3D-SOP Millimeter-wave Functions for High Data Rate Wireless Systems Using LTCC and LCP Technologies

J.-H. Lee, **D. Thompson**, **S. Pinel**, **J. Papapolymerou**, **and M. M. Tentzeris**
Georgia Institute of Technology, USA

Millimeter-wave (mmW) electronics for commercial applications, such as short-range broadband wireless communications and automotive collision avoidance radars, require low-manufacturing cost, excellent performance, and high level of integration. The multilayer LTCC System-On-Package (SOP) approach is very well suited for these requirements because it offers a great potential for passives' integration and enables microwave devices to be fabricated with high reliability, while maintaining the low cost. The very mature multilayer fabrication capabilities of LTCC up to 100+ GHz enable the replacement of broadside coupling by vertical coupling and make LTCC a competitive solution to meet millimeter wave design requirements. As an alternative, Liquid Crystal Polymer (LCP) is an organic material that offers a unique low-cost all-in-one solution for high frequency designs due to its ability to act as both a high-performance flexible substrate ($\varepsilon_r = 2.9-3.1, \tan\delta = 0.002-0.004$) and a near-hermetic package for multilayer modules. These characteristics make LCP very appealing for many applications and it can be viewed as a prime technology for enabling system-on-package RF and mmW designs. In this paper, we present the development of various advanced 3-D LTCC and LCP system-on-package architectures enabling a complete passive solution for compact, low cost wireless front-end systems to be used in RF and mmW frequency ranges. The 3D embedded functions, which have been developed, include slotted patch resonator filters for achieving compactness and great compromise between size and power handling and directional filters to provide easy and compact solutions for different applications, such as mixing and multiplexing.

One important function that can be easily integrated in multilayer modules is filtering. In order to maintain their properties in compact topologies, band pass filters are commonly realized using slotted patch resonators in mmW frequencies due to their miniaturized size, the great compromise between size and power handling and their easy-to-design layout. In this paper, one single mode slotted patch filter (1-pole) with a transverse cut on each side has been designed and embedded in LTCC ($\varepsilon_r = 5.4, \tan\delta = 0.0015$) for 38–40 GHz applications such as vehicular communications. The patch filter (1.02 mm × 1.02 mm) has been optimized in aim of 6.5% bandwidth, 39 GHz center frequency, and $<$ 3 dB insertion loss. Such a structure has been developed from the commonly used half-wavelength square patch at 39 GHz by adding one transverse cut on each side leading to a significant reduction of the patch size and a good power handling. The desired coupling coefficients are obtained by inserting the feedlines and the single resonator into different metal layers. The stripline filters are excited through vias connecting the top metal with the next underlying metal, enabling the package to prevent radiation loss. The experimental results of the filter agree very well with simulation data, demonstrating a minimum insertion loss of 2.3 dB, the return loss $>$ 18.2 dB over pass band, and bandwidth about 6.4%.

The LCP filter 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. Two slots have been added in each of these low impedance sections to enhance the ripple amplitude, and 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 -35 dB in the lower band. Capacitive feeding can be used to remove the low frequency pass band if it is required resulting in a pass-band response centered at 60 GHz and a relative 3 dB bandwidth of 15% with minimum insertion losses as low as -1.5 dB. A ripple of $+/-0.15$ dB has been measured over a bandwidth of 6 GHz centered at 60 GHz.