A NOVEL CONCEPT FOR MM-WAVE MMIC INTERCONNECTS AND PACKAGING

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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 for interconnects and package feed-through elements. First theoretical and (scaled) experimental results are presented.

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.

- Flip-chip mounting of chips /1/ may cause interferences of EM fields of the chip with the carrier substrate and degrade the circuit performance. Furthermore, the realization of heat sinks for the chips becomes extremely difficult.

- The wall thickness of a package compared to wavelength can no longer be neglected at mm-wave frequencies, leading, once again, to strong discontinuities for feed-through elements. Furthermore, every galvanic feed-through structure is a potential source of leakage concerning hermetic sealing.

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.

NOVEL CONCEPT

Based on electromagnetic coupling, a novel concept for interconnects and packaging is proposed (Fig. 1). The MMIC chips are placed on a common carrier substrate which, at the same time, acts as an integral part of a package. The mm-wave signals are coupled contactlessly from the chips to the carrier while DC and IF signals are connected conventionally by bonding across the edge of the chip. A mm-wave interconnect from the interior of the package to the outside, once again, can be done by electromagnetic coupling through the carrier substrate. A seal ring containing feed-through elements for DC and IF can be soldered flash onto the carrier substrate. With this concept,

- a highly precise and therefore costly step - the bonding - can be omitted.
- tolerance requirements probably can be reduced, as it is shown by first investigations.
- the chip interconnect gives a definite capacitive load at low frequencies, favourable for the stability of FET-circuits.
- the number of feed-through elements into the package is lower, reducing possible sources of leakage for hermetically sealed packages.

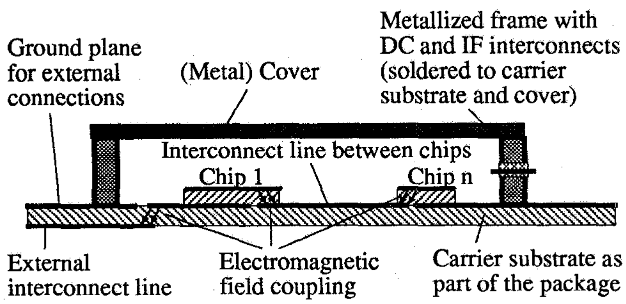

Fig. 1 : Principle of the proposed interconnect/packaging solution for mm-wave monolithic integrated circuits

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REALIZATION OF ELECTROMAGNETIC FIELD (EM) COUPLING

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. 2 and 3. 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.

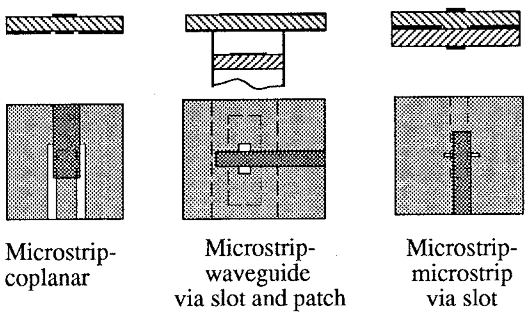

Fig. 2 : Some possible configurations for interconnects through a carrier substrate (from inside to outside of package)

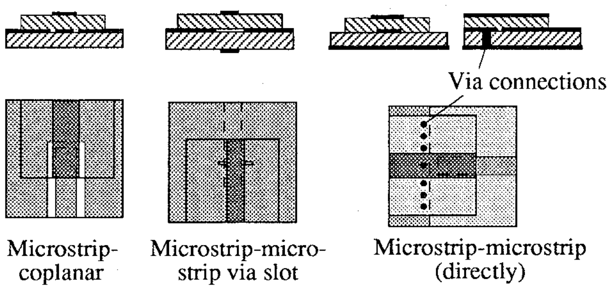

Fig. 3 : Some possible configurations for interconnects from a MIMIC chip to the carrier substrate

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. 2 gave promising results already, a simple, rather small matching circuit was added, giving a 50% bandwidth at 15 dB return loss (Fig. 4). 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. One problem, especially with millimeter waves are tolerances. Fig. 5 gives variations of the return loss for lateral and longitudinal shifts between top and bottom metallization, showing some, but not really severe affects on the performance of the transition.

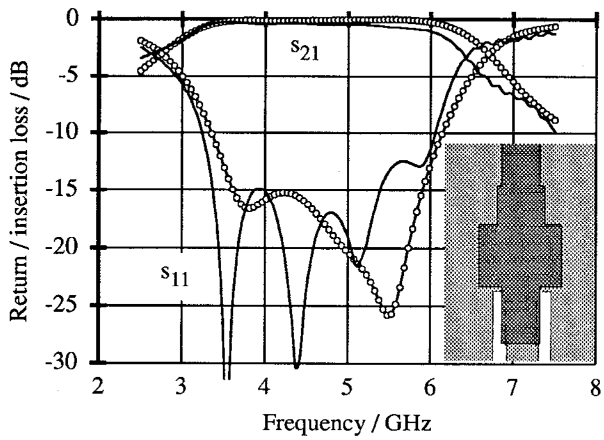

Fig. 4: Theoretical and experimental results of a microstrip-to-coplanar transition including a matching circuit (scaled structure, substrate: ε_r=11, h=1.27 mm. Microstrip: w = 2.4 mm {at transition}. CPW: w = 2.8 mm, s = 0.8 mm. Overlapping: d = 4.4 mm. Gap: g = 1 mm.}

Fig. 6 gives first theoretical results - without matching circuit - for a transition from microstrip on a chip to coplanar line on a carrier substrate.

Another structure, a transition from microstrip on a chip to microstrip on a carrier substrate was calculated (see Fig. 3, 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. 7). A further improvement will be done, once again, adding some small matching circuit.

Finally, results of a mm-wave transition from microstrip to waveguide based on a 0.1 mm alumina substrate for the microstrip circuit and a 0.11 mm quartz substrate for the patch element in the waveguide are presented in Fig. 8. This structure was designed in cooperation with DASA, Ulm /6/. The experimental results include two transitions back to back, connected by a 21 mm microstrip line. This line exhibits already about 1.6 dB of losses; therefore the loss per transition amounts to 0.3...0.4 dB only.

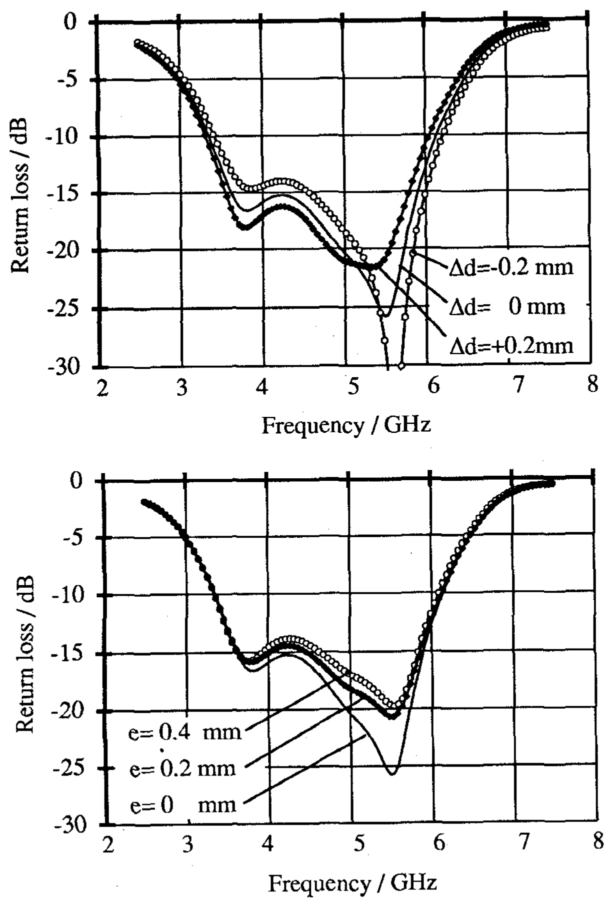

Fig. 5: Longitudinal (Δd) and lateral (e) displacement of top and bottom metallization patterns of the transition according to Fig. 4.

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.

ACKNOWLEDGEMENT

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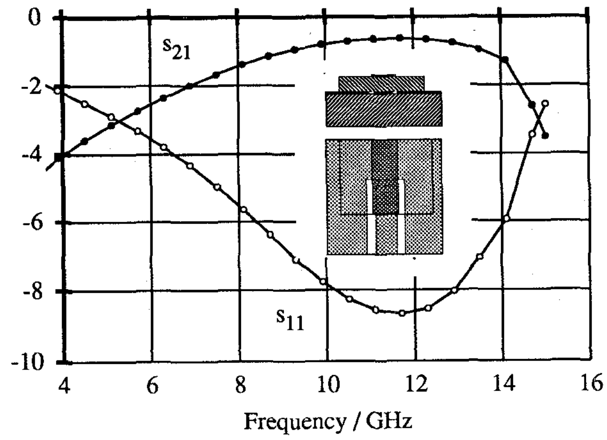

Fig. 6: Theoretical transmission characteristics of a microstrip-to-CPW transition from a chip to a carrier substrate without matching (scaled structure, chip substrate: ε_r=11, h=0.635 mm, w=0.516 mm, carrier substrate: ε_r=11, h=1.27 mm,w=2 mm, s=0.6 mm, overlapping 2.7 mm, gap 0.5 mm)

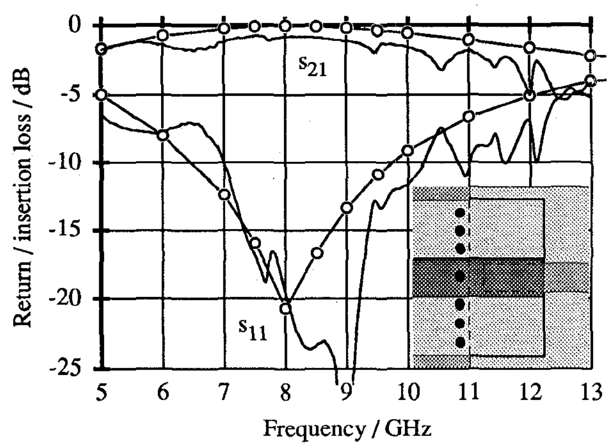

Fig. 7: Theoretical and experimental results of a microstrip-to-microstrip transition (scaled structure, carrier substrate: ε_r = 11, h = 1.27 mm, w = 1.4 mm. Chip substrate: ε_r = 11, h = 0.635 mm, w = 1.2 mm. Overlapping: d = 2.4 mm. Gap to second level ground plane: g = 0.4 mm.}

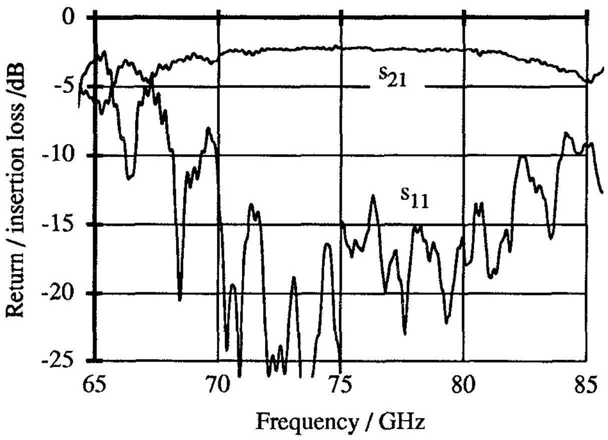

Fig. 8: Transmission characteristics of two back-to-back mm-wave transitions from microstrip to waveguide.(Microstrip substrate:ε_r=9.8, h=0.1 mm; patch substrate: ε_r=3.75, h=0.11 mm)

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