Millimeter-Wave MMIC Interconnects Using Electromagnetic Field Coupling

Georg Strauss, Wolfgang Menzel

University of Ulm, Microwave Techniques, D-89069 Ulm, Germany
Tel. ++49-731-5026350
Fax ++49-731-5026359

ABSTRACT

Standard interconnect and packaging techniques for MMICs tend to get more and more difficult at mm-wave frequencies due to the increased influence of discontinuities and tolerances, especially in conjunction with temperature and hermetic sealing. To overcome these problems, a novel concept is proposed based on electromagnetic field coupling. First theoretical and experimental results are presented in this contribution.

INTRODUCTION

With increasing frequency, interconnects and packaging of MMICs become more and more difficult. Galvanic interconnects from a MMIC chip to a carrier substrate include strong, low-pass type discontinuities due to bond loops (temperature compensation!) and stray capacitances. Compensation of these discontinuities requires tight tolerances and, possibly, techniques for adaptive dimensions of bonding structures.

On the other hand, wavelength at mm-wave frequencies, especially in conjunction with GaAs or alumina substrates, becomes rather small. Therefore, electromagnetic coupling between (typically $\lambda/4$) transmission line segments with lengths of a fraction of a mm becomes compatible with MMICs.

REALIZATION OF ELECTROMAGNETIC FIELD (EM) COUPLING

Recently, a novel concept for interconnects and packaging of mm-wave MMICs has been proposed by the authors /1/. Electromagnetic coupling can be applied both to the MMIC chip interconnect and an interconnect from the inner to the outer surface of a package.

The principle of EM coupling is based on overlapping $\lambda/4$-sections of transmission lines. This can be done in a number of ways for different types of transmission lines as it is shown in Fig. 1 and 2. It includes the transitions from microstrip to coplanar line /2/, microstrip-slot-microstrip, or a direct transition from microstrip to microstrip. The theoretical computation and design of these structures can be done with different approaches, e.g. spectral domain method or mode matching /2/-/5/. In a second step, a small matching network placed on the carrier substrate is designed.

RESULTS

First electromagnetic coupling arrangements have been designed and tested in a scaled version, so that the structures can easily be tested without GaAs technology using soft substrates. As a first example, a transition from coplanar waveguide to microstrip on the opposite side of the substrate was investigated in detail (see /2/, too). Although the simple transition as shown in Fig. 1 gave promising results already, a simple, rather small matching circuit was added, giving a 50% bandwidth at 15 dB return loss (Fig. 3). Some difficulties occurred with the transition from coaxial to coplanar line; therefore, the return loss below 12...15 dB shows some discrepancies between theory and experiment. The overall agreement, however, is very good.

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Tolerance investigations have been made for this structure, showing only slight variations in performance for 0.4 mm lateral and ± 0.2 mm longitudinal shift between top and bottom metallization /1/.
A second structure, a transition from microstrip on a chip to microstrip on a carrier substrate was calculated (see Fig. 2, structure on the right). This transition requires via holes to connect the ground planes of the two microstrip lines; this, however, is done with standard techniques on the carrier substrate. Once again, a scaled model on RT Duroid material was designed and tested, in this case without matching elements. Some difficulties arose with the transition from coax to microstrip at the rather thick carrier substrate; nevertheless, a satisfying agreement between calculated and measured results can be stated (Fig. 4). A further improvement will be done, once again, adding some small matching circuit.
A last example will be a transition from a MMIC chip with a microstrip line to a carrier substrate with coplanar line (Fig. 2, left side structure) at 35 GHz. The theoretical results with and without matching network are presented in Fig. 5. A GaAs chip with a homogeneous transmission line only was used, together with a Duroid 6010 (ε_r=11, thickness 0.635 mm) substrate were used to realize and test two matched transitions placed back-to-back. The measurements were performed using a wafer prober and a vector network analyser. Although the design was originally done for an alumina carrier substrate with ε_r=9.8 and a thickness of 0.38 mm, and in spite of the rather high losses of the Duroid material used here at mm-wave frequencies, satisfying results can be found (Fig. 6). The ripple in the return loss is due to the interactions of the two transitions and due to the limited accuracy of the network analyser calibration procedure using wafer probing on the soft substrate with rather thick metallization.

CONCLUSION

First scaled and mm-wave results for electromagnetically coupled transitions between transmission lines in different substrate planes have been presented. These transitions will be the basis of a novel concept for MIMIC interconnects and packaging techniques.

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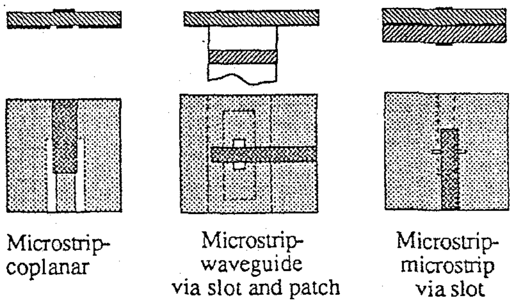

Fig. 1 : Principle of the proposed interconnect/packagingsolution for mm-wave monolithic integrated circuits

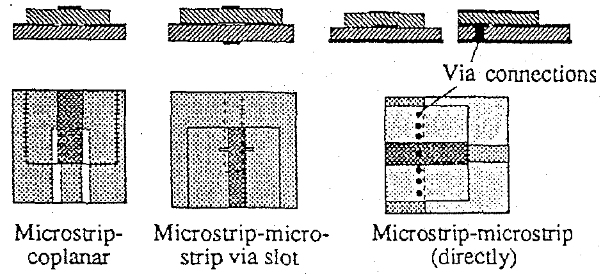

Fig. 3 : Some possible configurations for interconnects from a mm-wave MMIC chip to the carrier substrate

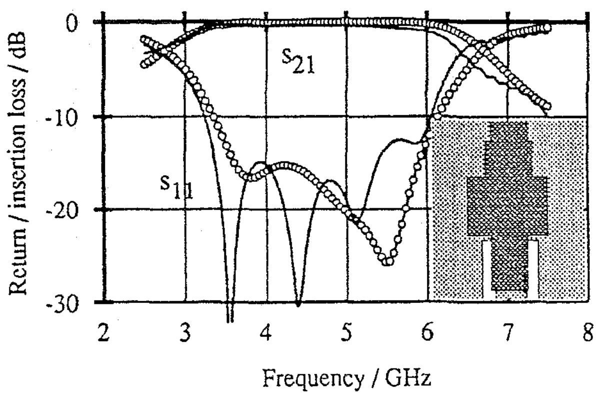

Fig. 3: Theoretical and experimental results of a microstrip-to-coplanar transition including a matching circuit (scaled structure, substrate: ε_r=11, h=1.27 mm. Microstrip: w = 2.4 mm (at transition). CPW: w = 2.8 mm, s = 0.8 mm. Overlapping: d = 4.4 mm. Gap: g = 1 mm.)

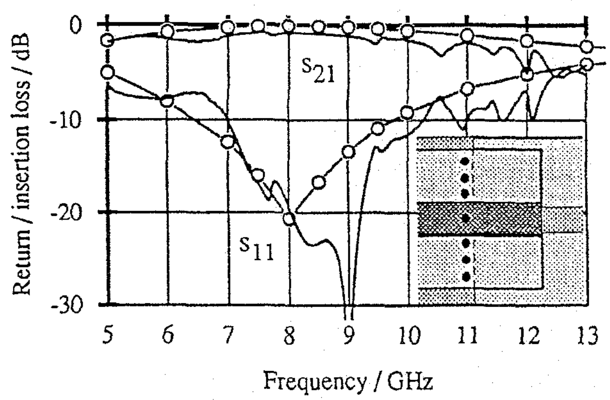

Fig.4: Theoretical and experimental results of a microstrip-to-microstrip transition (scaled structure, carrier substrate: ε_r = 11, h = 1.27 mm, w = 1.4 mm. Chip substrate: ε_r = 11, h = 0.635 mm, w = 1.2 mm. Overlapping: d = 2.4 mm. Gap to second level ground plane: g = 0.4 mm.)

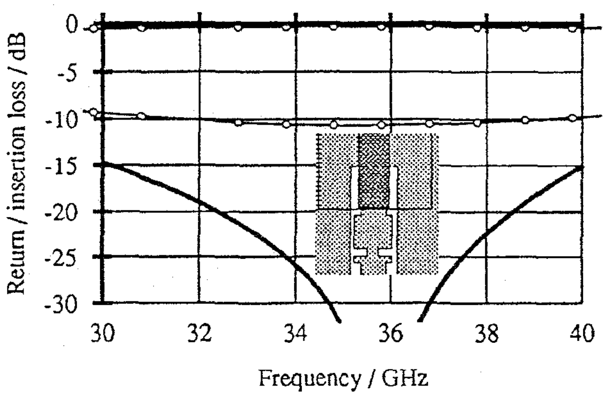

Fig.5: Theoretical results of a microstrip-to-coplanar transition with and without matching circuit. (Chip substrate: ε_r=12.95, h=0.15 mm, w = 0.145 mm. Carrier substrate: ε_r=9.8, h=0.38 mm, w = 0.5 mm, s = 0.15 mm. Overlapping: d = 0.74 mm. Gap: g = 0.12 mm.)

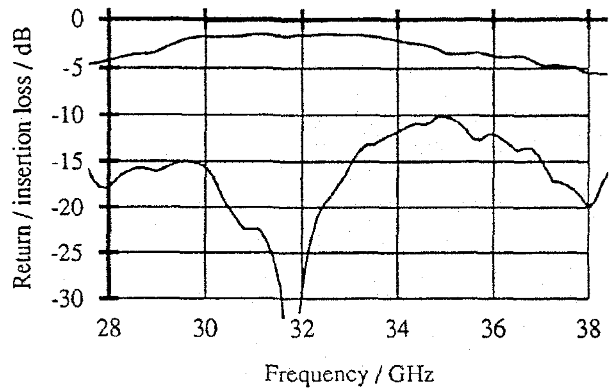

Fig.6: Experimental results of two microstrip-to-coplanar transitions with matching circuits. (Data as in Fig. 5, except for carrier substrate ε_r=11, h=0.635 mm)