NOVEL TECHNIQUES FOR PACKAGING AND INTERCONNECTS IN MM-WAVE COMMUNICATION FRONT-ENDS

Wolfgang Menzel, Jürgen Kassner

Abstract

Modern mm-wave systems, e.g. 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. To this end, a combination of planar transmission line circuits (coplanar or microstrip lines, MICs and MMICs) with metal waveguide for low-loss filters and diplexers has to be designed, fabricated, assembled, and packaged effectively. After a short review of some general problems and techniques with respect to interconnects and packaging for mm-wave front-ends, achievements of a research program in Germany will be presented, mainly at the example of components for a 28 GHz communication front-end. This includes the investigation of conventional interconnect techniques, a novel feed-through structure using multilayer carrier substrates for mm-wave circuits, new results in electromagnetic field coupling for interconnects to mm-wave MMICs, and the realisation of packages including waveguide components like filters and diplexers by plastic injection moulding and electroplating.

Introduction

Modern mm-wave systems, e.g. for traffic applications (automotive radars), 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). If possible, tuning of components should be avoided or at least kept to a minimum. 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]. The front-end has to be shielded against environmental influences (water, vapour, chemicals, etc.) by a suitable package, and it has to withstand a defined temperature range. To this end, 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.

28 GHz communication front-end

A number of techniques for packaging and interconnects will be described in this paper with the example of a communication front-end. Its basic block diagram and the general set-up of the different parts of the system are sketched in Fig. 1. The front-end consists both of planar circuits and metal waveguide components.
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 moulding (MIM) based on steel powder. This already provides a reasonable heat sink; should this not be sufficient, an insert of copper-molybdenum can be soldered into a special grove in this carrier. A metallized plastic cover protects the circuit. This cover includes part of the waveguide-to-microstrip transitions (backshort) and a channel structure forming waveguides below cut-off and separating the different parts of the planar circuits.

Wolfgang Menzel is with the University of Ulm, Microwave Techniques, D-89069 Ulm, Germany.
Jürgen Kassner now is with IMST, D-47475 Kamp-Lintfort, Germany.

The waveguide filters, the diplexer [12] and a 3 dB coupler are fabricated using plastic injection moulding and electroplating. The antenna consists 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 moulding [21].

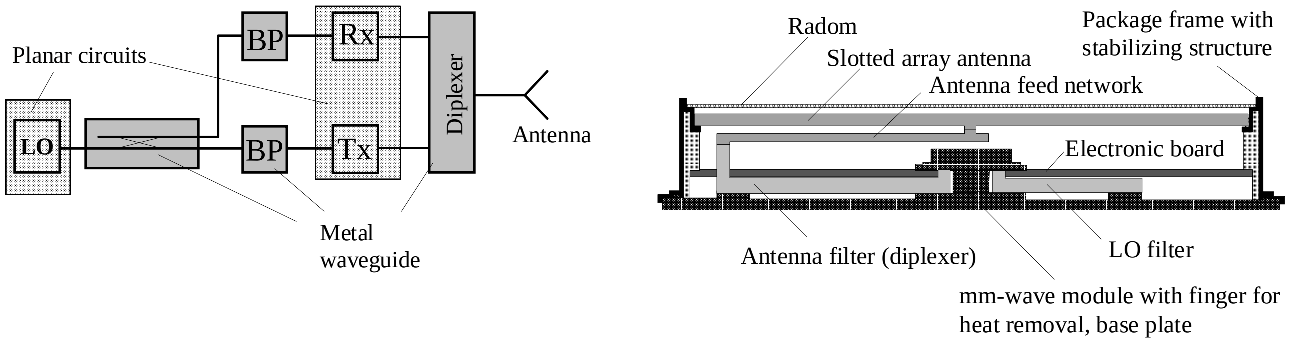

Fig. 1: Principle block diagram of a typical communication module and basic mechanical setup (BP: bandpass filter, Tx: transmitter, Rx: receiver, LO: local oscillator**).**

Electromagnetically coupled feed-through element

The microwave interconnects between different parts of a planar circuit (interconnects between the different package channels) can be realised via a lower metallisation level of the multilayer (LTCC) carrier substrate. A direct feed-through structure uses vias from a microstrip line to a triplate line and back [22]; should a DC separation be necessary, or if the top layer of the carrier substrate must not be perforated (possible loss of hermeticity), a slot coupling between microstrip and triplate line is possible, too (Fig.2). Such a transition has been designed for the 28 GHz range [13]. Theoretical and experimental results of this transition are displayed in Fig. 3. Some problems occurred during the calibration process around 25 GHz; except for this however, the agreement between theory and experiment is quite good.

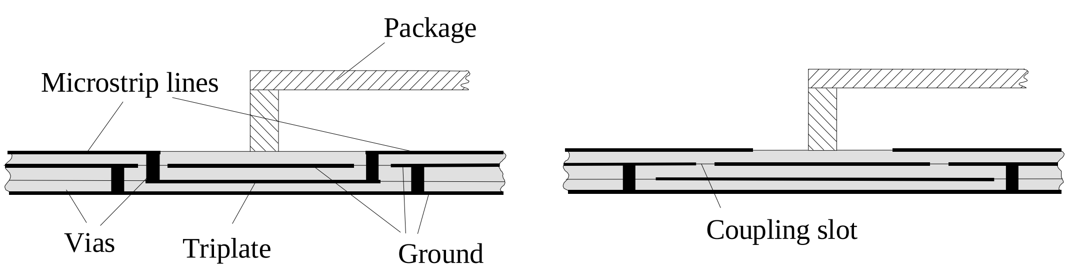

Fig. 2: Cross section of two possible feed-through structures using multilayer substrates.

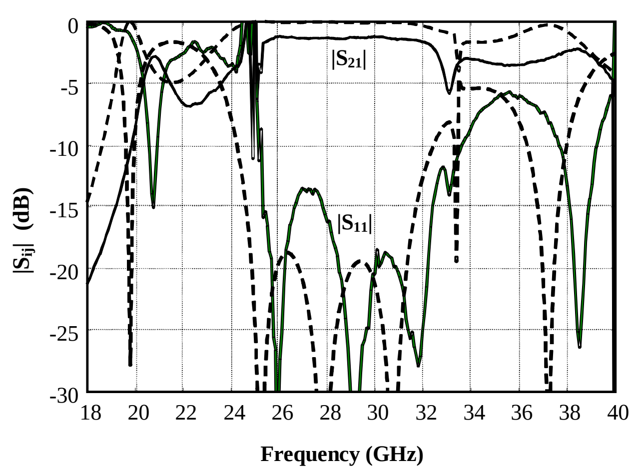

Fig. 3: Theoretical and experimental results of a feed-through structure on LTCC substrate according to Fig. 2, right side.

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. 4). Using microstrip lines on the carrier substrate, vias have to connect the different ground planes of MMIC and carrier substrate. The bonding between the microstrip lines on the MMIC and the LTCC substrate can be done by bond ribbons. Theoretical calculations (FDTD) and measured results of a single transition of this type (deembedded from the results of two transitions back-to-back with different interconnect line lengths) are given in Fig. 4.
Instead of the microstrip lines on the carrier substrate, coplanar lines with their ground plane in the same level as the MMIC ground plane can be used equally [9] and [16]. Results of a single ribbon bonded transition from a microstrip line to a coplanar line on a carrier substrate are shown in Fig. 5.

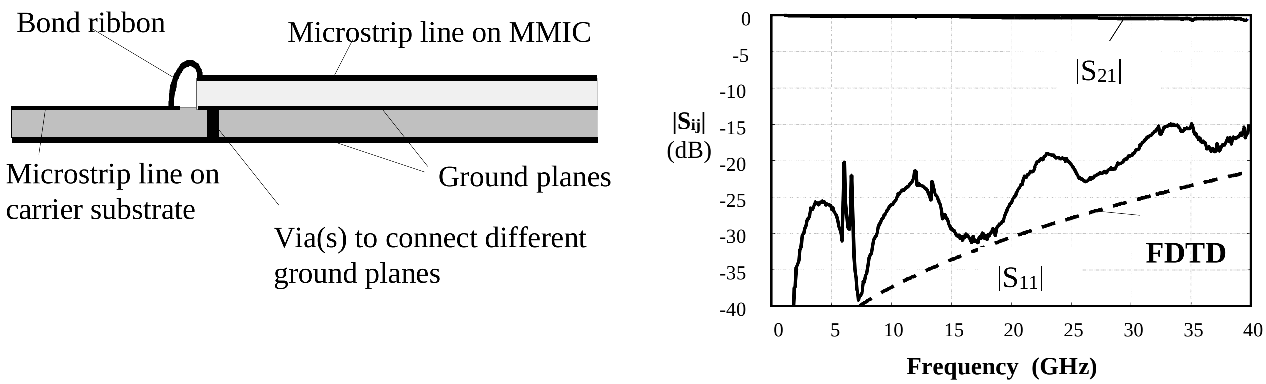

Fig. 4: Cross section of microstrip – microstrip bond interconnect and measured insertion and return loss, together with a FDTD calculation of the transition(alumina substrates, substrate height 0.127 mm).

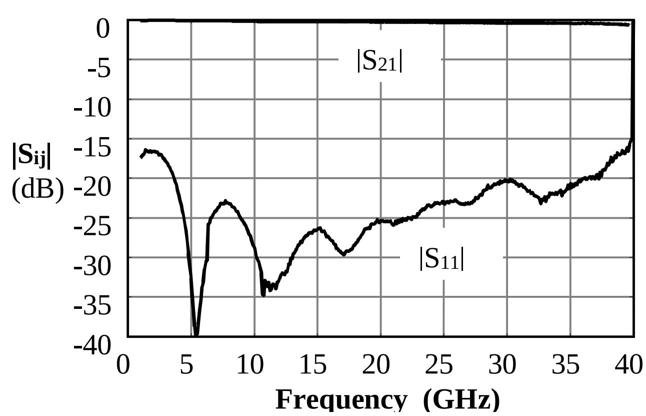

Fig. 5: Measured insertion and return loss of a single transition from microstrip line on top of a coplanar line on a carrier substrate (alumina substrates, substrate height 0.127 mm and 0.635 mm).

As an alternative to bonded interconnects, electromagnetic field coupling has been demonstrated in [17]. This type of interconnect has been improved in the meantime by the possibility of integrated means for on-wafer measurements without via holes which would disturb the interconnect performance [18], [20]. To this end, quarter-wave stub structures – rather small at mm-waves – are placed besides the microstrip line on a MMIC (Fig. 6, left side).
After on-wafer tests, the chips can be separated and mounted using field coupling as shown in Fig. 6, right side [19], together with some small matching structure on the carrier substrate. A frequency scaled test structure was fabricated at 20 GHz. The transition from the on-wafer probe to the microstrip line is plotted in Fig. 7 on the left side, showing an excellent performance. On the right side of Fig. 7, results of an electromagnetically coupled transition of the same microstrip line to a coplanar carrier substrate are shown. Some tolerances of the employed alumina substrates led to a slight modification of the experimental results.

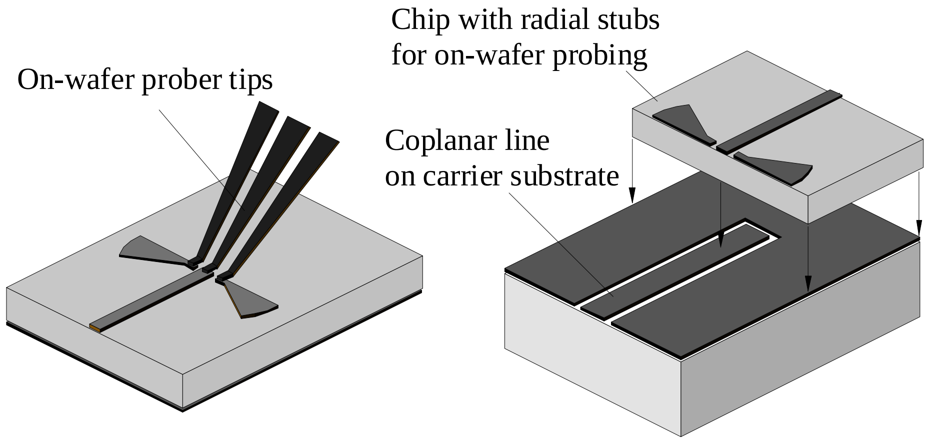

Fig. 6: Arrangements for electromagnetic field coupling of MMICs including on-wafer measurements without via holes.

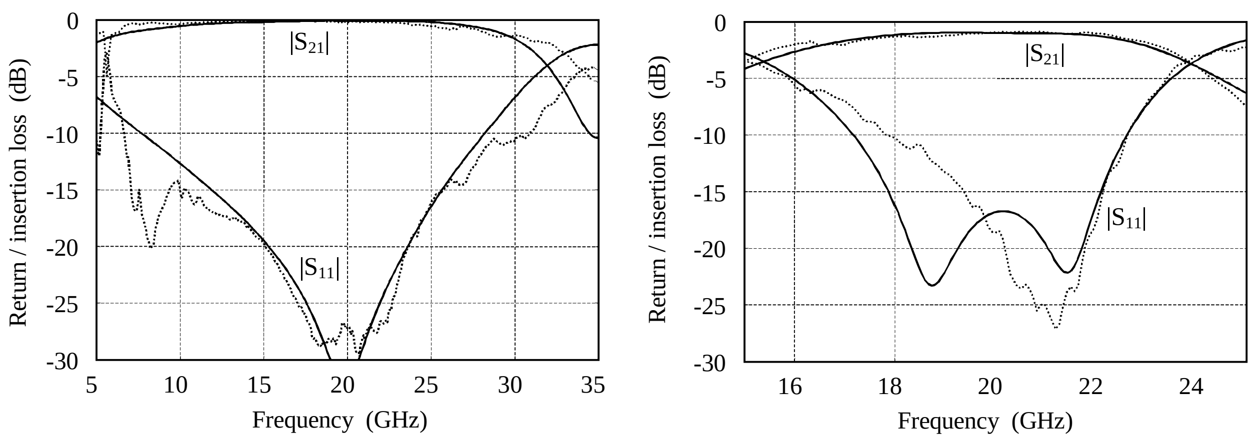

Fig. 7: Theoretical (dotted lines) and experimental (solid lines) results of the transition from the on-wafer probe to a microstrip line without via holes (left side) and of an electromagnetically coupled transition from microstrip line to coplanar line on a carrier substrate (right side).

Waveguide filters and diplexers

For the front-end according to Fig. 1, two standard waveguide filters combined with a 3 dB coupler were designed for the LO, and a modified arrangement was chosen for the diplexer. 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 [12]. 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.

The two filter blocks as shown in Fig. 8 are fabricated as plastic parts. After electroplating, fully metallized printed circuit boards are soldered to the top of the filters as cover plates.

For a low-cost, high volume fabrication using plastic injection moulding, some modifications already have to be considered during the design. To avoid, as far as possible, tensions within the material, wall thickness has to be constant, i.e. iris thickness and the thickness of walls between waveguide sections (see Fig. 8) have to be set to a common value – 1.2 mm in this case. Furthermore, the filter structure is extended below the bottom wall to maintain symmetry in this respect, too.

A major problem with respect to tolerances of the production process is the shrinking of the injection moulded plastic parts during cooling. On the one hand, this can be precalculated to some extent, but this 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 then are adjusted in the form. Once the filters produced with this modified form have an acceptable performance, the reproducibility during production is sufficiently good.

Fig. 9, left side, gives results of one of the LO filters. Four different structures fabricated by injection moulding were tested; overall performance and reproducibility are sufficient. (It should be noted that these results include the coupling loss of the 3 dB coupler). On the right side of Fig. 9, results of four different diplexers fabricated in the same way are plotted. Except for the return loss of the higher frequency passband, an excellent performance with -0.8 dB of insertion loss in the two design passbands and more than -60 dB rejection in the respective other passbands are achieved.

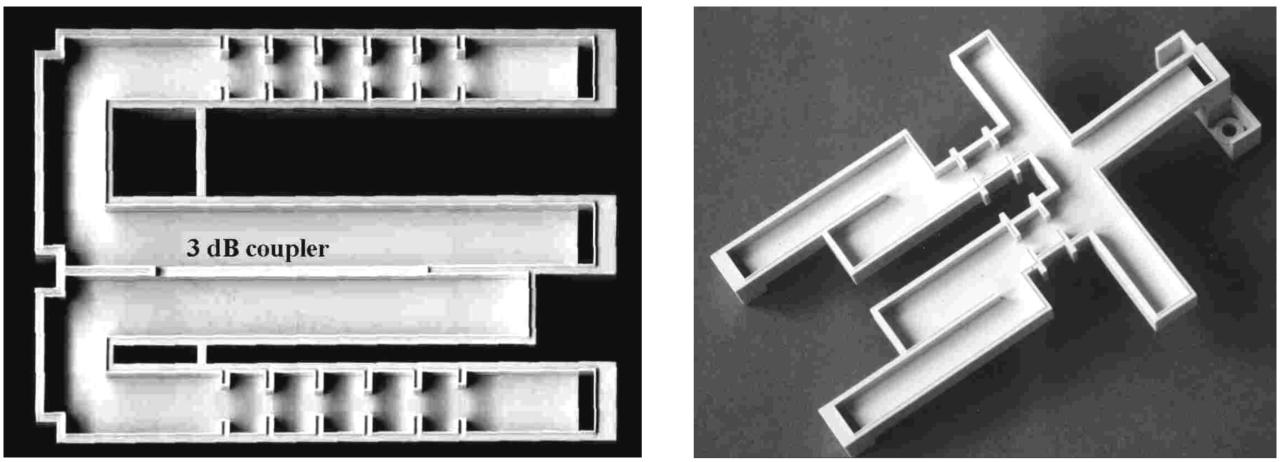

Fig. 8: Photograph of a filter block including two five-resonator chebishev filters and a 3 dB coupler (left side) and a diplexer (right side). The parts are fabricated using plastic injection molding.

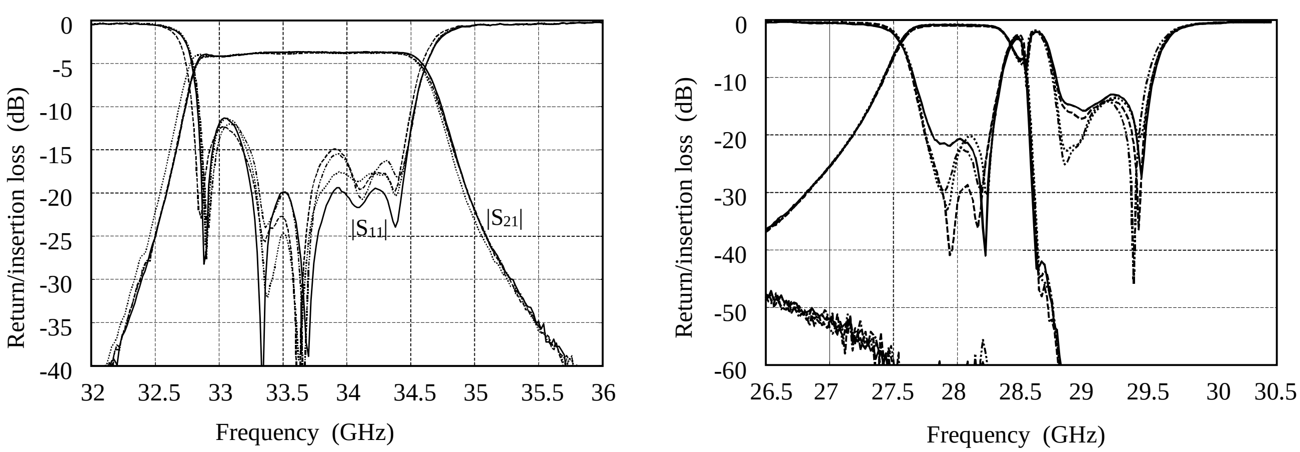

Fig. 9: Return and insertion loss of one LO filters (left) and of the diplexer. Four different blocks each were tested and compared.

Acknowledgement

Part of this work was funded by the German Ministry of Research under contract no. 16 SV 420/1.

References

[1] Daembkes, H., Luy, J. F.: Millimetrewave components and systems for automotive applications. Microwave Engineering Europe (Dec.-Jan. 96), 43 - 48.

[2] Meinel, H.: Recent advances on millimeterwave PCN system development in Europe. IEEE Intern. Microwave Symposium MTT-S (1995), Orlando, pp. 401 – 404.

[3] Berson, B.: Strategies for microwave and millimeter wave packaging today. IEPS, Proc. Of the tech. Program, 9th Annual Intern. Electronics Packaging Conf., San Diego, USA, 1989, Vol. 1, 697 - 720.

[4] Bierman, H.: Designers strive for low cost packages. Microw. J., Sept. 1992, 100 – 106.

[5] Boheim, M., Goebel, U.: Low Cost Packages for Micro- and Millimeterwave Circuits. 24th European Microw. Conf., 1994, Cannes, France, 122 - 132.

[6] Nagy, C. et al.: Advanced Manufacturing and Packaging Technologies for Military and Commercial Markets. Microw. J., Aug. 1995, 22 - 36.

[7] Reichel, H.: Packaging aspects of single and multichip modules. EuPac '94, 1st European Conference on Electronic Packaging Technology & 7th Intern. Conf. on Interconnection Technology in Electronics, 1994, pp. 6 - 9.

[8] Felton, L. M.: High yield GaAs Flip-Chip MMICs Lead to Low Cost T/R Modules. IEEE Intern. Microw. Symp. MTT-S, 1994, San Diego, USA, 1707 - 1710.

[9] Menzel, W.: Packaging and interconnects for millimeter wave circuits: a review. "Annales de Télécommunications", France, Vol. 52 (1997), No. 3 - 4, pp. 145 - 154.

[10] Menzel, W.: Interconnects and packaging for MMIC's. 27th European Microw. Conf., 1997, Jerusalem, pp. 649 - 654.

[11] Brown, R. L., Polinski, P. W., Shaikh, A. S.: Manufacturing of microwave modules using a low-temperature cofired ceramics. IEEE Intern. Microw. Symp. MTT-S, 1994, San Diego, 1727 - 1730.

[12] Menzel, W., Alessandri, F., Plattner, A., Bornemann, J.: Planar integrated waveguide diplexer for low-loss millimeter-wave applications. 27th European Microw. Conf., 1997, Jerusalem, pp. 676 - 680.

[13] Kassner, J., Menzel, W.: An electromagnetically coupled package feed-through structure for multilayer carrier substrates. 28th Europ. Microw. Conf., 1998, Amsterdam, Vol. 2, pp. 428 – 432.

[14] Grabherr, W.; Huder, B.; Menzel, W.: Microstrip to waveguide transition compatible with mm-wave integrated circuits. IEEE Trans. on MTT, September 1994, 1842-1843.

[15] Thiel, W., Menzel, W.: An efficient FDTD analysis of a waveguide-to-microstrip transition. 28th Europ. Microw. Conf., 1998, Amsterdam, Vol. 2, pp. 576 – 580.

[16] Rittweger, M.: 2nd Report of the research program of the German Ministry of Research "System Technologies for Micro- and Millimeter Wave Circuits" (in German), Contract No. 13 MV 0218.

[17] Strauß, G., Menzel, W.: Millimeter-Wave Monolithic Integrated Circuit Interconnects Using Electromagnetic Field Coupling. IEEE Trans. on Components, Packaging, and Manufacturing Technology - Part B, vol. 19, No. 2, May 1996, pp. 278 - 282.

[18] Strauß, G., Ehret, P., Menzel, W.: On-Wafer Measurements of Microstrip Based MIMICs without Via Holes. IEEE Intern. Microw. Symp. MTT-S 1996, San Francisco, 1399 - 1402.

[19] Kassner, J., Menzel, W., Waidmann, S.: New results on electromagnetic field coupling for mm-wave interconnects. PIERS'98, Nantes, France, Conf. Proceed. p. 484.

[20] Menzel, W., Kassner, J., Goebel, U.: Innovative Packaging and Fabrication Concept for a 28 GHz Communication Front-End (Invited). IEICE Transactions on Electronics – C, Japan, Special Issue on "High-Frequency/ High-Speed Devices for Information and Communication Systems to Support 2K Society", Vol. E82-C, No. 11 (Nov. 1999), pp. 2021 – 2028.

[21] Baggen, L. C. J., Simon, W., Goebel, U.: Antenna Design for a mm-Wave Communication Module. European Microwave Conf. 1999, Munich, Germany, Workshop on "Multifunctional Microwave and Millimetre Wave Modules".

[22] W. Simon, R. Kulke, A. Wien, I. Wolff, S. Baker, R. Powell and M. Harrison: Design of Passive Components for K-Band Communication Modules in LTCC Environment. IMAPS Symposium, Chicago, October 1999, pp. 183-188.