Measurement of a 24-GHz Broad-Band Multilayer Ceramic Feedthru for Microwave Packaging

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***Abstract*—A feedthru using a microstrip to stripline to conductor backed coplanar waveguide (CBCWG) design is investigated for microwave performance. The feedthru was manufactured using a high-temperature cofired multilayer ceramic process. The study was instigated from the need to have a field-replaceable, Ku-band transmit/receive module as part of an existing DARPA MIMIC program. The result is a feedthru capable of transmitting microwave frequencies to 24 GHz with acceptable loss characteristics. The feedthru performance exceeds existing published results.**

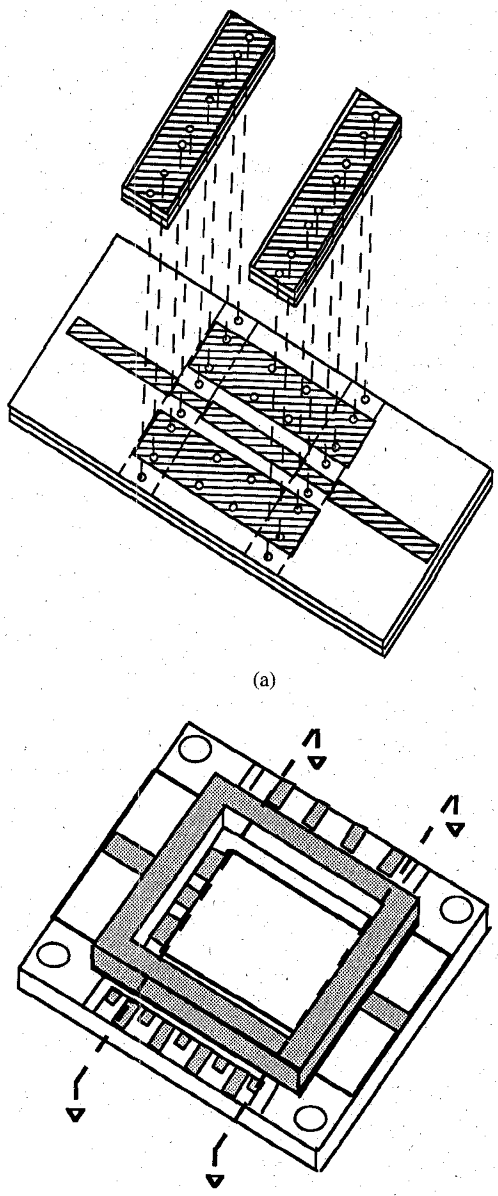
I. Introduction

A TEST vehicle was designed to prove the capability of a cofired, multilayer ceramic (MLC) process. The material system, consisting of 94% alumina (Al2O3) and tungsten–nickel–gold (W–Ni–Au) metalization, was to be proven suitable for microwave integrated circuit (MIC) packaging. The feedthru structures were designed for 50-Ω impedance lines, based on 20-mil microstrip and 40-mil stripline dielectric thicknesses. Together with the feature of multilayer routing, the system was required to have microwave feedthru capability to 20 GHz.

A microwave test vehicle (MTV) was designed with a microwave line transitioning thru a ceramic wall. The feedthru consists of a microstrip, a stripline thru the wall, and a conductor backed coplanar waveguide to the die cavity of the package. The upper stripline ground plane was used to attach a metal seal ring for hermeticity. Fig. 1(a) shows the back-to-back design used to measure the effective loss through a two port package, Fig. 1(b), eliminating the inaccuracies involved in de-embedding a bonded microstrip insert. The loss characteristics of all three transmission media were measured individually using the same material as the feedthrus. The results of the individual measurements aided in the design of the feedthrus.

II. Microwave Interconnect Technology

As the interconnect for dc and microwave energy, a GaAs MMIC package can be limited by design for either functionality or bandwidth. Single chip packaging using an MLC process has shown reasonable loss characteristics to Ku-band [3], [4]. The most common interconnect to a microwave device from outside its package is by either a pin, connector, or planarized G-S-G feedthru. If more than one device is housed within the container, routing is completed by microstrip and/or stripline



(a)

(b)

Fig. 1. Design of (a) back-to-back feedthru design using 20-mil microstrip and conductor backed coplanar waveguide and 40-mil stripline and, (b) multilayer cofired ceramic package with 2 microwave feedthrus and 8 bias lines for MMIC devices. Cavity area was removed to create the microwave test vehicles and to measure the loss of feedthrus only.

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TABLE I
FEEDTHRU DESIGN MODIFICATIONS

Part Type	Description
MTV02	Reference feedthru.
MTV03	Less vias connecting coplanar ground to bottom ground.
MTV04	Coplanar grounds moved 5 mils closer to center conductor.
MTV13	Less vias, no tapered transition, no tapered CBCPW.
MTV14	Coplanar grounds moved 5 mils further, less vias in stripline.
MTV15	Ground planes on each layer of stripline region.
MTV16	Coplanar grounds moved 5 mils further, less vias in stripline, stripline shorter.

interconnects. One of the limits to high-density packaging of microwave components has been the unavailability of a broad-band high-frequency multilayer ceramic technology.

Typically the microstrip interconnects within a multichip module consists of a single layer substrate made from either a low-dielectric PTFE material, or an inorganic ceramic [5], using gold or aluminum as the conductor. Although they are easy to cut and place for assembly and routing purposes, they force the module assembler to jigsaw puzzle the interconnects between devices. This also causes a slight inconvenience for the designer of the chip layout because of the restriction of RF or bias I/O placement. Because of the expense of MMIC technology, the chip set needs to be housed in a rigid container, or package, to protect the devices from environmental effects. This usually results in more custom packaging that adds to the cost of the module.

Multilayer ceramic technology has been around for many years and is commonly used in digital applications. The trend for this technology is higher density, smaller size and lower cost. Since these devices are getting larger, faster, and with more functionality, they require packaging that maintains signal integrity throughout the system. This requires the mechanical package to take into account three-dimensional transmission line effects. With the integration of high-density MMIC's and mixed-signal components for modular applications, microwave packaging has become a major issue.

Low-temperature MLC technology has proved successful for microwave applications below 4 GHz. There are structural and thermal differences between high-temperature and low-temperature MLC processing [6] which are beyond the scope of this letter. Numerous other processes, materials, and designs are offered, [7]–[11], for microwave packaging, but there were trade-offs with each that would not facilitate the application of interest.

III. FEEDTHRU STRUCTURES

The design for the feedthru began from classical equations for two-dimensional analysis of planar transmission lines. There was no three-dimensional analysis program available to predict the effects of transitioning from one media to another, i.e., microstrip to stripline and taking into account losses within the materials. It was, therefore, decided to approach the problem by starting with qualitative and intuitive design modifications based on previously constructed, X-band modules.

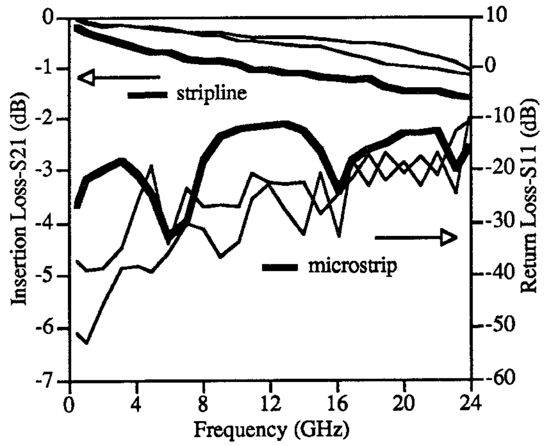

Fig. 2. Insertion and return loss for 1.000" of transmission line structures. Stripline insertion loss is most significant because of tungsten metalization. Microstrip return loss is most significant because of inadequate ground contact.

TABLE II
CUTOFF FREQUENCIES FOR MEASURED FEDDTHRUS

Part Type	S21 @ 1dB	S11 @ 15dB
MTV02	24.94 GHz	24.42 GHz
MTV03	14.02 GHz	8.82 GHz
MTV04	22.08 GHz	9.08 GHz
MTV13	17.14 GHz	15.32 GHz
MTV14	21.04 GHz	20.52 GHz
MTV15	20.78 GHz	20.52 GHz
MTV16	24.42 GHz	21.82 GHz

A description of the modifications to each feedthru are given in Table I. MTV02 was used as the reference design, and all other modifications were made to this reference. This was useful for direct correlation of measured performance based on modification. Table II lists the part type versus insertion loss (S21) and return loss (S11) performance at specified cutoff frequencies. An insertion loss through the package of 1 dB, and a return loss of 15 dB was considered acceptable for the application to 18 GHz.

Of the three types of planar transmission line configurations used, the stripline structure was found to have the most significant insertion loss (S21) per unit length, with a loss value of 1.6 dB @ 24 GHz, as shown in Fig. 2. This is because of the relatively low conductivity of the unplated tungsten — a refractory metal typically used in high-temperature cofire technology. Gold has a volume resistivity of 2.5 $\mu\Omega$-cm, whereas tungsten paste is $\approx$20 $\mu\Omega$-cm. This process has had only limited success in microwave applications because of the loss characteristics. Therefore, it was important to have the feedthru length thru the ceramic wall as short as possible, without sacrificing the ability to produce a hermetic seal. The microstrip structure had the worst return loss of the three, 11 dB @ 13GHz, due to inadequate ground contact to the fixture. The results of the insertion and return loss for the de-embedded MTV's is also provided in Fig. 3.

IV. FIXTURING

The existing equipment set-up and test methodology worked well within the framework of the program. A commercially available universal test fixture (UTF) was used for the mea-

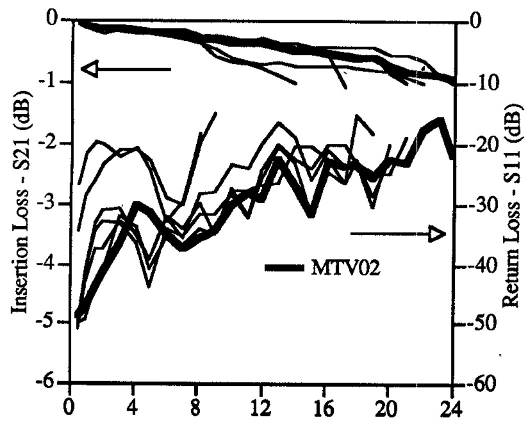

Fig. 3. Insertion and return loss results from microwave test vehicles. MTV02 provided lowest loss to 24 GHz.

surements, designed to contact variable length and thickness substrates. The UTF was designed to perform both calibration and measurement to 26.5 GHz with 3.5-mm connectors. The actual bandwidth capability of the fixture calibration and measurement was 25 GHz with the internally manufactured calibration kit. This resulted in greater standard deviation between return loss measurements in some of the feedthrus above 20 GHz.

The TRL calibration for microstrip de-embedding was found to be inadequate using two lines to de-embed the fixture. The two calculated line lengths did not cover the bandwidth necessary to make accurate measurements, from 500 MHz to 26 GHz. More reasonable results were obtained after recalibrating with three line lengths. The line lengths and associated bandwidths were as follows to obtain 0.200" of de-embedded microstrip: 0.470" covered a bandwidth of 3.5–28 GHz, 0.500" covered 2.5–20 GHz, and 0.900" covered 0.5–4 GHz. The overlap of bands supplied the necessary information for a good calibration by use of the standard 12-term error correction technique used in calibrating the network analyzer.

There were also some difficulties using the UTF for microstrip measurements. The UTF was designed to make ground contact at the edges of the device-under-test. Since the UTF did not have a continuous ground connection along the ground plane of the microstrip lines, there were improper terminations of the fields, resulting in antenna effects. The measurements were made using extra grounding and shielding to reduce these effects.

V. Conclusion

A number of design modifications to an existing technology were made for package and feedthru characterization. The loss per unit length for microstrip, stripline, and coplanar microstrip was quantified in the 94% cofired alumina material system. The results of the measured data aided in the design of a feedthru structure, developed for transmitting microwave signals to 24 GHz. Using standard fixtures for substrate characterization proved to be adequate for this analysis. A successful calibration and measurement technique has been developed using the in-house material system for characterizing the substrates and feedthrus by using TRL and de-embedding the fixture and connector launch parasitics.

Ground plane vias in both the stripline and coplanar regions of the feedthru can be critical at higher frequencies. Larger ground plane via diameters reduce the effective inductance, thereby increasing the cutoff frequency. Making a transition before or after entering the seal ring can have an effect on overall performance. Ground planes placed on every layer to reduce the effective inductance has no appreciable effect on the overall loss of the feedthru. The transition between each transmission interface must allow for proper electric field orientation in order to minimize mismatches through the ceramic wall.

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