# Design of Efficient Filter on Liquid Crystal Polymer Substrate for 5 GHz Wireless LAN Applications

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*Abstract:* - Next generation wireless communications terminals will demand the use of advanced component integration processes and high density packaging technologies in order to reduce size and to increase performance. This paper presents high-density multilayer interconnects and integrated passives used to design high performance prototype filter for 5GHz wireless LAN receiver realized on LCP substrate.

The thin film implementation of Multichip Module technology is identified as a useful platform for the integration of GaAs MMIC and silicon device technologies for microwave applications where performance, size and weight are critical factors. The ability of the MCM-D technology to provide controlled impedance, microstrip structures and integrated thin film passive components with useful performance in the microwave frequency regime has now been demonstrated.

*Key-Words:* - Quality factor, Bandpass filter, LCP, MCM, Low noise amplifier, RF front-end.

## 1 Introduction

The demand for wireless and mobile devices requires integration, maintaining low cost, of passive components including inductors. Among the several technologies available for passive integration [1]-[4], the present paper studied systematically the spiral inductors and capacitors embedded on organic substrate using MCM-D technology.

This approach uses high-quality passive components that are realized in a thin-film MCM (MCM-D) interconnection technology. Passive components such as individual inductors and also complete RF bandpass filters are directly integrated into the MCM substrate. The quality factors 'Q' of the passive components are very high, especially compared to on-chip passive components. The MCM technology features high quality inductances between 1 and 40 nH. Compared to a standard thick-film technology or a low-temperature cofired ceramic (LTCC) technology, this high-resolution thin-film MCM-D technology features smaller component tolerances, also at GHz frequencies. The technology then eases many of the design problems in bringing RF systems into production [5].

## 2 RF MCM-D Technology

The MCM-D substrate technology employs a high resistivity silicon substrate on which is defined a two level metal – BCB dielectric structure that provides power, ground and controlled impedance interconnection functions together with a full range of integrated passive components is shown in Figure 1.

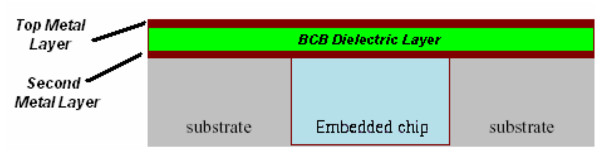


Figure 1. The substrate with embedded chip

The MCM-D technology developed by GEC Plessey Semiconductors has been described in detail elsewhere [6]. One of the constraints on the design of integrated RF systems is the availability of suitable and cost effective components. The system builder is also facing demand for ever greater functional density in RF products, particularly for portable products such as mobile phones and sub notebook computers [7]. MCM-D technology offers many of the necessary components and also gives advantages of size, repeatability and externally component count reduction. The MCM-D technology allows the integration of different families of ICs together with integrated passive components to produce miniature radio modules and RF functions which offer considerable size and performance advantages over conventional discrete solutions [5], [8]. The benefits are further enhanced by the use of MCM-D passive components to produce structures such as filters which would normally consume significant space and cost in a conventional design [5]. MCM-D processes have been offering 4 to 10 fold reductions in the area of RF functions when compared to the surface mounted equivalent [6]. MCM-D technology as a solution for use in RF systems offers many significant advantages over more traditional technologies. In particular the size reductions and performance improvements possibly allow product developers to meet more closely the requirements of the marketplace. The technology then eases many of the design problems in bringing RF systems into production [5].

## 3 Design of Passive Components

- **Inductors**

Integration of passive elements in a package is the most important factor in chip-package co-design's success. Without this technology, chip and package designs are nearly independent. With the ability to integrate resistors, inductors, capacitors, and distributed transmission-line elements, chip and package designs couple closely. Chip designers can then move critical passive elements that require high quality factors and large space off the chip. This improves circuit performance and potentially saves costs [5]. The conventional planar spiral inductor has been fabricated on a single layer. Increase in inductance has been obtained by increasing the number of turns laterally. As the area increases proportionally to the number of turns, Rs, Cs, and Ls increase while Rp decreases. Therefore, this topology is expected to have both low Q and self-resonance frequency (SRF). One of the important factors of an inductor is the quality factor (Q). High Qs at the frequency range of interest can be obtained by designing multilayer inductors [9]. In this design both multilayer as well as single layer inductors has been designed.

Simulation results of 0.5 turn inductor are shown in Figure 3(a), the Q is 64 and the inductance Leff, is 1.4 nH at 5.25 GHz shown in Figure 3(b) and for 1.5-turn inductor, the Q is 31 shown in Figure 4(a) and the inductance, Leff, is 3.0 nH at 5.25 GHz shown in Figure 4(b).

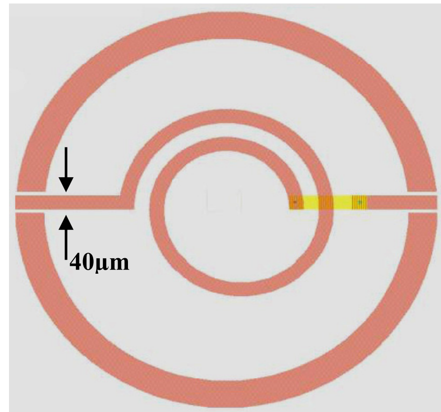


Figure 3(a). Series inductor

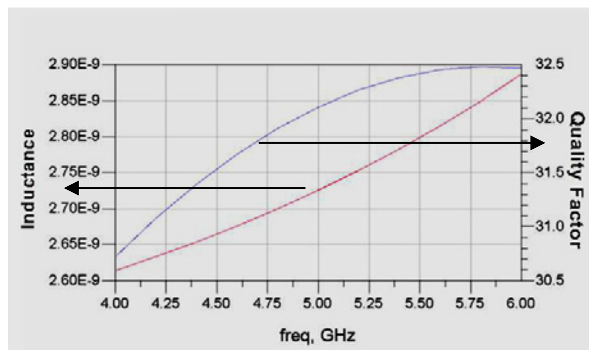


Figure 3(b). Series inductor simulation results

Also, the thick aluminum metallization in the packaging process made it possible to get a very high-Q. This has decreased the shunt parasitic capacitance and reduced the eddy current flowing in the ground plane, producing negative mutual inductance effect. As a result, higher Q and Leff have been achieved [10].

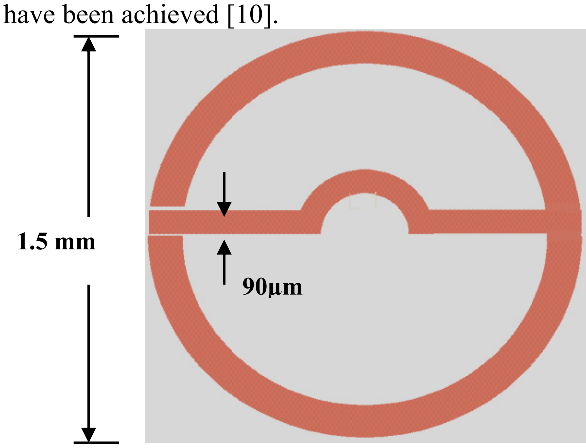


Figure 4(a). Parallel inductor

The inductors used for filter design have been designed on single layer because the metal layer 2 is only 0.5 µm thick whereas, the inductors used for Low noise amplifier have made use of both layers because high inductances as well as better Q were required at the same time.

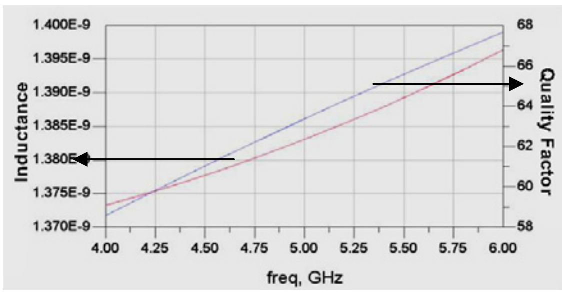


Figure 4(b). Simulation results of parallel inductor

The inductors have been made in the metal 1 layer (3 µm thick aluminum). The inductor values range between 0.3 to 3.6 nH, with a maximum quality factor Q up to 64 at 5.25 GHz. The frequency of maximum Q and the maximum value of Q itself can be exchanged. Inductors with lower values have higher Q values, because they can be smaller (lower parasitic) or use wider metal tracks. An inductor with a larger inductance value using wider tracks would suffer a lower frequency of self-resonance due to higher parasitic capacitance. Therefore, inductors with lower inductance values can have higher Q-factors, given a certain technology and application (i.e., the required operation frequency).

- **Capacitors**

The MCM-D process provides a range of capacitors using BCB dielectric layer sandwiched with in the substrate. Several series and parallel capacitors are designed to be used in RF circuits. Figure 5(a) shows the layout of 110fF parallel capacitor and Figure 5(b) shows its simulated results.

## 4. Bandpass Filter Design

Filters are essential components in many electrical circuits. For RF and low microwave applications, the filters may be realized by combinations of capacitive and inductive lumped passive components [11]. These passive filters may then be integrated in the MCM-D interconnection substrate, creating a functional inter-connection.

We have designed Embedded MCM, lumped element filters. Now we design bandpass filter for HIPERLAN/2 receiver front end module. Since we are looking at the two lower frequency bands only, the passband of interest ranges from 5.15 to 5.35 GHz. Implementing this design in a planar technology such as MCM-D imposes some restrictions. For any device in front of the low noise amplifier (LNA), the insertion loss should be minimized, since the value of the insertion loss (expressed in dB) directly adds to the noise figure of the complete receiver with same amount.

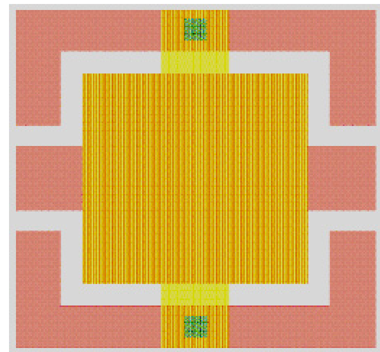

Figure 5(a). Layout of parallel capacitor

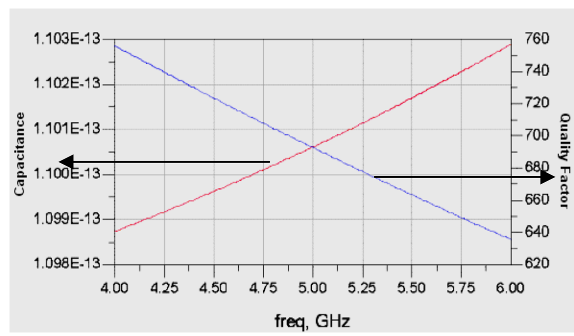


Figure 5(b). Simulation results of parallel capacitor

A sixth-order filter is required in our design but the sixth order filter in MCM-D would have too much insertion loss, due to losses in the passives. Therefore, the RF bandpass filter for the receiver is split into two filters, one second-order filter in front of the low noise amplifier (LNA) and a second one after the LNA. A second-order bandpass filter with lumped elements is realized. The design actually consists of two parallel LC resonators, which are coupled to each other and to their input and output terminals with capacitors. The inductors must have a high quality factor for the filter to have low loss. The quality factor drops with increasing inductance. On the other hand, the inductor cannot be too small. The LC tank determines the center frequency, which needs to be kept constant (at 5.25 GHz). A smaller inductor implies a smaller capacitor, which in turn is related to the required coupling capacitance. To have a good reproducibility and robustness against process tolerances, this coupling capacitance may not become too low. The values of the LC tank components are 1.38 nH and 485 fF respectively. The capacitor that couples the two resonators has a value of 46 fF and the input and output coupling capacitances are of 156 fF. In order to select the appropriate bandwidth and center frequency of passband, analysis has been done by considering different design implementations. The inductors used have wide conducting path so that they must offer less resistance and by doing so, Q of the inductors has increased.

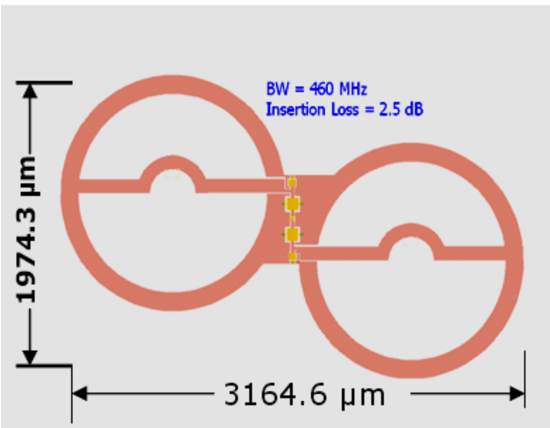


Figure 6. Bandpass filter layout design

Moreover, to increase the Q to achieve the required value, inductors have been made wider [5] although this approach leads to the inductors which occupy more area, but by using smaller area the Q of the inductor was not high enough to meet the design requirements. More precisely, low Q value of inductors lead to higher insertion loss of the filter. The Q of the capacitors is not of much concern in this design, as it has been high enough that the designed capacitors have given almost values closer to their ideal models. The layout design and the measurement results are shown in Figure 6 and Figure 7 respectively. This filter has an insertion loss of 2.5 dB and bandwidth of 460 MHz. By comparing this filter with [12], it has good results even though in this design aluminum metal is used than copper in [12].

There has been acceptable compromise on bandwidth and insertion loss because in order to further improve the design the size of the filter has been increasing beyond the acceptable values.

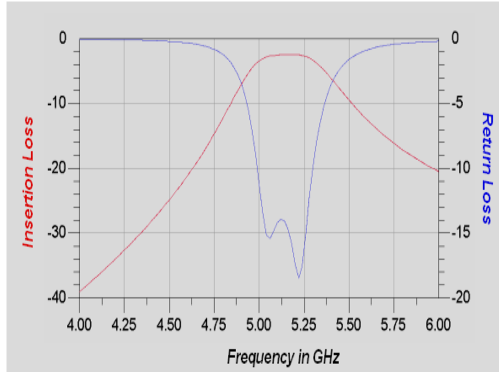


Figure 7. Insertion loss & return loss

## 5 Wireless Receiver Front-End

The presented integration demonstrator contains two bandpass filters, an LNA and a downconversion mixer. The prototype module is intended to demonstrate the concept of SoP. A lot of optimization work on the different blocks, especially on the LNA, is still possible.

An on-package integrated multilayer filter offers a more attractive implementation than on-chip and discrete filters [9]. There is possibility to improve the filter design by making multilayer inductors by having the freedom of equal thickness of metal layers. The size of the inductors influences much on the quality factor. The quality factor improves by increasing the conductor coil width, inner diameter. However, increase in inductance occurs by increasing the number of turns but at the same time if the inductor is drawn on one layer, this causes the decrease in quality factor which in turn increases the insertion loss of the filters. This problem can be solved by designing multilayer inductors explained. All components are matched for 50Ω, which is not necessarily an optimum, but is often a requirement when using of-the-shelf components or when measurement of the separate functions is mandatory. The low noise amplifier is built around a GaAs high electron mobility transistor [7]. Amplifier is designed to be unconditionally stable, which means that the amplifier is stable for every possible source and load impedance. The amplifier consumes 10 mA for a 2 V power supply [7]. The downconverter is a GaAs MMIC [8]. The device has a minimum specified gain of 12 dB. The complete receiver front-end measured conversion gain of better than 22 dB. The conversion gain is with in the acceptable range, it can be further improved by making the filters with more improved performance.

## 6. Conclusion

In this paper, high quality factor passive components integrated in liquid crystal polymer substrate are designed. Q of the inductor is better than 60 in this design. As a result, good performance of sub-blocks of the receiver front-end module is obtained. We have demonstrated feasibility of using multi-layer technology as a cost effective, high density RF/microwave packaging solution.

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