MILLIMETER-WAVE 3D INTEGRATION TECHNIQUES USING LTCC AND RELATED MULTILAYER CIRCUITS

Wolfgang Menzel, Jürgen Kassner*

University of Ulm, Microwave Techniques, D-89069 Ulm, Germany
* now with IMST, D-47475 Kamp-Lintfort, Germany

Abstract - **LTCC, HTCC, and similar sandwiched substrate structures provide the basis for high-density 3D integration and packaging of microwave and mm-wave circuits. Such multilayer substrates serve, at the same time, as carrier substrates for MIMICs and as a medium for high-density hybrid circuits which can be realized in a manifold of transmission line types in different substrate layers and combinations of these, coupled directly or via the electromagnetic field. This contribution will address a number of aspects of such substrates, especially for mm-wave applications, and it will provide two examples of realized circuit elements and components. One is a multilayer electro-magnetically coupled feed-through structure into a package on top of the multilayer substrate, the other one a band pass filter in a mixed alumina - LTCC layer system to cope with the tolerance requirements of mm-wave filters in a standard production LTCC environment.**

I. INTRODUCTION

The need for increased integration density and reduction of fabrication cost for military, space, and commercial applications has strongly pushed the development of combining a number of MMICs and hybrid circuits (multi-chip modules, MCM) on multilayer substrates [1] – [5]. Besides laminated assemblies of soft substrates or multi-layer thin film circuits, low temperature and high temperature cofired ceramics (LTCC and HTCC, respectively) seem to become favorite solutions for MCMs. LTCC consists of ceramic powder sintered in a glass matrix at temperatures as low as 850°C, while HTCC mostly is based on standard ceramic materials (e.g. Al_2O_3 or AlN) sintered directly at much higher temperatures (1600°C). As a consequence, good conductor materials, even silver or gold, can be used for the (inner) conductors. Due to the glass matrix, however, thermal conductivity is decreased. For HTCC circuits, metals with high melting temperatures (like tungsten) have to be used as inner conductors, resulting in increased losses. On the other hand, the high thermal conductivity of AlN, for example, is maintained, resulting in excellent thermal management for high power applications.

Metallization layers typically are applied by screen printing on the green tape. Together with the shrinking of the material during sintering, this mostly leads to some restrictions in dimensional accuracy.

Multilayer substrates can both carry other circuits like MMICs placed on top [7] - [9], and (mostly passive) hybrid structures can be integrated in the different substrate layers [4], [5]. A high degree of flexibility exists due to the possibility of integrating different types of transmission line including waveguide ([6], Fig. 1), with different types of transitions, and different ground plane levels separating different parts of the overall circuit.

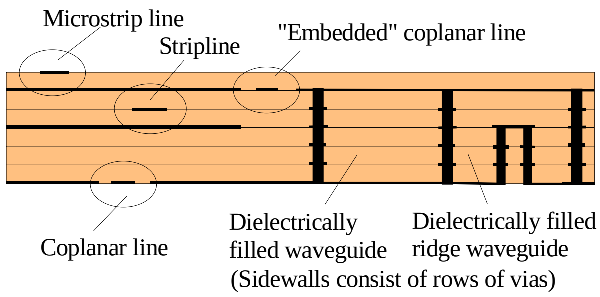

Fig. 1: Cross section of a multi-layer substrate with different types of transmission lines.

With increasing maturity and precision of this technique, its application now is pushed even up to the higher mm-wave range [6], [9], [10].

This contribution will demonstrate two examples of (simple) circuit structures - transitions between different circuit layers, e.g. as package feed-through elements. It will, at the same time, show a present limit of standard low-cost LTCC techniques for mm-wave filter design due to tolerance problems, but it demonstrates a suitable and effective solution to this problem.

II. TRANSITIONS BETWEEN DIFFERENT METALLIZATION LEVELS

Transitions between the different conductor layers are major circuit elements within a multilayer structure. For example, a combination of two of them can be used as a feed-through element into and out of a package. Two typical structures of this type are shown in Fig. 2.

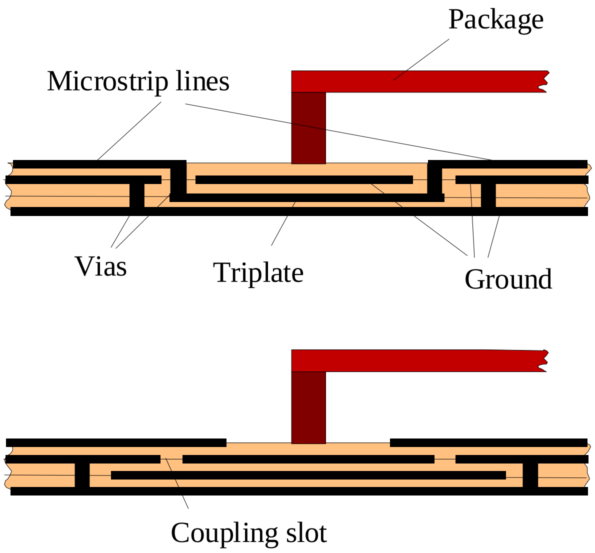

Fig. 2: Cross sections of two possible feed-through structures using multilayer substrates.

In the top structure, galvanic coupling is applied, while electromagnetic coupling through a slot is chosen for the example on the bottom. Electromagnetic coupling may be of interest if an inherent DC isolation is required, or if the top substrate must not be perforated with respect to hermeticity. In both structures, vias are required around the transitions to suppress parallel plate modes between the ground plane layers above and below the stripline. An example of a galvanically coupled transition from coplanar line to stripline and back and its results are given in Fig. 3, [5]. The design for this is done using a 3D field simulators, in this case FDTD. Although this structure is relatively large, good results were achieved up to 25 GHz; better results are possible with reduced transmission line and slot dimensions.

The second example uses electromagnetic field coupling from a microstrip line to a stripline and back [9], [10]. Its design and optimization, too, were done using FDTD calculations. Due to the electromagnetic coupling, it exhibits a band pass characteristic.

A standard and a X-ray photograph of this structure and the results realized on a LTCC substrate are displayed in Fig. 4 and 5, respectively.

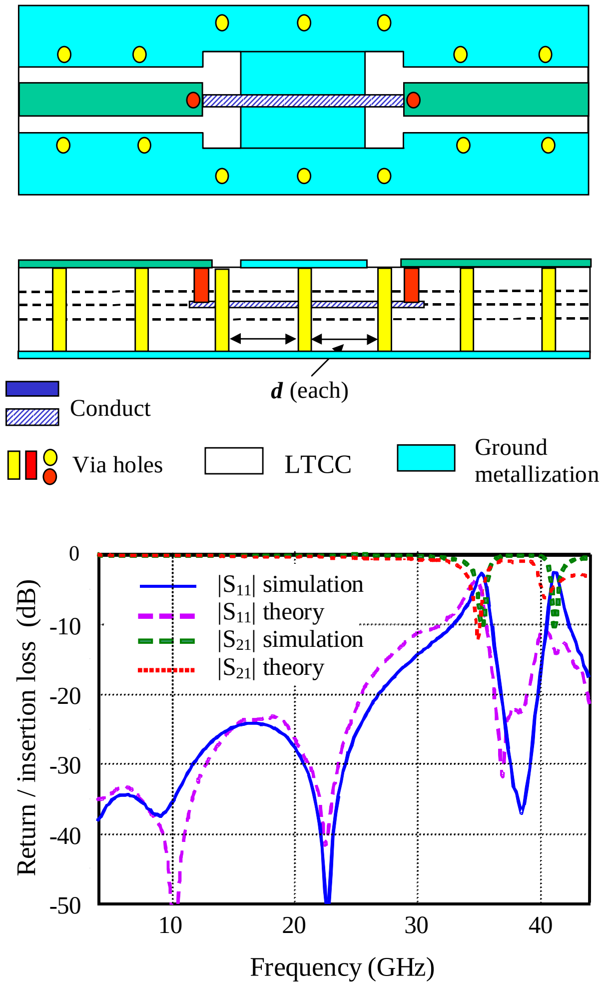

Fig. 3: Structure and scattering parameters of two transitions from coplanar line to stripline and back (courtesy of IMST, Kamp-Lintfort, Germany. Four layer Ferro substrate; fired layer thickness: top & bottom : 185 µm, inside : 2 × 93 µm; ε_r = 5.9; coplanar line width 400 µm, slot width 125 µm; stripline width 203 µm).

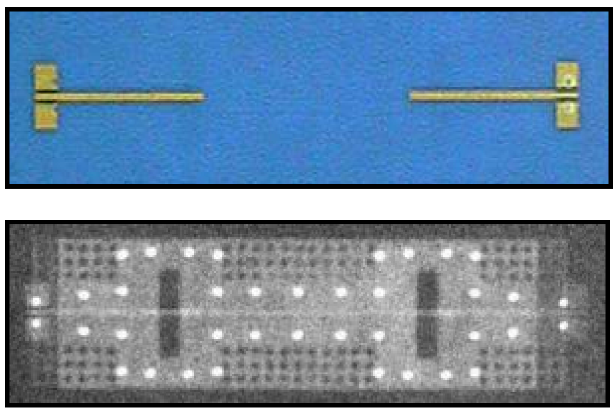

Fig. 4: Standard and X-ray photograph of an electromagnetically coupled feed-through structure.

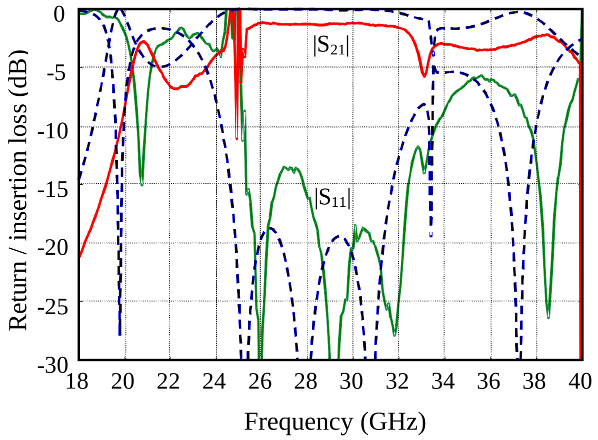

Fig. 5: Scattering parameters of an electromagnetically coupled feed-through structure (dashed lines: theory, solid lines: experiment).

III. DROP-ON BAND PASS FILTER

Within a communication front-end [10], a band pass filter for the 30 GHz was required integrated on a LTCC substrate. Several designs were made and investigated with respect to the tolerances of the available LTCC technology; the required accuracy of around or better than 10 µm could not be achieved. As a consequence, a different solution was proposed and tested [11]. The filter was fabricated on a small alumina substrate with its tight tolerances and placed on top of the LTCC substrate. To avoid a critical placing and gluing process, a two-step electromagnetic field coupling was selected. The filter coupling was done between strips on the top and bottom side of the alumina substrate. These can be aligned quite precisely. Following this, another broad-band quarter-wave coupling was used between the connecting lines of alumina and LTCC substrate, separated by a non-conductive epoxy of about 10 µm thickness (Fig. 6). The ground planes of both substrates, again, were coupled only by the electromagnetic field. In this way, placing tolerances of 30 µm or even more can be tolerated. Fig. 7 shows a photograph, and Fig. 8 the results of this filter. In such a way, an accurate fabrication process can be combined with the advantages of low cost multilayer substrates.

IV. CONCLUSION

In this contribution, some properties of multilayer circuits have been presented. With respect to an application in the mm-wave range, some passive structures have been investigated. While interconnects between different metallization layers can easily be realized both with vias and electromagnetic coupling up to higher frequencies, problems occur with filters due to the strict tolerance requirements associated with this

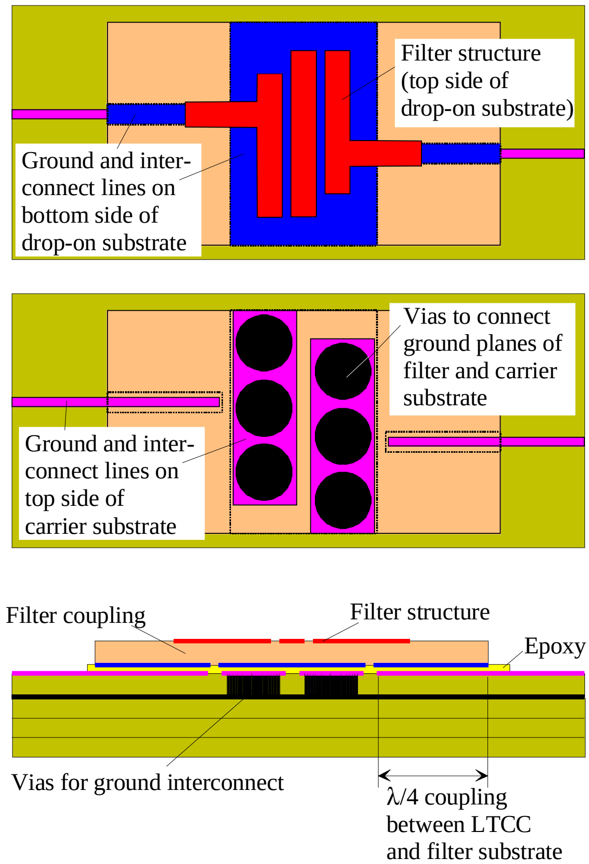

Fig. 6: Basic principle of the drop-on filter.

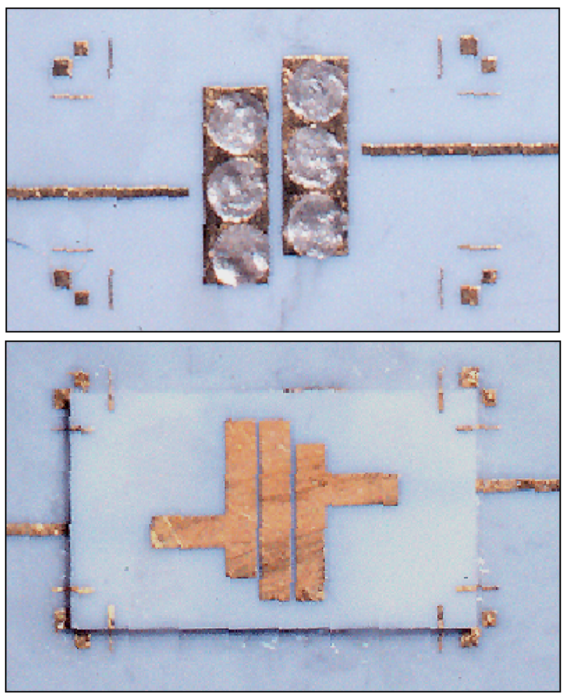

Fig. 7: Photographs of carrier substrate structures and filter substrate placed on top of the carrier substrate (for this test, alumina was used for the carrier substrate).

application. As an alternative solution, such a filter can be built on a separate alumina substrate, simply glue on top of the LTCC substrate, and the coupling can be performed via the electromagnetic field. With the special coupling technique as described in this paper, large tolerances can be allowed for circuit placement.

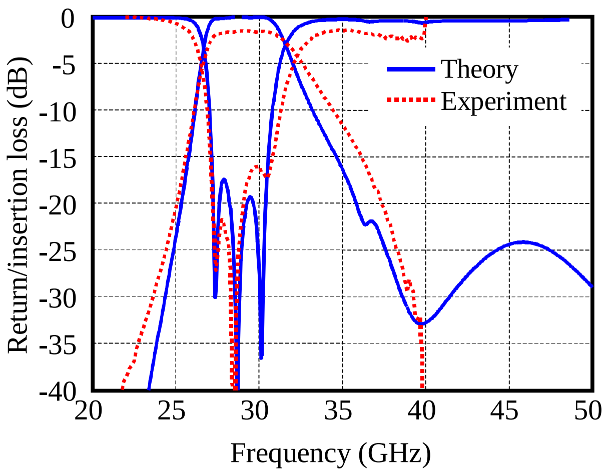

Fig. 8: Theoretical and experimental performance of the drop-on filter.

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