.11a WLAN applications.

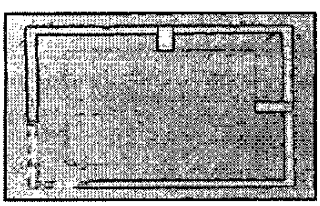

Fig. 7. Photograph of implemented BPF in LCP technology.

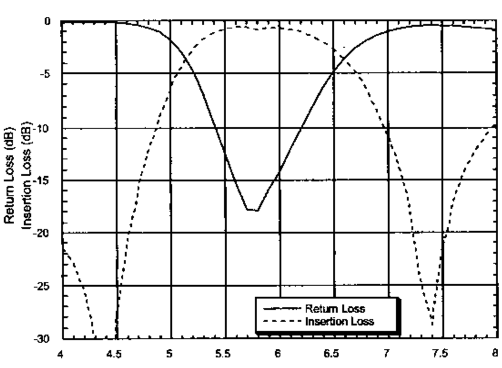

Fig. 8. Performance of 5.8 GHz BPF.

VIII. CONCLUSION

In this paper, we present a Liquid Crystal Polymer (LCP)-based process as a potential for the next generation of RF SOP module applications. We demonstrate the integration of passives taking advantage of the superior characteristics of LCP. We have reported measured and modeled results for ultra-compact high Q inductors implemented in various configurations. A maximum Q of 80 in c-band as well as a SRF to 29GHz was achieved. The bandpass filter demonstrates potential for realizing a compact c-band transmitter for future SOP module applications using multilayer LCP.

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