Design of Passive Components for K-Band Communication Modules in LTCC Environment

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Abstract

The ongoing development of LTCC materials and multilayer processes are making this technology more and more attractive for use in the manufacture of microwave multichip modules. However, prior to the manufacture of modules, the high frequency behavior of the passive RF components needs to be investigated to determine the performance limitations due to the manufacturing process. The aim of this paper is to give solutions for waveguides and transitions that can be applied in the packaging of a 24 GHz communication link module. The passive components have been designed with the assistance of 3D electromagnetic field simulations using a Finite Difference Time Domain technique. Several types of transitions from the top of the LTCC to an inner layer and back to the top, which are used for the feeding of hermetic sealed packages, are considered. These activities are supported by the European community through the Brite-Euram project RAMP[1]

1 Introduction

Multilayer LTCC substrates offer the opportunity to manufacture compact, low cost, high volume, modules for a wide range of micro-wave applications since they combine well established screen printing techniques with multilayer ceramic lamination and low firing temperatures. This enables the integration of other materials to realize passive components such as resistors, and capacitors to provide increased functionality within a given volume. Two drawbacks for radio frequency and power applications are the low thermal conductivity of the ceramic tape and the materials and fabrication processes, which in the past have limited this technology to the lower GHz-frequency range [1]. Improved material and fabrication capabilities are currently under development and are being investigated by a European consortium in the Brite-Euram project RAMP[1]. The goal of the project is to demonstrate the improved capabilities of LTCC technology for radio frequency and power applications. This paper will publish results of transitions and feedthroughs that have been investigated for use in hermetic sealed packages. The test components have been designed for use in a 24 GHz point to multipoint wireless communication module.

2 Transition Analysis

High performance RF transitions are a key requirement for multichip modules. The applications include routing an RF signal through a ceramic wall either from an external circuit or between cavities that contain MMIC devices within a module. Another application is to route the signal from the top surface

[1] RAMP: "Rapid Manufacture of Microwave and Power Modules", BE-97-4883

to an inner layer or to the bottom surface. This allows the placement of a MMIC in a cavity on the bottom side of the substrate or the placement of planar circuits in an inner layer. The RF performance of the transitions has been investigated for various transmission line types and feedthrough geometries. The results of simulations, measurements and a tolerance analysis are presented.

2.1 Design

The design of the transitions has been performed with the aid of a 3D electromagnetic field simulator. This is necessary so that the 3D coupling effects between the via holes and conductors in different layers are included in the simulation. The simulation program Empire^{TM} [2] has been used. This is based on the Finite Difference Time Domain (FDTD) method [3] and allows the efficient simulation of large multilayer ceramic structures [4].

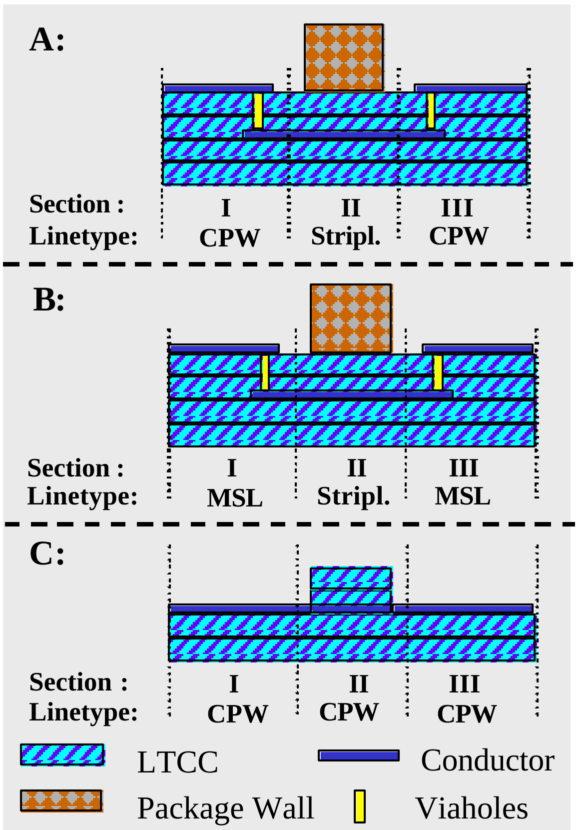

Fig. 1: Cross view of transition A, B and C.

Three transition types have been investigated. In transition types A and B the conducting lines are routed from a top layer to an inner layer with metal filled via holes. This routing is depicted in Section I of figure 1. In section II the lines are located in the inner layer so that a package wall can be placed on top of the substrate. This wall can either be part of a metal seal ring or a multilayer frame fabricated with LTCC tapes. To form a feedthrough the lines are routed back to the top surface in section III. Alternatively, in this section, the signal could have been routed to the bottom of the substrate using a similar transition.

In transition type C the conductors forming the waveguides are in the same layer. This has the advantage enabling lower reflections at the input port to be obtained as is demonstrated by the simulation results reported in Section 2.4. For this type of transition the package wall in section II must be comprised of ceramic layers, since a metal wall would short the conducting lines.

Either Coplanar waveguides or microstrip lines have been used in sections I and III. In section II coplanar waveguides and striplines have been chosen.

A transition of type A with a coplanar waveguide in sections I and III and with a stripline in section II has been designed and optimized with the 3D-FDTD field solver. The optimization aim was to achieve reflections below -15dB up to a frequency of 30GHz. The transition consists of a 4 layer substrate designed using the Ferro A6M system. The fired thickness between the central stripline conductor and the top and bottom conductors is 267 µm. The design uses two different ceramic layer thicknesses of approximately 93 µm and 185 µm to improve the fabrication process. Figure 2 shows a top and cross view of the optimized transition.

The top and bottom grounds are connected by via holes and catch pad fences. The transition from the center line of the coplanar waveguide to the stripline is also realized by a filled viahole. To obtain the optimum broadband RF performance in a frequency band from DC to about 35 GHz, a number of parameters had to be optimized. The first parameter is the distance between ground and signal via holes.

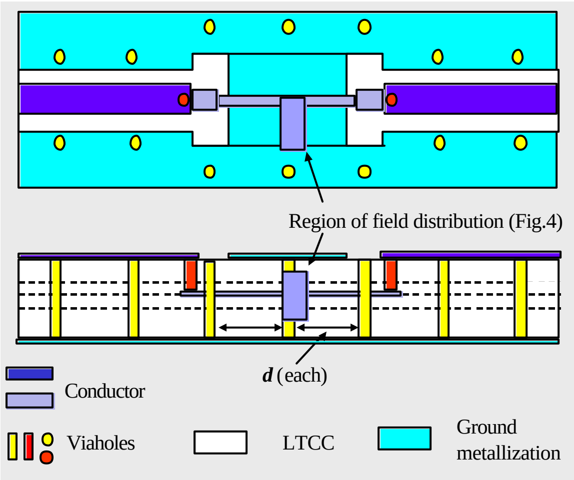

Fig. 2: Top and cross view of CPW to stripline transition.

It could be shown that via holes, which are placed too close to the signal line impair the electric performance. This could be improved by moving these via holes from the region of the stripline to the border. The distance ***d*** between the via holes for shielding and ground contact (see Fig. 2) causes a resonance around 30 GHz, also impairing the electric performance. By reducing the distance ***d*,** the resonance is shifted up to 35 GHz. A matching step in the line width of the coplanar center line was found to be un-necessary to improve the performance of the transition, since to provide compensation of the viahole inductance, the ground plane has been modified at the end of the coplanar waveguide on top of the substrate. The dimensions ***a*** and ***b*** have been chosen for optimization (see Fig. 3).

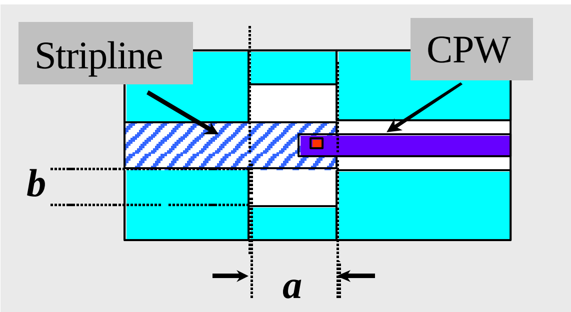

Fig. 3: Optimization parameters.

The effect of this compensation can be seen in the field distributions in the vicinity of the triplate line. Figures 4 and 5 show the electric field at 25 GHz before and after optimization.

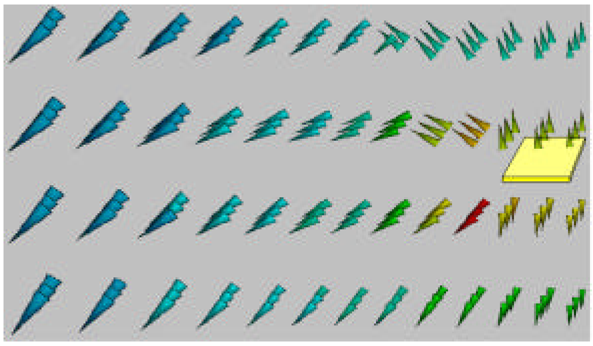

Fig. 4: Electric field before optimization.

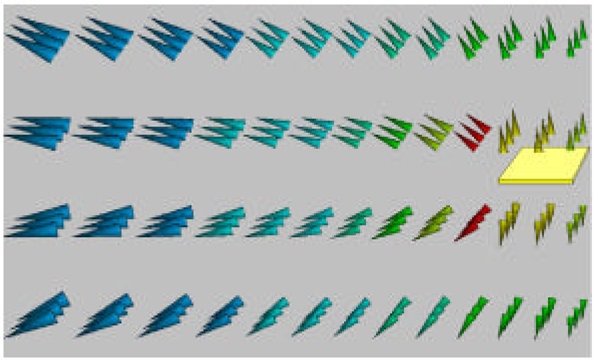

Fig. 5: Electric field after optimization.

On the left side in figure 4 it can be seen, that a significant component of the undesirable unsymmetrical mode is excited. Due to the compensation of the viahole inductance by optimization a high purity symmetric mode is achieved (Fig. 5).

2.2 Tolerance Analysis

The transitions have been manufactured at Sorep-Erulec in France using a 4 layer Ferro substrate with gold metallization on top and silver metallization inside. In the manufacturing process the "green" dielectric tape is first cut into blanks for each of the layers. The via´s are punched in these blanks and filled with ink. This is followed by screen printing of the conductors. The printed blanks are collated, laminated and then cofired at a temperature of about 850°C.

To investigate the production accuracy the dimensions of the structures on the top surface have been measured and compared with the layout data. The measurements have been made on two LTCC substrates to obtain information about their reproducibility.

The 50 Ohm coplanar waveguide should have a 400µm width center line and a 125µm width gap to the ground. The measured center line width differed about ± 10µm (~ ± 2%) and the gap differed between +2 µm to + 10 µm (~ + 1% to + 8%). The differences have been the same on both LTCC´s. Another important region for the design is the gap in the ground plane at the end of the coplanar waveguide (Fig.3). The dimensions ***a*** and ***b*** have been matched with a very good accuracy of - 0.6% to + 4% for ***a*** and ± 1.6% for ***b***. The position of all via holes is very precise. The distance ***d*** between the via holes at the border (see Fig. 2) fits with an accuracy of -.2% to + 0.8%. To obtain an impression about the geometry of the alignment, a comparison of the position of the structures between the fabricated waver and the layout data has been made. In x-direction a distance of 50 mm was matched with an accuracy below +0.5% (+ 170µm) and in y-direction a distance of 24 mm agrees with an accuracy below +0.4% (+104µm). These results show that the shrinkage of the ceramic during the firing process has been predicted with a good reliability and that the reproducibility is high.

Figure 6 shows a zoomed photo of one manufactured transition. It is evident that the gold metallization of the conductors have a constant width and a smooth surface. Only the via holes extend at the top surface.

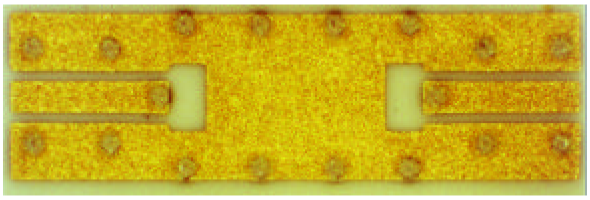

Fig. 6: Photo of the CPW to Stripline transition.

These results show that it is possible to produce circuits using LTCC with a close agreement between the designed and manufactured dimensions. This is a fundamental requirement for RF-applications. The comparison of electrical measurements vs. simulation in the next section supports these results.

2.3 Comparison Measurement vs. Simulation

The electrical measurements were made using 450µm pitch RF probes (GGB industries), a HP8510 Network Analyzer and a SOLT calibration technique.

A comparison between the measured and calculated scattering parameters is given in figure 7. The simulation results and measurements correspond well with each other. The return loss is below -20 dB in simulation and measurement up to 25 GHz. The insertion loss is better than -1 dB up to 30GHz. The usable frequency range can be increased further by reducing the distance ***d*** of the outside via holes (see Fig 2). These results, together with the accuracy achieved in the manufacturing process, indicate that it should be possible to realize microwave transitions using LTCC to frequencies of at least 35GHz. A 3D simulation tool is essential for the development of such designs. The prediction of the resonance at 35 GHz and the agreement between simulation and measurement show the performance of the applied simulation tool.

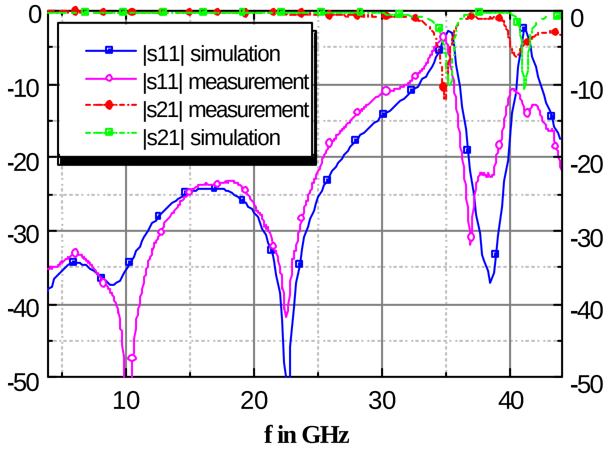

Fig. 7: Comparison from the scattering parameters of the CPW to Stripline transition.

2.4 Simulation results for further transitions

Following on from the design of transition type A a microstrip line to coplanar waveguide transition (type B) and a coplanar waveguide to coplanar waveguide transition (type C) have been designed (see Fig. 1). For the microstrip line to coplanar waveguide transition the linetypes were first matched in their respective layers to 50 Ohms. This was achieved by reducing the center conductor width of the coplanar waveguide in the inner layer. To optimise the performance of the transition the ground plane at the end of the coplanar waveguide, in the inner layer, has been modified in a similar manner to that used in transition type A. The simulation results in figure 8 show that an excellent performance is achieved Up to 45 GHz the reflection is below -15 dB and up to 34 GHz it is below -20dB. The transmission losses are below 0.5 dB up to 45 GHz.

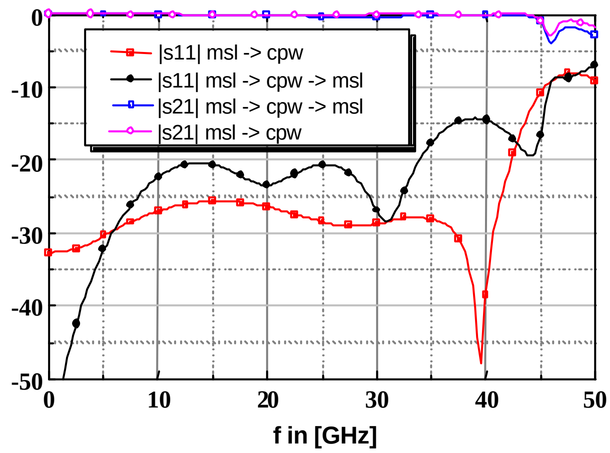

Fig. 8: Simulation results for microstripline to CPW transition and feedthroughs.

For the coplanar waveguide to coplanar waveguide transition (Type C) the width of the center conductor has been reduced in section II. This was necessary due to an increased effective permittivity caused by the ceramic wall above the coplanar waveguide. As the location of the centre line width step was used to optimise the performance of the transition.

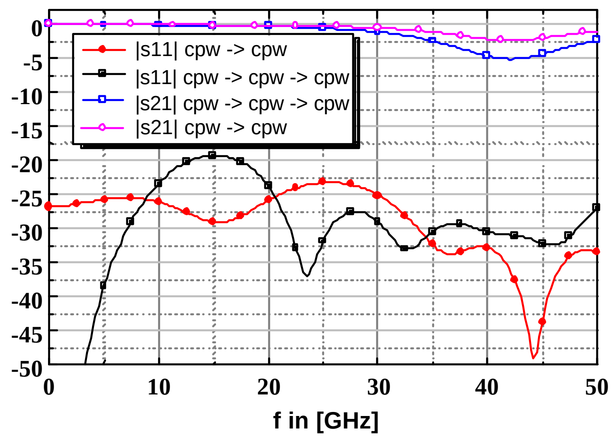

Fig. 9: Simulation results for CPW to CPW transition and feedthrough.

In Figure 9 the simulation results for the optimized transition and feedthrough are depicted. The reflection is below -20 dB for frequencies up to 50

GHz. The transmission losses are below 0.5 dB up to 30 GHz and below 5dB up to 50 GHz.

These designs show that it is possible to develop transitions to an inner layer and feedthroughs under a package wall using different transmission lines. The simulations show that the best results are achieved if the ground plane stays in the same plane and only the signal line is routed to another layer.

3 Conclusion

Several transitions and feedthroughs for LTCCs have been presented using common transmission line geometries. The designs have been produced with the aid of a 3D field solver and verified by measurements. A comparison between the simulated and. the measurement data shows that the 3D field solver is a suitable tool for designing passive multilayer structures. Good dimensional accuracy was achieved in the manufacturing process. This work indicates that it may be possible to produce transitions for frequencies up to 50 GHz.

The transitions and feedthroughs that have been presented are fundamental to the manufacture of communication modules. They enable RF signals to be routed into hermetic sealed packages, the creation of circuits within the internal LTCC layers and the distribution of RF signals between MMICs placed in cavities within the LTCC.

4 Acknowledgements

The authors wish to thank the European Commission for supporting these activities financially, as well as the other partners of the project consortium for the excellent co-operation, the helpful discussions and ideas as well as their competent advising in solving several problems. Special acknowledgement is given to Jean-Pierre Bertinet and Arnaud Girard from Sorep-Erulec in France, who have fabricated the designs with great success.

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