A MILLIMETER-WAVE PERPENDICULAR COAX-TO-MICROSTRIP TRANSITION

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Abstract — **A novel transition from coaxial cable to microstrip is presented in which the coax connector is perpendicular to the substrate of the printed circuit. Such a right-angle transition has practical advantages over more common end-launch geometries in some situations. The design is compact, easy to fabricate, and provides repeatable performance of better than 14 dB return loss and 0.4 dB insertion loss from DC to 40 GHz.**

I. Introduction

The transition from coaxial-cable to microstrip is a very common feature of microwave and millimeter-wave systems. It is widely used in commercial products which incorporate printed circuits, and also in microstrip test fixtures that can be found in almost any microwave research lab. Traditionally, the transition is accomplished by aligning the axis of the coaxial connector with the end of the microstrip line, and connecting the outer conductor of the coax to the microstrip's ground plane and the center conductor to the microstrip.

Over the years, various improvements have been proposed [1]-[5] that extend the transition's bandwidth and enhance its performance, but the basic end-launch geometry has remained the same. Unfortunately, there are some practical problems associated with this arrangement that have not been addressed. Specifically, in order to hold the coax connector rigidly in position beside the printed circuit, there must be a flange or other fixed structure that rises above the top surface of the substrate. This blocks access by most wafer probes to the circuits in a multi-chip module, making it difficult to verify the chips independently after they have been mounted in the chassis. Also, in some microwave receivers that employ MMIC technology, a side-mounted coaxial connector can interfere with the narrow profile of the modules that is necessary for packing them in a close-fitting focal-plane array. Under those circumstances, a coax connection that enters or exits through the back of the module, rather than the side, is advantageous.

Perpendicular coax-microstrip connections have been made in the past by attaching a bond-wire from the center-pin of the coax to the microstrip line [6]. However, the length of the bond-wire, which is often difficult to control, is critical to the performance. Often it is necessary to tune the transition for a specific frequency by trimming microstrip stubs or other features. This lowers repeatability of the transition and limits the useful frequency range and bandwidth.

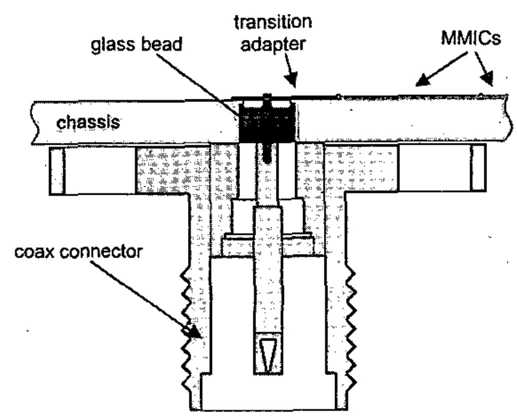

Fig. 1. Assembly diagram of the perpendicular coax-microstrip transition. A K flange launcher is shown, but threaded "sparkplug" launchers can be used as well.

With these issues in mind, a novel perpendicular transition has been developed in which wideband compensation of the junction is achieved on the printed circuit through entirely lithographic techniques, allowing easy fabrication and repeatable performance.

II. Transition Design

A diagram of the perpendicular transition is shown in Fig. 1. A key component of this design is a "transition adapter", shown in Fig. 2. The adapter is a two-sided printed circuit on a 100 μm thick Alumina substrate. It has a circular hole that fits over the center pin of a commercially available glass bead mated to a standard K-connector flange or sparkplug launcher [7]. The ground plane of the adapter substrate is electrically connected to the outer conductor of the coaxial bead. The center pin of

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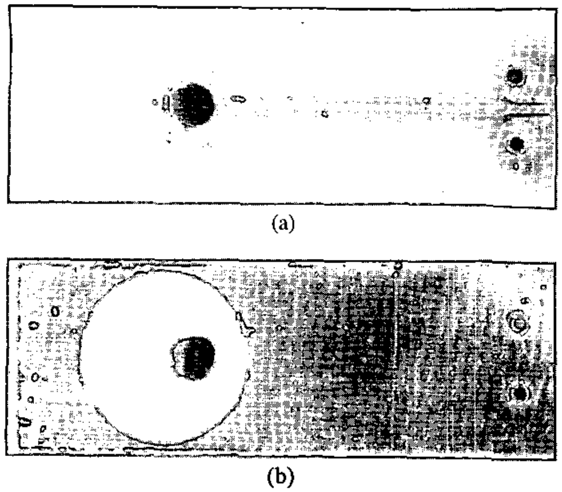

Fig. 2. Top (a) and bottom (b) views of the transition adapter. The hole in the center of the 100 μm-thick Alumina substrate fits over the center pin of a standard K-connector coaxial glass bead. The substrate dimensions are 3.75 x 1.35 mm.

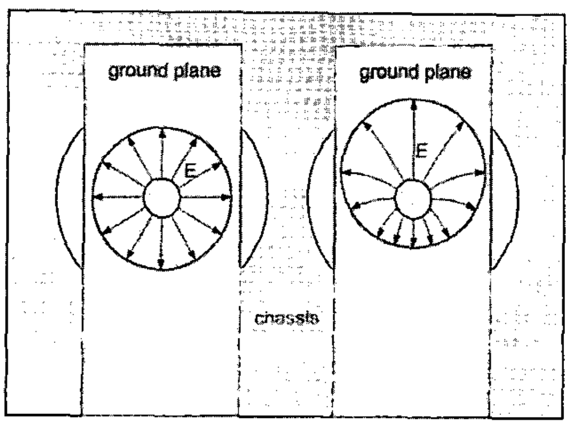

Fig. 3. Comparison of field distribution with concentric and offset ground plane apertures.

this bead passes through an aperture in the ground plane, extends through the substrate, and is soldered to a metal ring on the top side, completing the connection to the microstrip line.. The critical geometry of the glass bead, the adapter substrate, and the mounting structure was analyzed using Ansoft's High Frequency Structure Simulator (HFSS).

A key parasitic of perpendicular transitions like this one is the inductance caused by ground currents that must flow around the circumference of the coax outer conductor to reach the underside of the microstrip section. This problem is alleviated by reducing the diameter of the aperture in the ground plane, effectively providing a short-

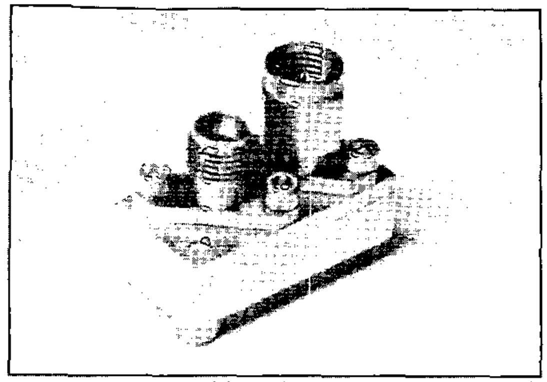

Fig. 4. Photograph of the back-to-back transition test block.

cut for ground currents from the outer edges of the coax shield. If the aperture is made too small, however, shunt capacitance from the center pin to the substrate ground once again degrades the performance of the junction.

It was discovered that offsetting the aperture as shown in Fig. 3 can greatly improve the performance of the transition. This redistributes the parasitic capacitance to the side nearest the microstrip, concentrating the fields on that side of the coax line where the ground inductance is least. It also reduces the inductance of the signal line by shortening the distance current must flow to get from the center pin to the 50 Ω microstrip line.

Additional compensation can be included in the form of a microstrip matching network on the top surface of the adapter, but it was found that the ground aperture manipulations described above had sufficient degrees of freedom to fully match the transition, and proved to be a more broadband solution. The resulting structure is low-pass, maintaining good performance from DC to millimeter-wave frequencies, limited primarily by over-moding of the coax line itself.

Although it would be best from an electromagnetic perspective to have the adapter's ground plane make contact with the full periphery of the coax line, it was decided to narrow the chip so that the bead was visible through a gap on either side. Observability of all critical components, such as the glass bead, can be very useful when trying to debug complex multi-chip modules.

Prior to assembly, the short pin of the coax bead was filed down to a length of approximately 375 μm past the rim of the outer conductor. A simple holding fixture was made to fit over the bead to prevent it from being filed too short. Also, a small dome was machined into the cover on the test block to ensure that there was enough clearance for the pin.

The transition is very robust with respect to assembly. Critical dimensions are defined lithographically on the

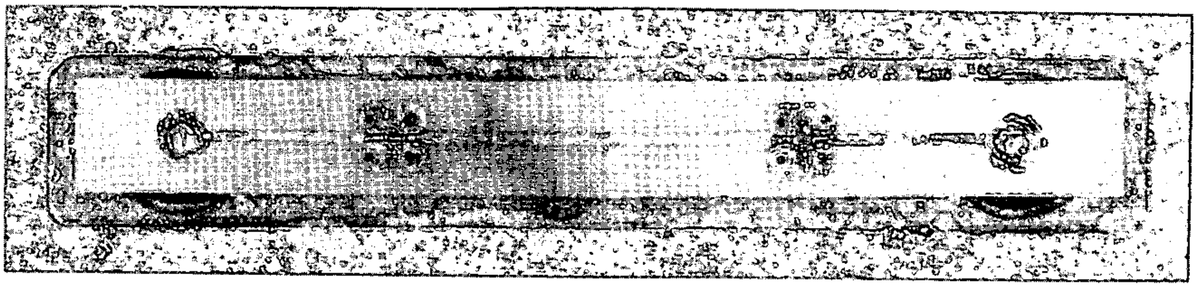

Fig. 5. Interior view of the test block, showing the back-to-back transitions with intervening microstrip line.

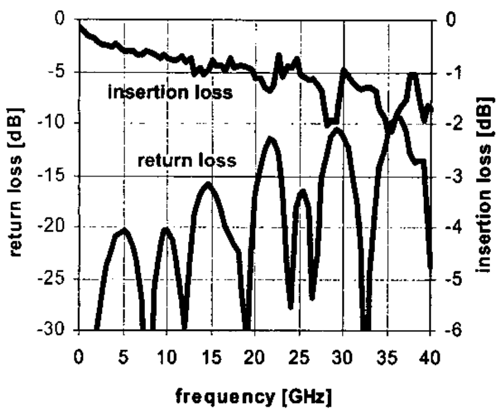

Fig. 6. Raw S-Parameters for two back-to-back transitions separated by a 10 mm-long 50 Ω microstrip line.

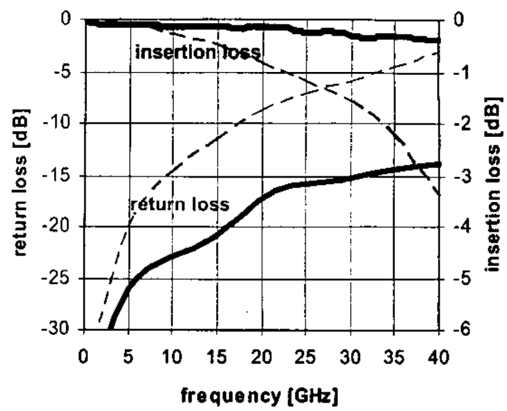

Fig. 7. S-Parameters for a single transition, corrected for multiple reflections and the loss of the microstrip line. For comparison, the dashed lines show simulated results for a perpendicular transition *without* the ground aperture compensation described in this paper.

adapter and proper alignment of those features is ensured by the snug fit of the coax pin in the hole through the substrate. Off-chip features such as the recess of the glass bead, the height of the coax pin, and clearance between the pin and top-cover were swept in simulation, and the design was found to be relatively insensitive to those parameters. Because all the critical features are contained on the printed circuit, this transition is easier to assemble than the common end-launch connectors which often require very tight machining tolerances.

For the purposes of this test, the adapters were made to include a CPW port because three bond-wire (ground-signal-ground) chip-to-chip interconnects tend to perform better than single bond-wire links. However, it does not play a role in the coax-microstrip transition.

III. MEASUREMENTS

A back-to-back configuration was used to measure the characteristics of this transition. A photograph of the test block is shown in Fig. 4. It was necessary to insert a long 50 Ω transmission line between the transitions, as shown in Fig. 5, to make room for the two coax connectors.

The back-to-back transitions were measured with an HP 8510 Network Analyzer from 0 to 40 GHz. The raw data is plotted in Figure 6. The peaks and nulls in the return loss at 5-6 GHz intervals are caused by reflections between the two transitions separated by a 10 mm long, 50 Ω microstrip line on 100 µm thick Alumina. The loss of the microstrip was measured separately with wafer probes and was approximately 0.08 dB/mm at 40 GHz.

Given that the peaks of the return loss curve occur when the reflections from both transitions add in phase, and taking into account the known loss of the intervening transmission line, it is possible to back out the return loss for a single transition at those frequency points. Specifically, the measured scattering parameters are:

$$m_{11} = s_{11} + s_{22}\frac{s_{21}^2 t_{21}^2}{1 - s_{22}^2 t_{21}^2} \qquad (1)$$

$$m_{21} = \frac{s_{21}^2 t_{21}}{1 - s_{22}^2 t_{21}^2} \qquad (2)$$

where m_{ij} are the measured scattering parameters for the back-to-back transitions, s_{ij} are the scattering parameters for a single transition, and t_{21} is the measured insertion loss of the microstrip line (this analysis assumes that the transmission line is matched, i.e. $t_{11}=0$). From equations (1) and (2), it follows that:

$$\begin{aligned} m_{11} &= s_{11} + s_{22} m_{21} t_{21} \\ &= |s_{11}| e^{j\theta_1} + |s_{22}||m_{21}||t_{21}| e^{j\theta_2} \end{aligned} \qquad (3)$$

Since θ_2 contains the phase of the long transmission line between the two transitions, it will vary more rapidly than θ_1 with frequency. The peaks in the measured return loss (m_{11}) occur when $\theta_1 = \theta_2$. At these points, then:

$$|m_{11}| = |s_{11}| + |s_{22}||m_{21}||t_{21}| \qquad (4)$$

Using the fact that $|s11| \approx |s22|$ (this would be exact for a lossless network), we can solve for the return loss of a single transition:

$$|s_{11}| \approx \frac{|m_{11}|}{1 + |m_{21}||t_{21}|} \qquad (5)$$

at those points where m_{11} peaks. This correction (which must always be less than 6 dB) was applied to the measured data at the appropriate frequencies. The insertion loss was also corrected by subtracting the known loss of the transmission line, dividing by two, and then smoothing. The result is shown in Fig. 7. The transition is low-pass, with better than 14 dB return loss from DC to 40 GHz. The insertion loss was less than 0.4 dB over the whole range.

IV. Conclusion

A perpendicular coax-to-microstrip transition suitable for millimeter-wave applications has been presented. It incorporates a novel offset ground aperture for compensation. Measurements indicate better than 14 dB return loss and 0.4 dB insertion loss from DC to 40 GHz. Although demonstrated with a K-connector and 100 μm Alumina substrate, the principle can easily be extended to V-connectors or 1 mm-coax, and to different substrate materials.

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