A Novel Approach for LTCC Packaging Using a PBG Structure for Shielding and Package Mode Suppression

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Abstract — **A packaging solution for multifunctional modules up to an operating frequency of 50 GHz based on Low Temperature Cofired Ceramics (LTCC) is presented in this paper. A Ball Grid Array (BGA) as well as a Land Grid Array (LGA) transition from Printed Circuit Board (PCB) into a surface mounted module are proposed. They use a Photonic Bandgap (PBG) structure to suppress the excitation of parasitic modes e.g. by the SMT interconnect. This approach provides process tolerant transitions as well as it allows the integration of wave guide structures in buried layers. This measure provides a greater flexibility in the design of microwave circuits and a major potential for miniaturisation of microwave subsystems.**

I. Introduction

LTCC has become an attractive solution for packaging of microwave circuits. On one hand LTCC provides a reasonably low loss, low cost ceramic substrate as a carrier for the passive and active devices. On the other hand the multilayer ceramics add some functionality to the package as it can contain the bias networks for the active devices or even passive wave guide structures like filters implemented in the buried layers. The LTCC thus forms a compact multifunctional module which can be processed in a standard SMT assembly. This packaging technology is particularly suited for low volume system on a package (SOP) solutions with short time to market requirement.

One major issue in context with this kind of modules is the excitation of package modes. Their excitation in many situations can't be avoided even by applying via fences to a great excess. The excitation of unwanted modes is strongest at discontinuities and at vertical connections between the different layers of the package which also holds for the PCB-to-LTCC interface and the transition from the bottom layer to the top layer across the entire module.

Hence a big effort is done to suppress these modes by avoiding discontinuities and thus avoiding the excitation of spurious modes. This measure strongly limits the design features which can be used in a module design. The approach presented in this paper is based on using a PBG structure inside the cavity, forming a kind of bandstop filter at the frequency of operation.

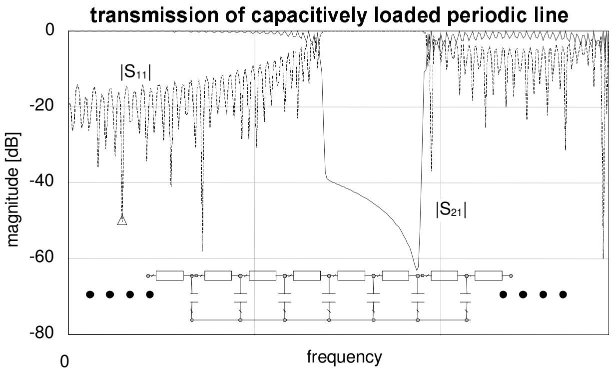

Fig. 1. A transmission line periodicaly loaded with capacitors as a one dimenssional PBG structure

II. PBG for Parallel Plate Mode Suppression

Structures with periodic variation in electric parameters are known to exhibit bandgap behaviour. This means, that for certain frequency bands and modes, waves become evanescent and thus the structure exhibits bandstop characteristic.

For calculation of such configurations, methods based on Bloch's Theorem are often chosen and can provide insight in many properties of periodic structures [1]. The persistent interest in photonic structures has driven the development of methods suitable for their analysis [2], [3],[4].

A simple, one-dimensional model of a photonic structure is given by a transmission line periodicaly loaded by capacitors as depicted in Fig. 1. As long as the distance between the capacitors compares small to the wavelength, they will simply contribute to the distributed capacitance of the line and slightly change its wave impedance. However, when it comes to line lengths in the order of half a wavelength, then waves scattered in backward direction exhibit constructive interference and wave propagation cannot occur as the simulated transmission and the reflection in Fig. 1 indicate. This effect also occurs in the structures presented and is applied to suppress parallel plate modes otherwise excited between the ground planes of buried layers in LTCC modules.

Unlike the one-dimensional PBG structure of Fig. 1 in a LTCC module a two-dimensional square grid of via

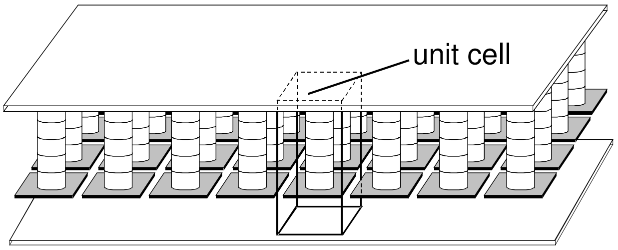

Fig. 2. The proposed PBG and its elementary cell

stacks as shown in Fig. 2 is introduced which can conveniently be implemented in all common manufacturing processes.

In order to calculate field patterns for the structure, usually 3D full wave simulators are used. In this case however primarily the upper and lower bounds of wave suppression are of interest. To evaluate the propagating modes of the structure an eigenmode analysis is performed. This is done by solving a particular eigenvalue problem of a unit cell as depicted in Fig. 2. In transverse direction of the unit cell magnetic boundaries apply. In longitudinal direction the electromagnetic fields at the boundary are periodic with a constant phase factor between the two longitudinal boundaries of the cell.

The solution of the eigenvalue problem yields the dependency for the dispersion relation and reveals that at an operating frequency of up to 50 GHz the TM_0- and TM_1-like modes are the lowest parasitic modes which can be excited in the structure.

Fig. 3 shows the dispersion relation of all modes within the photonic structure. As the simulation shows there exists a band where no wave propagation is possible. Since no propagating mode exists within the marked area, it is a full bandgap.

To demonstrate the capabilities of a PBG structure LTCC modules were designed which contain a module-to-PCB interface, a vertical transition from the interface to the top layer and a transition to a transmission line on or in the top layer respectively. One module approach is based on a BGA footprint, a second one is based on a LGA footprint. Both approaches are commonly used in Surface Mount Technology (SMT) manufacture and offer

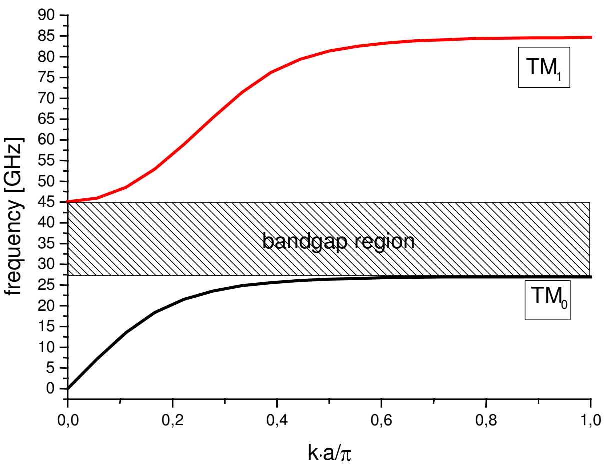

Fig. 3. Dispersion relation of relevant modes

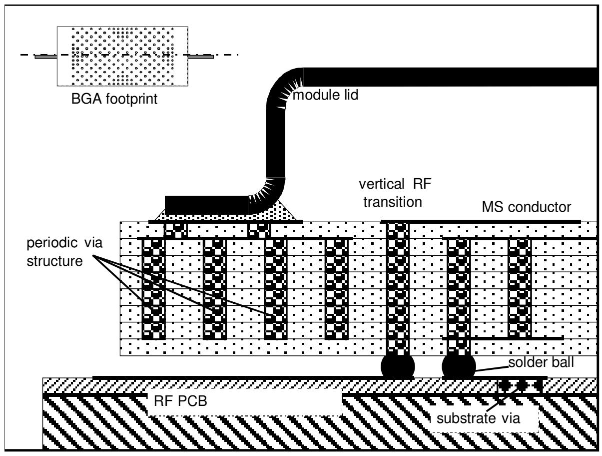

Fig. 4. Cross section of the transition and footprint of the BGA module.

distinct advantages: The BGA connection is considered to be more reliable for larger module outlines than the LGA transition in terms of thermal cycling. On the other hand the LGA fits better to the commonly used SMT manufacture and it avoids the process of printing or placing solder balls on the ceramic but can be applied only for modules with smaller outlines.

III. THE BGA TRANSITION

In a BGA the electrical connection is formed by solder balls between the module and the PCB. The solder balls are easily applied to the ceramic module e.g. by stencil printing. Fig. 4 shows the cross section of the BGA transition. A Microstrip (MS) line is used as the waveguide on the PCB as well as on the top layer of the module.

The vertical transition is formed by semi-coaxially arranged conductors where the outer conductors provide the shielding of the electromagnetic fields in the vicinity of the discontinuity of the module to PCB transition and towards the modules inner circuitry. The shielding is connected to the PCB ground by PCB vias. For a frequency of operation up to 50 GHz a 500 µm pitch for the BGA and the vertical conductors was chosen.

In order to provide the area for the footprint of the module lid on the top layer a wide overlap of the module

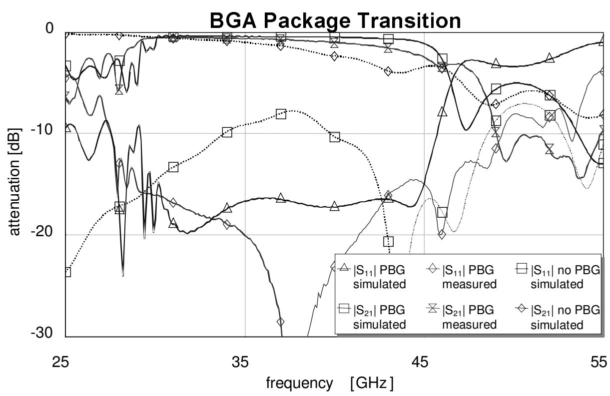

Fig. 5. Simulated and measured performance of the BGA transition.

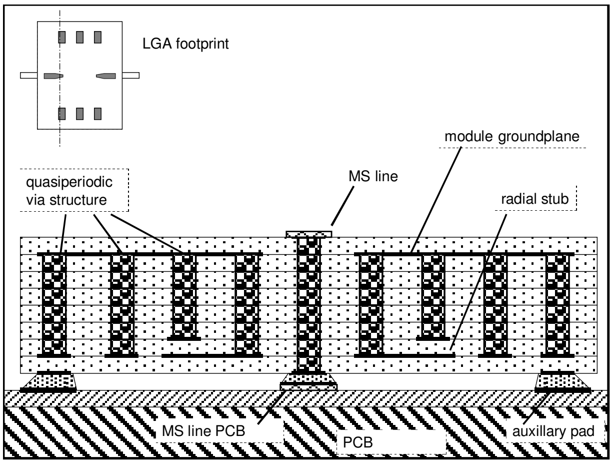

Fig. 6. Cross section of the transition and footprint of the LGA module

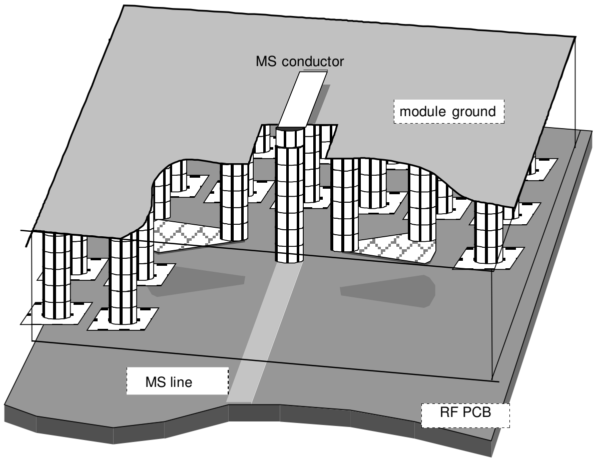

Fig. 8. Vertical transition of the LGA

over the substrate results. In this part the module ground plane and the carrier ground plane face each other and parallel plate modes can be excited. Hence measures are in inevitable to suppress the occurrence of these modes and to provide shielding against the radiation into the module. A novel approach to achieve this is by using a PBG structure similar as published in [5] in this area of the module.

The actual dimensions of the measured BGA device were 9 x 15 mm^2 with an overlap of 1.4 mm. The simulated and measured transmission and reflection characteristics of the transition are shown in Fig. 5. As can be seen from the comparison between the simulation of the transition with and without PBG the transmission of the transition is improved by 4 dB at 44 GHz. The measured insertion loss of 0.9 dB at 40 GHz is slightly higher than simulated. This is due to the fact that the simulation was performed for a lossless device.

IV. LGA TRANSITION

In case of the LGA the interconnects are established by metallised pads on the bottom of the module to a corresponding land structure on the PCB. In order to relax the manufacturing requirements a footprint pitch of

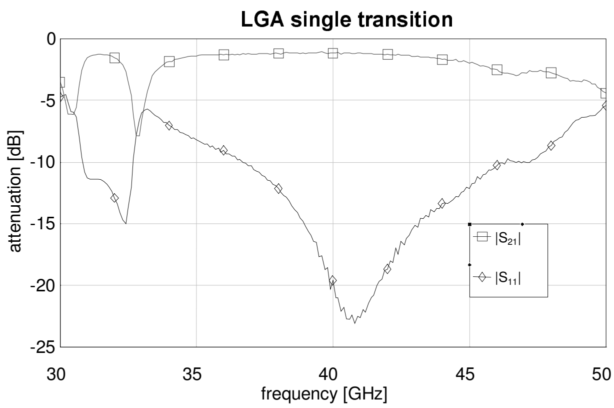

Fig. 7. Measured transmission an reflection of the LGA transition

at least 1 mm between signal and ground at the module-to-PCB transition is desirable. A pitch of this size is too large for single mode operation up to 50 GHz. Hence a novel interconnect structure is proposed that eliminates soldered ground pads entirely and the necessity of shielding measures as in the footprint of Fig. 4.

As shown in Fig. 8 in the novel footprint the vertical transition is formed as a coplanar waveguide. Only the signal line is soldered to the MS line on the PCB. The ground conductors of the vertical transition are field coupled to the MS ground by radial stubs. Hence the footprint is much more relaxed in terms of shortening the signal conductor to ground and it also avoids the need for vias in the PCB. A similar approach is described in [6].

Due to the open coplanar structure and the radial stubs, parallel plate modes are strongly excited within the module. Hence the PBG structure in this transition is inevitable to suppress these modes in the LTCC.

Fig. 7 shows the transmission and reflection characteristics of the LGA transition. The flat transmission characteristic indicates that moding in the device is effectively suppressed. The insertion loss of a single transition is 1.1 dB at 40 GHz and hence slightly higher than the loss of the BGA. The actual manufactured device is 8 x 7 mm^2 in size which is considered to be the maximum acceptable size in terms of reliability.

Though both transitions become band limited by introducing the PBGs the achieved bandwidth of more than 10 GHz is sufficient for a large class of applications up to 50 GHz.

CONCLUSION

A novel method for shielding and suppressing moding in multilayer packages such as LTCC has been described. The proposed PBG structure enables the design of transitions from PCB to the top layer of the module without exciting resonances within the LTCC. It also enables a novel type of LTCC-to-PCB transition which does not use ground pads and ground connections. They are substituted by submerged radial stubs which relaxes greatly the manufacturing requirements.

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