VERTICAL TRANSITIONS IN LOW TEMPERATURE CO-FIRED CERAMICS FOR LMDS APPLICATIONS

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Abstract - **To realize the advantages of Low Temperature Co-fired Ceramics (LTCC), such as highly integrated and low cost microwave packages, a library of repeatable and low loss vertical transitions is necessary. This paper presents measured results of three LTCC vertical transitions: stripline to coplanar waveguide (CPW), CPW to CPW, and CPW to microstrip. A novel grounding structure for intermediate ground planes is presented and discussed. The measured results demonstrate vertical transitions with good performance across the LMDS range.**

I. INTRODUCTION

Low Temperature Co-fired Ceramic packages are multi-level structures that allow conducting traces to be embedded within the substrate. This feature dramatically increases the functional density of a package by burying passive elements. These buried components are smaller due to the higher dielectric constant of the ceramic, and can be vertically stacked, thus creating highly integrated packages.

Advantages such as circuit-area improvements, cost reduction, and minimized losses are necessary for LMDS applications (27.5 – 31.3 GHz), where the dual requirements of low cost and high performance create difficulties for system designers.

In a prototype that operated over the frequency range 869-894 MHz, the improvements over traditional packaging were dramatic: O'Hearn demonstrated a 400% improvement in PCB area use due to embedded passives [1]. Amey et al claim a significant cost reduction by using embedded passives versus external components in the lower gigahertz range [2]. Embedded passives can also yield performance benefits by reducing line discontinuities encountered in multi-package systems.

For these advantages to scale up from the lower microwave frequencies to the lower millimeter-wave range then the multi-level properties of LTCC must be exploited. Therefore there is a need for a library of vertical transitions which can operate at these frequencies. Without low loss and repeatable vertical transitions, microwave packages cannot achieve the same degree of high integration reached by their lower frequency counterparts. This paper fills this gap by presenting measured results for three vertical transitions. The vertical transitions cover a variety of transmission media, improving design flexibility.

II. LTCC VERTICAL TRANSITIONS

This paper presents three vertical transitions that connect three different types of transmission lines: stripline to CPW, CPW to CPW, and CPW to microstrip.

These vertical transitions use vias to connect the signal carrying conductors. It is also possible to make transitions from vertically coupled lines, but in this paper vias were chosen to reduce radiation and build simpler interconnects.

A six-layer LTCC package was built using DuPont 943, fabricated by the Technical Research Centre of Finland (VTT). DuPont 943 has a dielectric constant of 7.5 (7.1 at 16-24 GHz, 7.05 at 40 GHz [3]) and a fired layer thickness of 107 μm. The design rules allowed a minimum conductor thickness/spacing of 150 μm. Vias are solid, 150 μm in diameter, and have via pads 250 μm in diameter. Both buried and exposed conductors are silver. The bottom surface of the package was built with a mostly gridded ground plane, while small solid intermediate ground planes are buried under each test structure, and connected to the bottom gridded ground plane with vias.

A. Stripline to CPW Vertical Transition

A vertical stripline to CPW transition is shown in Fig. 1. An exposed microstrip feed is converted to buried stripline which connects to a buried CPW line through a vertical via. The buried CPW line then connects to a buried stripline which converts to exposed microstrip output feed.

There are 4 vertically spaced conductors in the overall transition of Fig. 1. The base conductor (level 0) is a gridded ground plane. 321μm above the grid is an intermediate ground plane (level 3), which forms the lower ground plane for the stripline and microstrip lines (level 4). Level 5 makes up the upper stripline and CPW lines. All the conductors are buried with the exception of the exposed microstrip feed lines. Grounding is accomplished through repeated vias that connect the top stripline ground plane / CPW grounds (level 5) to the lower stripline

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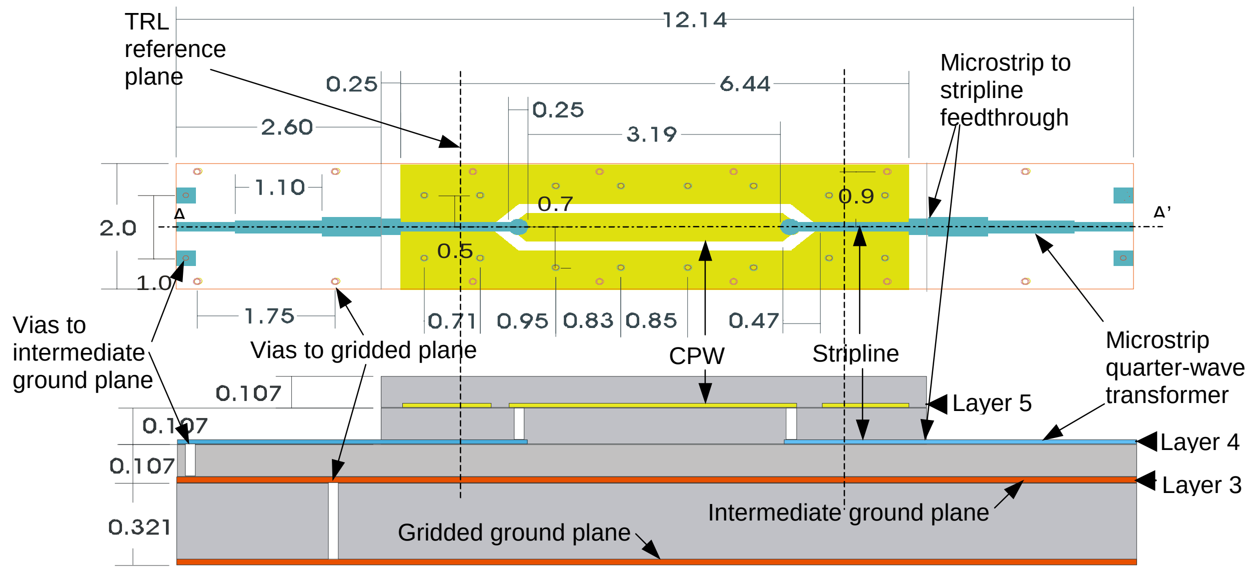

Fig. 1. Top and Side (cut along A-A') views of a stripline to CPW vertical transition, including back-to-back microstrip quarter-wave transformers and microstrip to stripline feedthroughs. In the top view, the vias near the edges connect the intermediate ground plane to the gridded ground plane while the vias nearer the transmission lines connect the CPW/stripline ground to the intermediate (level 3) ground plane. Only two grounding vias are shown for clarity. The dimensions are in mm.

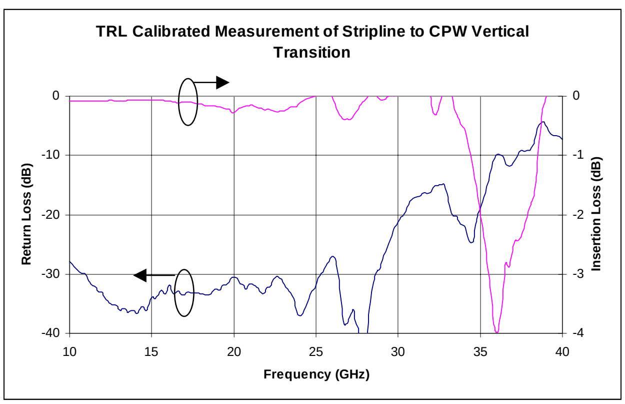

Fig. 2. S-Parameter results for the back-to-back stripline to CPW vertical transition of Fig. 1, using TRL calibration.

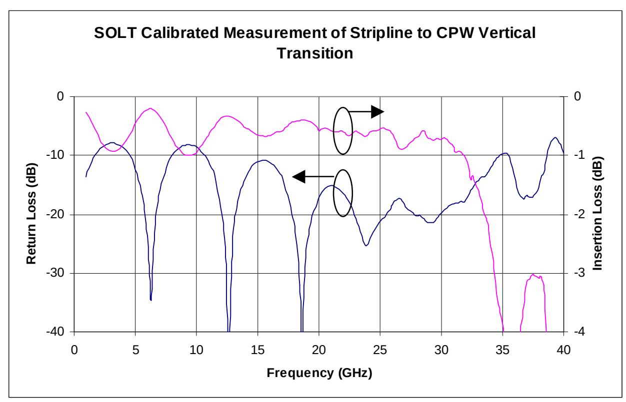

Fig. 3. S-Parameters of the stripline to CPW vertical transition of Fig. 1, using SOLT calibration.

ground plane (level 3) and from level 3 to the gridded ground plane (level 0).

Minimum conductor width design rules forced the use of 30Ω stripline, which forced the use of 30Ω CPW. The transition from a 50Ω network analyzer (Wiltron 360B) to 50Ω microstrip to 30Ω microstrip (made with quarter-wave transformer) to 30Ω stripline (feedthrough) was calibrated out using through-reflect-line (TRL) calibration, and the reference planes are shown in Figure 1. The stripline had a width of 150 μm, with 214 μm ground plane spacing. The CPW line had a lower ground plane 214 μm below the coplanar lines, with conductor-gap spacing 150–580–150 (μm). The imperfection of the TRL calibration can be seen in the insertion loss curve of Fig. 2, which occasionally shows gain, particularly after 30 GHz. However, the transition shows excellent performance up to 30 GHz with return loss better than –20 dB.

To verify the transition performance, the measurement of the transition was repeated, using a short-open-load-through (SOLT) calibration. This measurement included back-to-back quarter-wave transformers, and back-to-back microstrip to stripline feedthroughs. The total length of the structure is greater than 12 mm. Even with the inclusion of these other effects in the measurement, Fig. 3 shows return loss better than –15 dB and insertion loss less than –1 dB across the entire LMDS band. The low frequency behavior is due to the quarter-wave transformers. The usable bandwidth of the transition ends just after

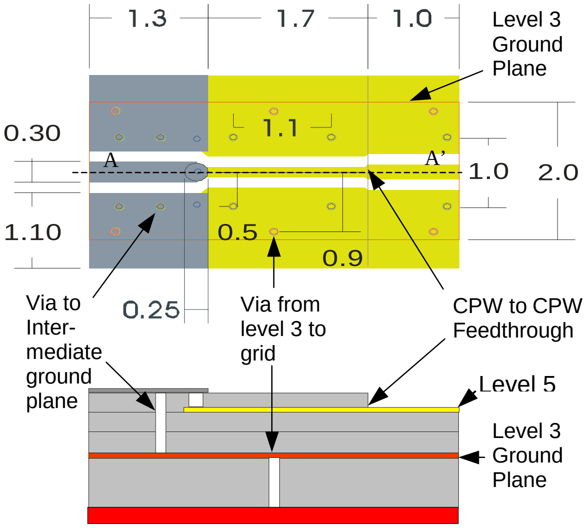

Fig. 4. Top and side (cut along A-A') view of CPW to CPW vertical transition. Vias closest to the transmission lines connect the CPW ground planes to the intermediate ground plane while the vias nearer the edges connect the intermediate ground plane to the gridded bottom ground plane. Only two grounding vias are shown for clarity. The CPW to CPW feedthrough involves a CPW change in width and the vertical transition is made with three vias that connect the two CPW lines. The level 3 ground plane is 3 layers above the grid. The left-hand side CPW is 3 layers above level 3. Each layer is 107 μm thick. The dimensions are in mm.

31 GHz, due to the low-pass nature of the via transition. To extend the bandwidth of this transition, tuning to compensate for the via discontinuity would be required.

B. CPW to CPW Vertical Transition

This transition is formed by connecting two vertically offset CPW lines with three parallel vias, one for each of the ground planes and the center conductor, as in Fig. 4. The design rules for via placement (minimum spacing: 3 times via diameter center to center) prevented the ideal case of having the vertical vias have the same spacing as the coplanar lines. Therefore the ground-connecting vias were placed as close as possible to the signal carrying via (450 μm center to center spacing).

Both CPW lines share a lower ground plane: the distance to the ground plane is 321 μm for the exposed line, and 214 μm for the buried line. The exposed CPW line is on layer 6, and the buried line on level 5. Both CPW lines are 50Ω. The dimensions are: 150-150-150 (μm, embedded fifth layer), 150-300-150 (μm, exposed sixth layer) and 150-220-150 (μm, exposed fifth layer). The probes were calibrated using a SOLT technique on a calibration substrate. The total length of the measured transition is 4 mm.

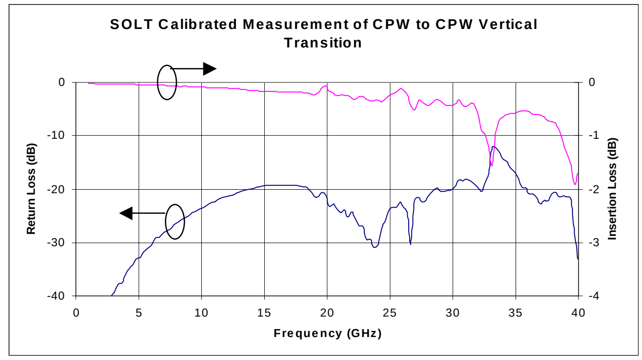

Fig. 5. S-Parameter results for a CPW to CPW vertical transition (Fig. 4). The measurements include one CPW to CPW hermetic feedthrough to allow the probing of the embedded line.

Despite the fact that the measurements included a CPW to CPW feedthrough as well as lengths of transmission line, the S-Parameters (Fig. 5) demonstrate a transition that is useful from DC to 32 GHz, with a return loss of less than –20 dB and insertion loss better than –0.5 dB.

At 33 and 40 GHz, deep insertion losses are seen in the transition response. This is due to the parallel plate / microstrip mode occurring between the intermediate ground plane and the CPW lines. This can be eliminated by using more vias to connect the CPW to the intermediate ground plane or by fabricating smaller CPW ground planes.

C. CPW to Microstrip Vertical Transition

In this transition shown in Fig. 6, a CPW line is formed from the ground plane of a microstrip line, as in [5]. The CPW line has conductor spacing 150-180-150 (μm), and a ground plane 214 μm below the conductors. The microstrip line is 150 μm wide and 107 μm above its ground plane. This transition was measured with and without extra grounding structures that connect the microstrip ground plane to a lower ground plane. The structures are shown in Fig. 6. The extra grounding structure is a planar strip on level 4 that connects parallel grounding vias.

The extra grounds were used in place of two-level grounding vias. The results (Fig. 7) show that the extra grounding structure (level 4 conductor strip and extra via) suppresses a resonance at 27 GHz. Connecting the grounding vias together on layer 4 reduces the inductance of the ground connection. Reducing the ground inductance limits power lost to parallel plate modes launched from the CPW to microstrip transition, thus increasing the usable bandwidth. With the extra grounding, the transition maintains an insertion loss of less than -1 dB and a return loss less than –20 dB across the LMDS band.

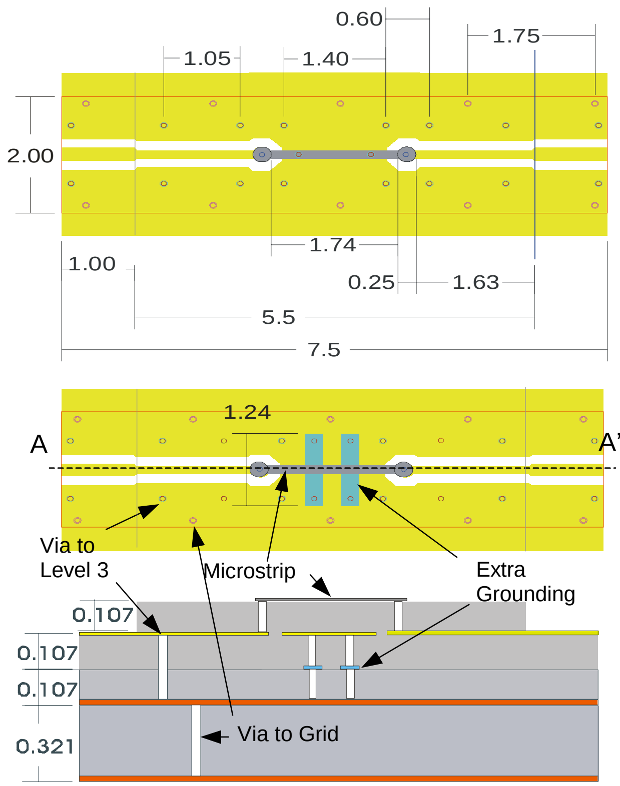

Fig. 6. Two top and one side (cut along A-A') view of two CPW to microstrip vertical transitions. The first top view uses four two-level vias to connect the microstrip ground plane to the intermediate ground, whereas the second uses extra level-4 conducting strips and six vias to connect the two planes. The two structures are identical except for grounding under the microstrip. The vias nearer the transmission lines connect the CPW/microstrip grounds to the intermediate ground and those nearer the edges connect the intermediate ground plane to the gridded bottom ground plane.

III. DISCUSSION

It is also possible for resonances to occur between the intermediate ground plane and the bottom ground plane. For this reason, it is advisable to connect all ground planes together with vias, on all sides, as well as the middle. As the parallel plate mode has no cutoff frequency, and conductor-backed CPW is known to be a leaky transmission line, resonances can happen in either length or width. The extra grounding structure prevents longitudinal resonances by providing a low impedance ground connection in the middle of the ground plane. It also suppresses parallel plate modes in general by maintaining similar potentials on both planes. However, the resonance occurring above 30 GHz indicates the need to further suppress the parallel plate/microstrip mode of the CPW lines by reducing the width of the ground planes or by using more grounding vias.

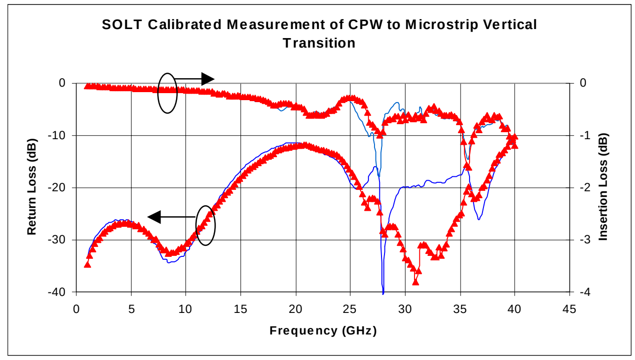

Fig. 7. S-Parameters of back-to-back CPW to microstrip vertical transition separated by 1.4 mm of microstrip line (Fig. 6). The measurements include two CPW to CPW feedthroughs necessary for probing purposes. The solid line represents the transition with the regular grounding, while the triangle line represents the extra grounding method.

IV. CONCLUSION

This paper presented three LTCC vertical transitions, all of which demonstrate excellent performance over the LMDS frequency band. A novel grounding structure was demonstrated which improved the connection of two ground planes and extended the bandwidth of a CPW to microstrip vertical transition. These transitions indicate that high-frequency multi-level packages are possible in LTCC and that the advantages of lower cost, higher performance and increased density are available for microwave (specifically LMDS) applications.

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