Technical Note

MCT-001

Designing Microwave Components Using Multi-layer Low-Temperature Co-fired Ceramic (LTCC) Substrates

Recent advances in Low-Temperature, Co-fired Ceramic (LTCC) technology has made the application of substrates with three or more layers a practical and cost-effective option for the design of broadband integrated microwave components that operate through Ka-band and beyond. Several vendors now provide LTCC dielectric materials with loss tangents comparable to that of 99.6% alumina. The low-loss characteristics of these LTCC systems enables the RF transmission media and other passive microwave elements to be integrated within a single 3-dimensional structure, along with all the peripheral bias and control interconnections required in an Integrated Microwave Assembly (IMA).

LTCC material systems are composed of glass/ceramic dielectric tape along with metallization pastes that are formulated to provide shrinkage characteristics similar to the dielectric. Processing of all the individual LTCC substrate layers is performed in parallel with the dielectric tape still in its "green state." The layers are stacked and laminated and then the entire structure is fired a single time. This differs from traditional thick film technology where each layer is processed and fired sequentially. The relatively low firing temperature of LTCC dielectrics allows high conductivity materials such as gold and silver to be included in the conductor metallization for the internal layers. The combination of low dielectric loss tangent and high conductivity metallization results in a substrate media with excellent RF and microwave characteristics.

A multi-layer substrate technology capable of supporting RF and microwave signals provides a number of advantages when compared to the more traditional high frequency substrate technologies. In most applications the RF, bias, and control interconnect along with the passive microwave elements (directional couplers, low-Q filters, etc.) required for an entire IMA can be integrated into a single substrate. With proper placement of ground structures within the substrate, high RF isolation can be maintained between circuits internal to the IMA. Forming these RF shielding structures directly into the substrate eliminates the need to machine RF isolation walls into the IMA housing or frame. Optimum RF isolation is achieved by placing RF components, such as MMIC die, within pockets formed into the substrate and then attaching metallic shields on top of these pockets, which essentially encases the component(s) within a metallic enclosure. The elimination of machined internal walls significantly reduces the complexity, and therefore cost, of the package.

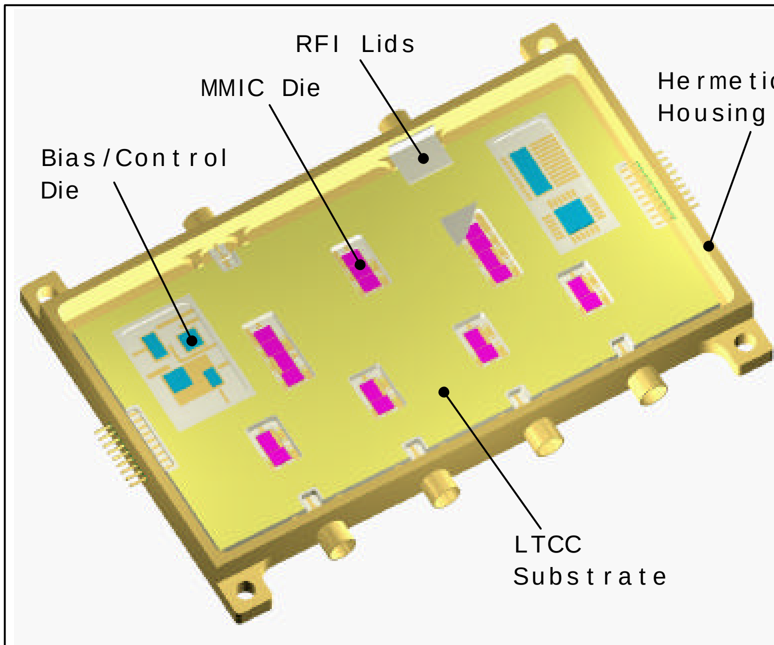

Figure 1. Example of an Advanced Integrated Microwave Assembly (IMA). All of the RF, Bias, and Control Interconnections are Formed Within a Single Multi-layer LTCC Substrate.

Multi-layer substrates can reduce the overall layout complexity of a multiple function IMA since high isolation RF crossovers can be formed internal to the substrate. Also, forming all interconnections on a single substrate and eliminating internal walls allows for higher packaging density within the IMA. The resulting reduction in the mechanical complexity of the IMA translates into reduced fabrication and assembly costs. Another key advantage related to the integration of all RF interconnect into a single substrate is the significant enhancement of mechanical and electrical uniformity from unit-to-unit. Improved unit-to-unit uniformity translates to reduced alignment, tuning, and test costs.

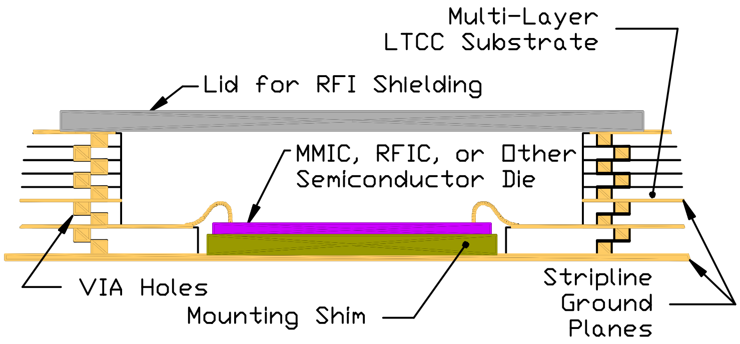

Figure 2. Cross-sectional View of a Typical RF Pocket Formed in an LTCC Substrate.

An example of the application of a multi-layer LTCC substrate in an IMA is illustrated in Figure 1. In this illustration a total of 16 MMIC devices and associated bias and control ICs are comfortably integrated into a single IMA. All of the bias, control, and RF interconnections, along with several passive RF components, are formed internal to a single LTCC substrate.

The MMIC devices, along with their associated external bias components, are mounted in cutouts recessed into the substrate. A cross-sectional view of a typical pocket cutout is depicted in Figure 2. The cutout is formed through the entire substrate to expose the underlying ground plane. The MMIC devices are mounted to a metal shim that is attached directly to the ground plane. The shim serves as a heat spreader for active devices and also raises the top surface of the MMIC to facilitate short bond wire connections.

The RF interconnection layer of the substrate is exposed by increasing the size of the cutout in the layers above it. As illustrated in Figure 3, the exposed surface is used to support bonding pads and peripheral chip components used to interconnect the MMIC(s) with the substrate. Exposed RF traces are typically microstrip or coplanar waveguide that transitions to stripline when exiting the pocket. Closely spaced via holes surrounding the pocket and connected to the ground planes are used to form RF shielding structures in the Z dimension. Lids for RF shielding can be attached to the top surface of the substrate as depicted in Figures 2 and 3.

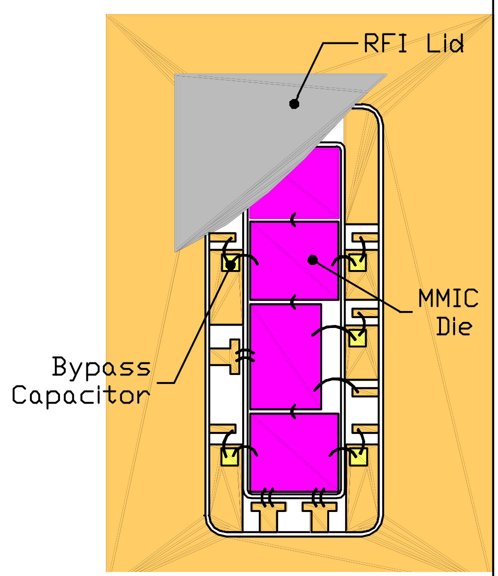

Figure 3. Top View of a Typical RF Pocket

While use of LTCC technology is an attractive option, there are a number of issues that must be carefully considered as part of the design of a multi-layer substrate that must support high frequency signals. Electrically, any potentially resonant structures must be eliminated from the substrate layout. This requires careful consideration of the physical spacing and proximity of RF ground structures, bias connections, and control connections. Also, the formation of pocket cutouts surrounded by ground via's will result in a resonant cavity. Pocket dimensions must therefore be chosen such that no waveguide modes can be supported in the band of operation.

Another key electrical consideration is RF transmission loss. Although the LTCC dielectric and metallization materials possess good low loss characteristics, actual RF losses can still be relatively high depending upon the thick-film metal deposition processes associated with the LTCC system. Typical thick film processes result in metallization patterns with high surface roughness and poor edge definition as compared to the thin film processes traditionally employed for microwave ceramic substrates. Due to skin effect, this results in higher conductor (resistive) losses, which is the dominant RF loss mechanism in a multi-layer LTCC substrate. An ideal RF layout would be such that the lengths of all interconnecting transmission lines are minimized. Also, the RF ground plane spacing can be increased, which results in physically wider and therefore lower loss transmission lines. However, the maximum ground plane spacing is limited by factors such as waveguide moding, maximum substrate thickness, and substrate cost.

A number of mechanical issues must also be addressed to assure a robust substrate design. These include the substrate's surface flatness, metal loading within the substrate to facilitate uniform shrinkage during firing, and other manufacturing design rules and constraints (i.e., minimum line widths and gaps).

In summary, recent improvements in multi-layer LTCC substrate technology has opened a new door for the RF and microwave circuit designer. Design engineers can begin thinking in terms of true 3-dimensional microwave structures that are integrated directly into the substrate layout. With careful consideration of fundamental RF and microwave constraints, LTCC multi-layer substrates can be an enabling technology for the design and development of very highly integrated and cost effective RF/microwave assemblies.