OPTIMUM MICROSTRIP INTERCONNECTS

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ABSTRACT

A simple, automated assembly technique has been developed which solves the high VSWR and insertion loss problems associated with variable wire inductance in microwave assemblies. The following paper discusses theory, design and fabrication of optimum microstrip interconnects from 2 to 20 GHz. Microstrip interconnects, modeled and measured, are shown to achieve VSWRs of 1.2:1 through 20 GHz, even when several interconnects are cascaded. The technique is tolerant of gap variations between substrates and of misalignment of the microstrip conductors.

INTRODUCTION

A key element affecting RF performance in microwave modules is the microstrip-to-microstrip interconnect. Errors in placement of microstrip lines during assembly, dimensional tolerance errors of thin-film networks and carrier plates, and variations in wire bonding produce varying gaps between substrates and wide variations in interconnect bond wire lengths. Interconnect series inductance varies because of this, often producing an interconnect with high VSWR (>2:1) and high insertion loss (<0.5 dB), particularly at frequencies above 12 GHz. Such interconnects can seriously degrade microwave module RF performance. Microwave amplifier gain ripple levels can be doubled or tripled by poor interconnects, and achieving amplitude and phase matching between amplifiers with nonrepeatable, nonoptimum interconnects is nearly impossible. Many new phased array radar, electronic warfare jammer and expendable decoy programs operate to frequencies of 20 Ghz or higher, where small variations in interconnect assembly can significantly change RF performance.

A simple, automated assembly technique has been developed which solves these problems and significantly increases repeatability. This paper discusses theory, design and fabrication of optimum microstrip interconnects from 2 to 20 Ghz. Experimental results are presented which verify the interconnect model and the constant wire length assembly technique. Microstrip interconnects are modeled and measured on 10-mil and 15-mil alumina, achieving VSWRs of 1.2:1 through 20 Ghz, even when several interconnects are cascaded.

MODELING

The model for a microstrip interconnect can be simply described by a shunt capacitor (C), series inductor (L), shunt capacitor (C) low-pass filter network. This CLC low-pass filter approximates very well the RF performance of the interconnect. The model shown in Figure 1 contains other circuit elements, but as noted there, the impedances of these elements are usually negligible compared to the reactances of the shunt capacitances near the ends of the microstrip lines and the series inductance of the bond wires connecting the two microstrip lines.

One goal of automated assembly of microstrip circuits and monolithic microwave integrated circuits is to achieve repeatable, low VSWR and insertion loss microstrip interconnects. This requires that the three major interconnect model circuit elements be both optimized for a given frequency range and held constant even when the spacing or alignment between the microstrip lines changes. A sensitivity analysis of wire inductance shows that control of wire length during autobonding, versus control of wire shape or height, results in a repeatable wire inductance. Wire inductance is directly proportional to wire length, but proportional to the logarithm of wire height. Wire inductance is typically 4 to 5 times more sensitive to changes in wire length than to height.

Maintaining constant, optimum wire lengths increases microstrip interconnect tolerance to spacing and alignment variations between microstrip lines. Autobonders today are capable of controlling wire lengths to within 0.001 inch. Flaring the microstrip lines at the ends increases the shunt capacitances and allows for longer bond wires and therefore larger wire inductances to be used with the interconnect. If the wire length is controlled, this allows even more tolerance to assembly variations in the placement of microstrip lines.

Microstrip line capacitance and open-end capacitance are modeled accurately by microwave circuit analysis/optimization programs like SuperCOMPACT and Touchstone. These programs were used in designing the optimized interconnects.

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DESIGN, LAYOUT, AND MEASUREMENT

An experimental thin-film network (TFN) mask set was designed to test and verify the interconnect model as can be seen in Figure 2. The 2- by 2-inch thin film circuits were fabricated at Texas Instruments. Circuits on both 10-mil and 15-mil thick alumina were developed with standard industry plating techniques used in the fabrication. After processing of the TFNs was completed, the microstrip interconnect regions were wire bonded. All wire bonding was accomplished on the Hughes 2460 automated thermosonic ball bonder, which now has a constant wire length bonding option as a product of this effort. The evaluation involved comparisons of conventional bonding without control of the wire length to the "constant wire length" option in which absolute control of the length of the wire bond was maintained automatically. Comparisons were also made of "short as possible" bonds compared to the flared, constant wire length approach as shown in Figure 3. The de-embedded s-parameter measurements analyzed were made using a Cascade prober and HP 8510 ANA. The measured data verified the microstrip interconnect model and verified the wire inductance sensitivity analysis prediction that wire length and not shape has the greatest influence on wire inductance.

Typically, gaps between the conductors in a microwave assembly are in the 10 to 20 mil range requiring wire lengths across those gaps of 20 to 30 mils. At frequencies near 18 GHz and above, the high series inductance associated with such wire lengths can increase interconnect VSWR to 4:1 or higher. Increasing the shunt capacitances at the ends of the microstrip lines allows a larger series inductance (longer bond wires) to be used in the interconnect. This is referred to as a "flared" interconnect. Flares can be used only when the wire inductance and, therefore, bond wire length can be controlled. Performance of both straight and flared optimum microstrip interconnects between 50-ohm microstrip lines on 10-mil alumina are shown in Figures 4, 5 and 6. The interconnect dimensions in Figures 7 and 8 are optimum based both on theory and experiment for the DC to 20 GHz frequency range, enabling VSWRs of 1.2:1 to be achieved across the band from cascades of several interconnects. Measurements have shown VSWRs can be maintained below 1.2:1 across DC to 20 GHz for gaps varying from 0 to 12 mils.

CONCLUSIONS

Modeling verified by empirical tests show that it is possible to repeatably achieve low VSWR and insertion loss mictrostrip interconnects on 10-mil and 15-mil alumina, across DC to 20 GHz. These optimum microstrip interconnects use flares at the ends of the lines to allow for longer bond wires in assembly. Constant wire length bonding controls the wire inductance and provides repeatability, even when gaps between the microstrip substrates vary. The optimum interconnect is tolerant of gap variations between microstrip substrates and of misalignment of the microstrip conductors.

Bonding microstrip interconnects with ribbons or very short wires is neither necessary nor desirable to achieve optimum performance across DC to 20 GHz. The optimum microstrip interconnects described in this paper are designed to work with high speed, automated ball bonders and with imperfectly placed and aligned substrates. The technique ensures excellent microwave performance in high volume production with the expected variability in parts tolerance and in component placement.

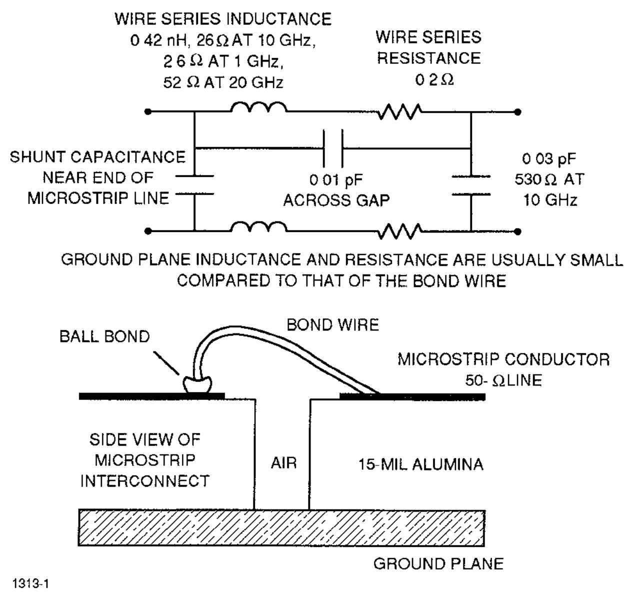

Figure 1. A Microstrip Interconnect Model; Schematic and Physical Side View (One 20-mil long, 1-mil diameter gold bond wire; 10-mil separation between conductor edges.)

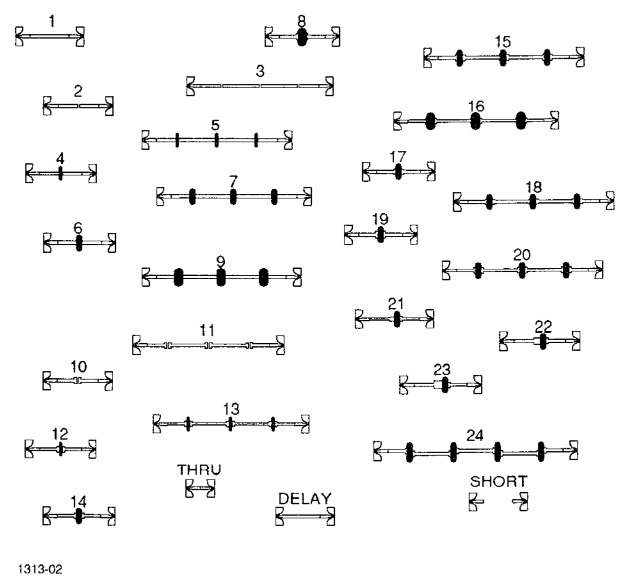

Figure 2. The 10-Mil Alumina Microstrip Interconnect Mask Set (This mask set contains both flared and straight interconnects, with single and cascade of three interconnects available for study. Slots are used to form air gaps; 0, 4, 8, and 12 mil gaps are used. Structure 24 offsets (misaligns) the microstrip lines. Coplanar-to-microstrip transitions are placed at the ends of each structure to enable "on-wafer" Cascade rf probing.)

ACKNOWLEDGMENTS

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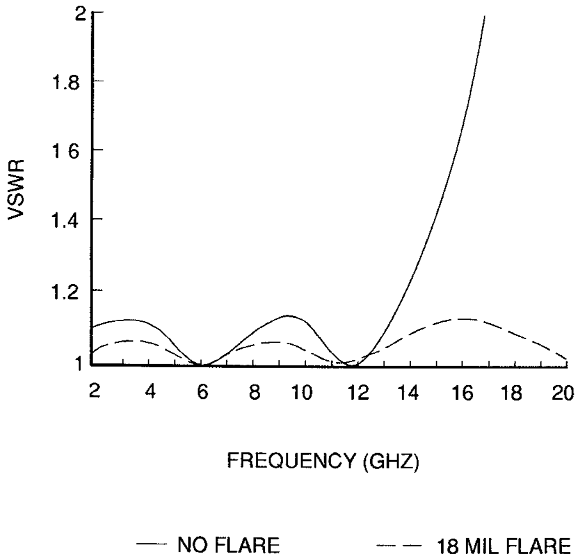

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Figure 3. Predicted SWRs for Cascades of Three Straight (No Flare) and Three Flared Microstrip Interconnects on 10-mil Alumina (Both interconnect types have series wire inductances of 0.25 nH. This again shows what happens when extremely short wire lengths cannot be maintained in assembly for the straight interconnect.)

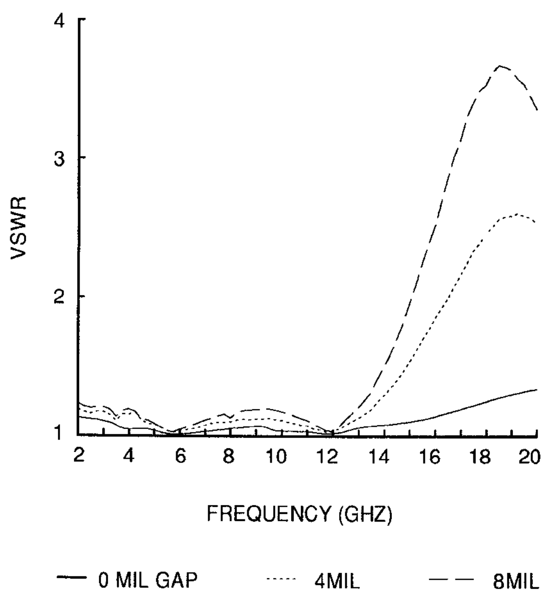

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Figure 4. Measured SWRs for Three Different Cascades of Three Straight Interconnects on 15-mil Alumina (Two parallel wires are used at each interconnect, and wire lengths are kept as short as possible. The cascade with three 8-mil gaps and therefore longest wire lengths has the highest SWR, 3.6:1 at 18 GHz.)

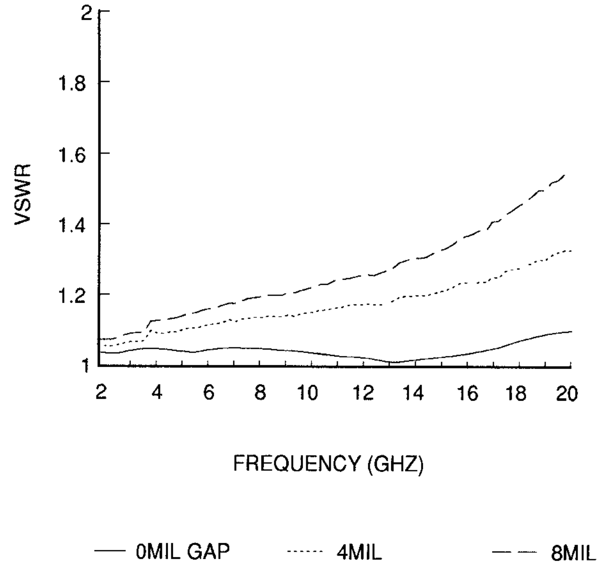

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Figure 5. Measured SWRs for Three Different Straight Microstrip Interconnects on 10-mil Alumina with Wire Lengths Kept as Short as Possible (Three air gap cases: 0 mils between substrates, 4 mils, and 8 mils)

Each interconnect has three parallel, short 1-mil diameter gold wires across the gap. The inductance is above the optimum value for the straight interconnect even with three wires in parallel.

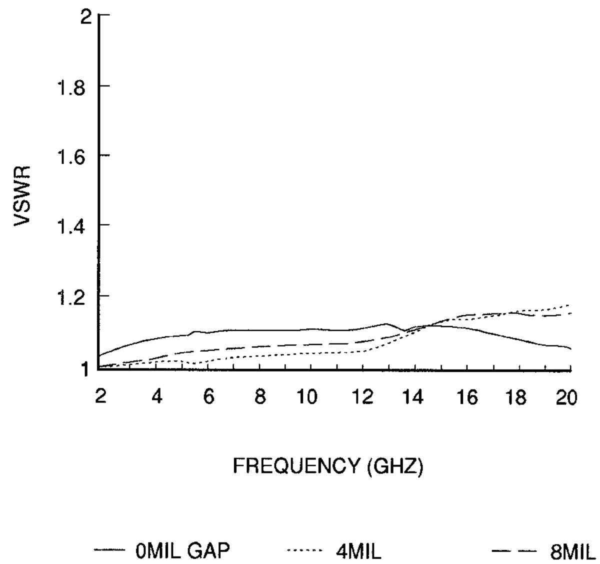

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Figure 6. Measured SWRs for Three Different Single Flared Interconnects with Air Gap Spacings of 0, 4, and 8 mils (Flare dimension: 18 mils wide by 7.5 mils long. Each interconnect has three 26-mil long, 1-mil diameter bond wires in parallel.

Even though the gap spacings vary, the wire lengths are held constant. Note that in all cases the interconnect SWR is less than 1.2:1 from dc to 20 GHz. Compare with Figure 4.

The flared interconnect with constant wire length offers tolerance to variations in TFN-to-TFN gap spacings.

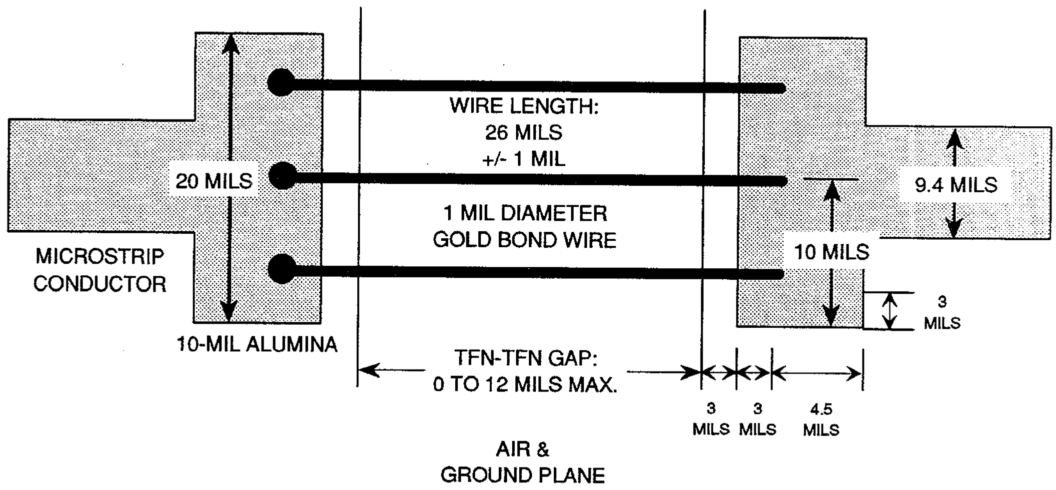

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Figure 7. A Three-Wire TFN-to-TFN Flared Interconnect on 10-mil Alumina DC-20 GHz, VSWR < 1.3 Effective Wire Inductance = 0.29 nH

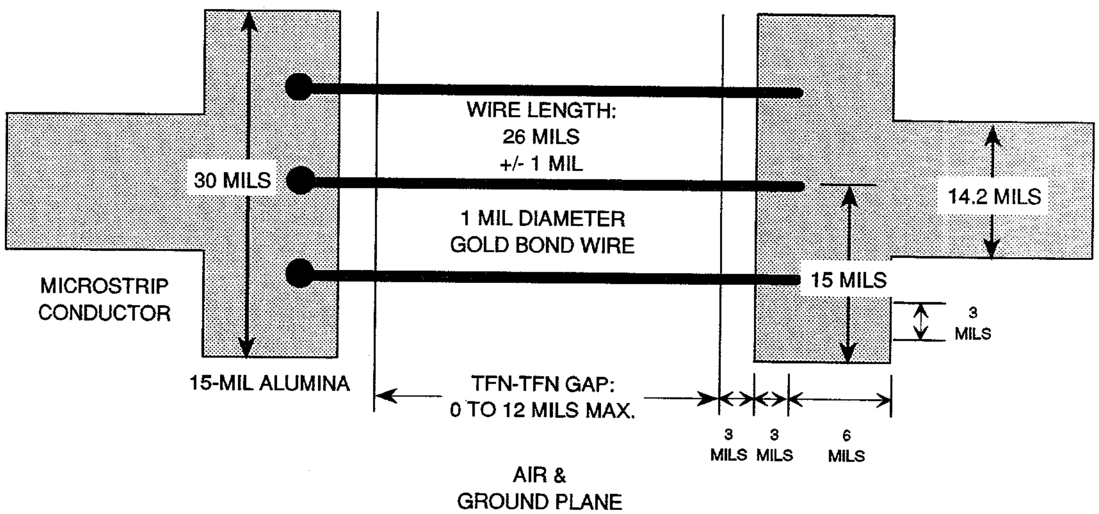

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Figure 8. A Three-Wire TFN-to-TFN Flared Interconnect on 15-mil Alumina DC-20 GHz, VSWR < 1.3 Effective Wire Inductance = 0.35 nH