PACKAGING AND INTERCONNECT TECHNIQUES FOR COMPLEX MILLIMETER-WAVE FRONT-ENDS

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ABSTRACT

Millimeter-wave systems increasingly are entering into commercial systems, both for communication and sensors for traffic or industrial applications. In many cases, circuit technology of the involved front-ends includes monolithic and hybrid integrated circuits and even waveguide components like filters or antenna feeds. In addition to the standard technical and environmental requirements, these front-ends have to be fabricated in large quantities at very low cost.
After a short review of the problems and some general interconnect and packaging techniques for mm-wave front-ends, achievements of different research programs will be presented with emphasis on the application of multilayer carrier substrates to mm-wave circuits and the realization of packages including waveguide components by plastic injection molding.

INTRODUCTION

Modern mm-wave sensors, e.g. for traffic applications, or communication front-ends for local area networks (LANs), tie lines to mobile communication base stations, or mobile mm-wave communication systems (micro cell communication) require high performance but low cost production [1], [2]. To this end, a combination of planar transmission line circuits (coplanar or microstrip lines) with metal waveguide for low loss filters and diplexers is used in many cases (Fig. 1). Furthermore,

- standard designs for planar hybrid or monolithic integrated circuits (MMICs) should be used, or even standard components from a large scale production should be employed.
- effective and accurate methods (full-wave designs) for the critical circuit elements are necessary. If possible, tuning of components should be avoided or at least kept to a minimum.
- good interconnects between the different parts of the front-end have to be ensured.
- the assembly of the components should be as easy as possible.
- the front-end has to be shielded against environmental influences (water, vapor, chemicals, etc.) by a suitable package.
- the front-end with the package has to withstand a defined temperature range.
- the different materials of front-end and package should match with respect to thermal expansion.
- heat generated in a circuit has to be effectively transferred to the outside.

Although mm-waves exhibit a number of advantages like small size, low weight, wide bandwidth, or reduced interaction with other services, tolerance requirements due to the shorter wavelengths, increased reflections at discontinuities and interconnects, and possible package resonances require precautions during design, fabrication and assembling [3] - [10].

COMMUNICATION FRONT-END AS EXAMPLE

A number of techniques for packaging and interconnects will be described with the example of a typical communication front-end. Its basic block diagram is given in Fig. 1. The front-end consists both of planar circuits and metal waveguide components. The general setup of the different parts of the system is shown in Fig. 2.

The planar circuits are based on a multilayer LTCC substrate [11] containing waveguide-to-microstrip transitions, a number of hybrid MICs and the interconnect elements for MMICs. The carrier substrate is placed on top of a carrier structure fabricated by metal injection molding based on steel powder. This already provides a reasonable heat sink; should this not be sufficient, inserts of copper-molybdenium can be soldered into special groves in this carrier. A metallized plastic cover structure protects the circuit. This cover includes part of the waveguide to-microstrip transitions and a channel structure forming waveguides below cut-off and separating the different parts of the planar circuits.
The waveguide filters, the diplexer [12] and a 3 dB coupler are fabricated using plastic injection molding and electroplating. The antenna will consist of a waveguide slotted array structure etched from a metal sheet and fed by a ridged waveguide feed network – once again fabricated using plastic injection molding.

FEED-THROUGH STRUCTURES

The interconnect between the different parts of the planar circuits (interconnects between the different channels) can be realized via a lower metallization level of the carrier substrate. A direct feed-through structure uses vias from a microstrip line to a triplate line and back; should a DC separation be necessary, or if the top layer of the carrier substrate must not be perforated (hermeticity), a slot coupling between microstrip and triplate line is possible, too (Fig. 3). Such an electromagnetically coupled feed-through structure has been designed for the 28 GHz range [13]; first results are given in Fig. 4. As transition to the waveguide circuits, modified transitions according to [14] or [15] may be employed.

INTERCONNECTS TO MMICs

The most easy way of adding MMICs to the planar circuitry would be just placing them on top of the LTCC substrate (Fig. 5). In case of a microstrip structure on the carrier substrate, vias have to connect the different ground planes. The bonding between the lines on the MMIC and the LTCC substrate can be done by bond tapes. Theoretical calculations (FDTD) and measured results (deembedded from the results of two transitions back-to-back with different interconnect line lengths) of a single transition of this type are given in Fig. 6, and the experimental performance of a MMIC amplifier connected in such a way is plotted in Fig. 7. Up to about 30 ... 40 GHz, this type of transition is reasonably good; problems occur, however, at higher frequencies. Instead of the microstrip lines on the carrier substrate, coplanar lines with their ground plane in the same level as the MMIC can be used equally [16] and [9], and electromagnetically coupled transitions [17] will work well up to higher frequencies.

WAVEGUIDE COMPONENTS

For the front-end according to Figs. 1 and 2, two standard waveguide filters combined with a 3 dB coupler were designed for the LO, and a modified arrangement was chosen for the diplexer [12]. By replacing inductive irises with short-circuited T-junctions as inverter circuits, stop band poles in the frequency response are created and can be placed at either side of the filter pass-band. For a given out-of-band attenuation - especially if this is required close to the filter pass-band, this allows the number of physical resonators to be reduced and, therefore, leads to lower insertion loss compared to standard filter designs. These two filter circuits are shown in Fig. 8 (already fabricated as plastic parts).
For a low-cost, high volume fabrication using plastic injection molding, problems with respect to tolerances of the production process have to be taken into account. The shrinking of the injection molded plastic parts during cooling, on the one hand, can be precalculated to some extent; this however, is not accurate enough for the fabrication of the filters. The parts fabricated from one

form, however, are nearly identical one to the other. Therefore, in the design of the filters, cylindrical posts as tuning elements were included in the resonators. In the injection form, this corresponds to holes at the respective positions; the depths of the hole are adjusted by screws. First samples of the filters then are fabricated with the post height being zero, external screws are used to trim the filter response, and the resulting post heights are adjusted in the form. Once the filters produced with this modified form have an acceptable performance, the reproducibility during production is assumed to be good enough.

Fig. 9 gives a first result of the (externally tuned) filter arrangement compared to the design performance. It should be noted that these results include the coupling loss of the 3 dB coupler; therefore the filter insertion loss is less than 0.6 dB, and both return loss and transmission behavior are close to the design.

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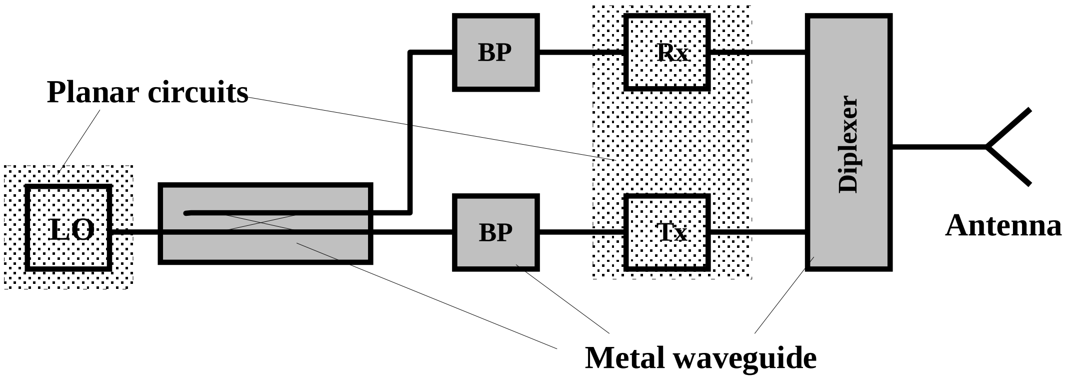

Fig. 1: Principle setup of a typical communication module (BP: bandpass filter, Tx: transmitter, Rx: receiver, LO: local oscillator**).**

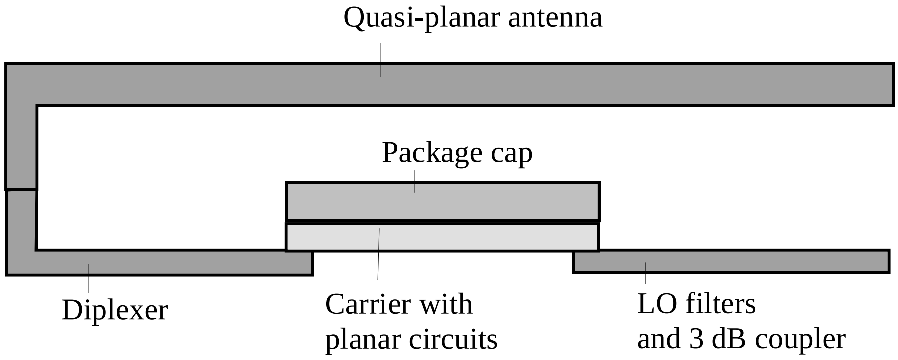

Fig. 2: Basic mechanical setup of the communication system.

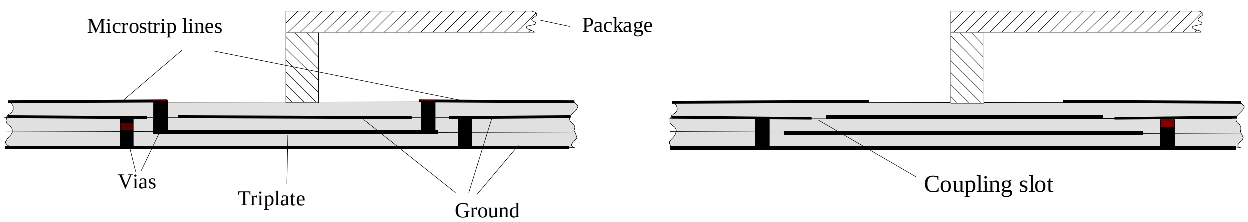

Fig. 3: Cross section of two possible feed-through structures using multilayer substrates.

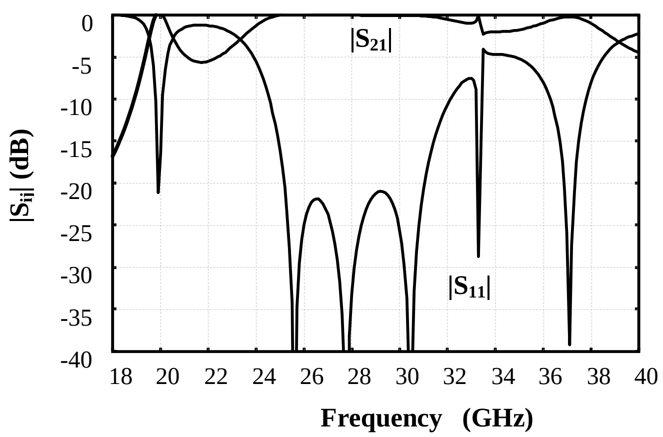

Fig. 4: Transmission behavior of an electromagnetically coupled feed-through structure using a multilayer substrate.

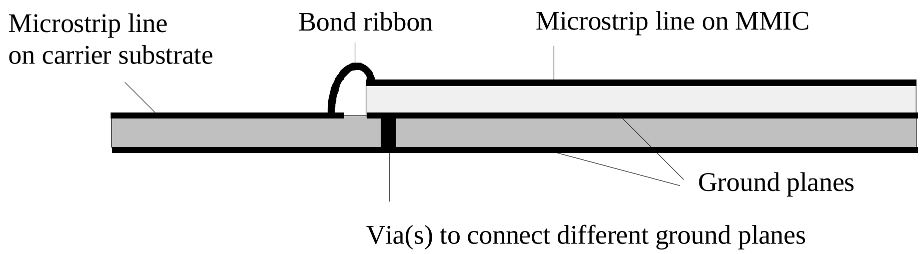

Fig. 5: Cross section of microstrip – microstrip bond interconnect.

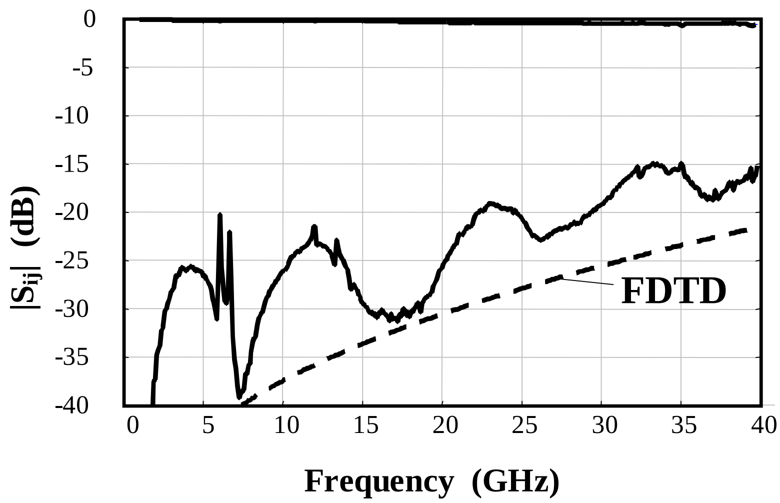

Fig 6: Measured insertion and return loss of a single transition according to Fig. 5 compared to a theoretical FDTD calculation (Alumina substrates, substrate height 0.127 mm).

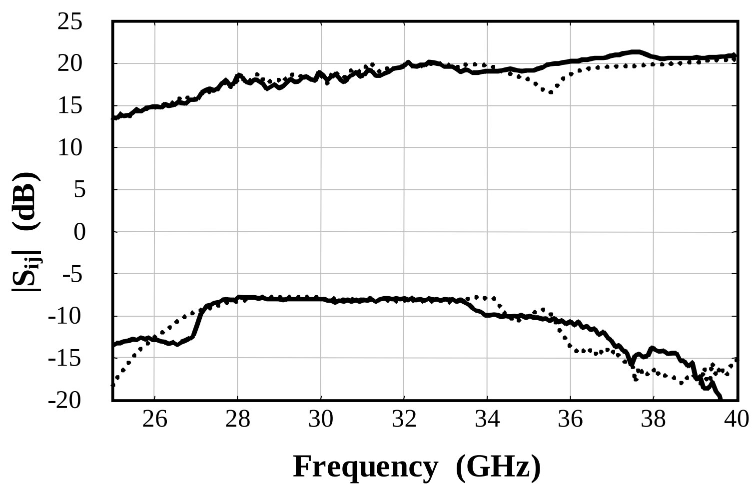

Fig. 7: Measured insertion and return loss of a MMIC amplifier (GaAs substrate height 0.15 mm). Dotted lines: direct on-wafer measurement. Solid lines: bonded according to Fig. 5.

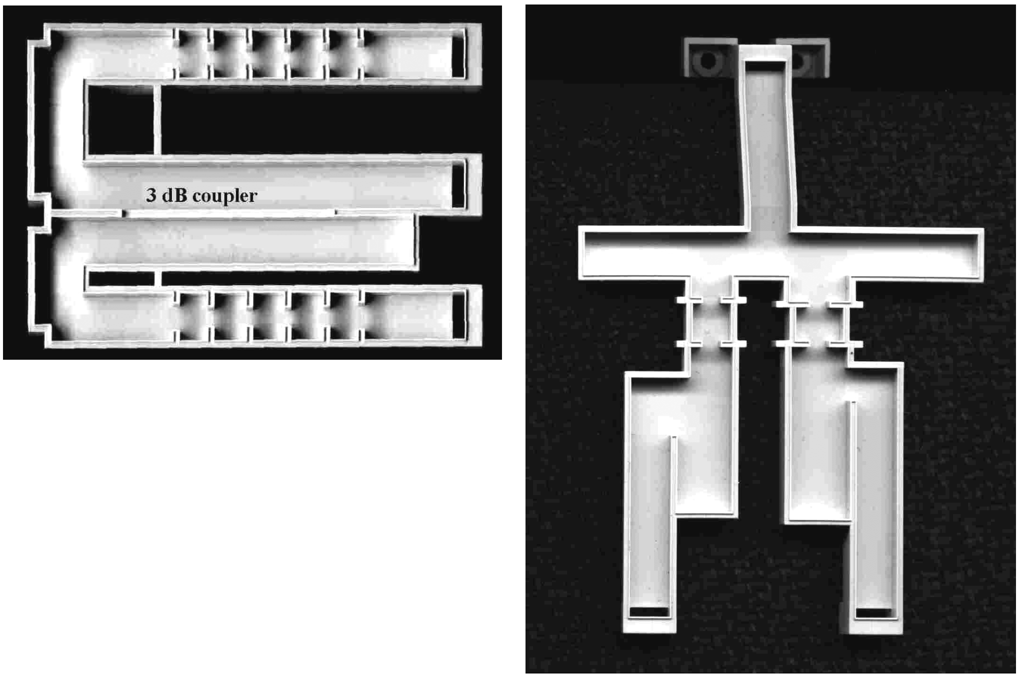

Fig. 8: Arrangement of two waveguide filters connected by a 3 dB coupler (left side) and a diplexer (right side) fabricated by plastic injection molding.

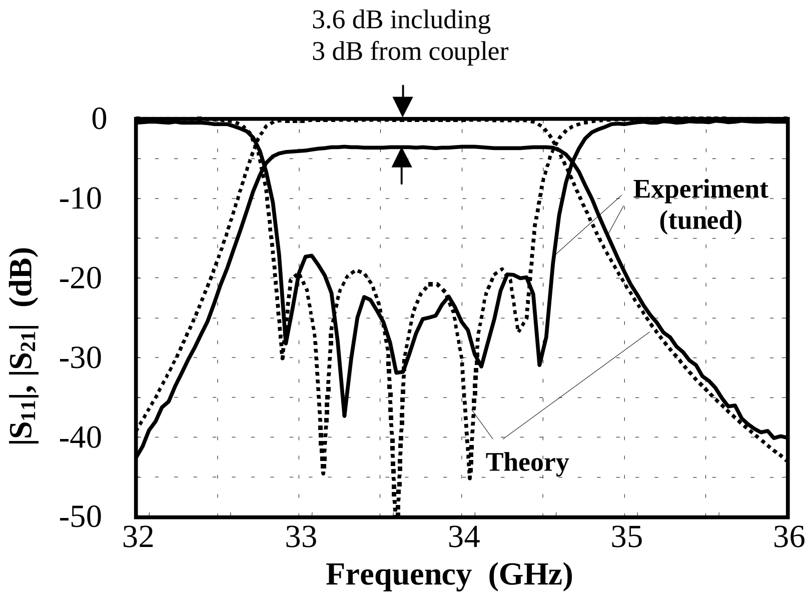

Fig. 9: Return and insertion loss of the LO filter block after tuning, compared to the design characteristics of a single filter.