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A Drop-On Band-Pass Filter for Millimeter-Wave Multichip Modules on LTCC

Juergen Kassner and Wolfgang Menzel, *Senior Member, IEEE*

Abstract—Low-temperature cofired ceramic (LTCC) is increasingly used to realize multichip modules (MCM's), even in the millimeter (mm)-wave frequency range. Fabrication tolerances of standard LTCC structures, however, still are limiting the performance of band-pass filters integrated directly on the LTCC substrate. This contribution therefore describes the design and the performance of a separate filter chip based on alumina which simply is placed on top and glued to the LTCC substrate using nonconductive epoxy. A special electromagnetic field coupling is used to provide both the interconnect of signal lines and filter ground. The design includes special measures to reduce the tolerance requirement for filter placement and glue thickness.

Index Terms— Electromagnetic coupling, microstrip filters, multilayer circuits, multichip modules.

I. INTRODUCTION

COMPLEX microwave and millimeter (mm)-wave front-ends including a number of monolithic microwave integrated circuits (MMIC's) as well as interconnect lines and hybrid components today often are realized as multichip modules (MCM's) on low-temperature cofired ceramic (LTCC) [1]–[3]. In some applications, band-pass filters are required within these front-ends [4]. In the mm-wave range, a medium-to narrow-band filter may require tolerances in the range of a few microns, which is not realizable with the standard LTCC production process due to uncertainties with the shrinking of the material. Therefore, a filter was developed using a separate small alumina substrate. To enable an easy integration of the filter with the rest of the circuit, field-coupling was used, so that the filter simply can be glued on top of the LTCC substrate; no further steps are necessary. This technique therefore is compatible with standard LTCC processing procedures. The complete filter design and optimization was done using an in-house finite-difference time-domain (FDTD) code.

II. DESIGN OF THE BAND-PASS FILTER

The three resonator filter is based on side-coupled resonators on top of an alumina substrate with capacitively coupled input and output lines. This capacitive coupling is realized using broadside coupled microstrip lines [5], where input and output lines are on the bottom side of the substrate. To this end, the ground plane in the coupling area has to be removed

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The authors are with the Microwave Techniques, University of Ulm, D-89069 Ulm, Germany.

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Fig. 1. Principle layout and cross section of the drop-on filter.

and another ground plane layer of the LTCC substrate now serves as ground plane for input and output lines (Fig. 1). Principally, ground planes of alumina and LTCC substrate could be connected by vias in the LTCC, and input and output lines of the filter could be directly connected to interconnect lines on top of the LTCC substrate. This solution, however, leads to stringent tolerance requirements for placing the filter on the carrier substrate, as the required capacitive coupling factor ($|s_{21}| \approx 0.8$) strongly depends on the overlapping length of the two microstrip lines. Furthermore, the contact of the adjacent metallization patterns on both substrates by soldering or gluing with silver epoxy is critical, and a possible air gap between the substrates has a strong influence on the circuit performance as well. To overcome these problems, another field coupling was introduced for both interconnect lines and ground plane (Fig. 1). Nonconductive epoxy serves as another very thin dielectric separating interconnect lines and

Fig. 2. Photographs of carrier substrate with coupling structure and drop-on filter placed on top of the substrate.

Fig. 3. Theoretical and experimental return and insertion loss of a 29-GHz drop-on filter.

ground planes on both substrates. The coupling length for the interconnect lines was chosen to a quarter wavelength at the center frequency of the filter. In this way, a very broad-band transition is realized ([5]–[7]) which is much less sensitive to dielectric thickness of the epoxy and placement of the filter substrate, especially with such a thin dielectric layer [7]. In the full-wave characterization of the filter, a loss tangent of 0.02 was included for the epoxy; this however, provides only about 0.05 dB of extra losses compared to the lossless case. The shape and size of the ground plane section on top of the LTCC substrate, together with the complete circuit, was optimized to provide a good ground connection and to avoid resonances within the desired frequency range. As a result, the filter substrate simply can be glued on top of the LTCC

substrate. No air gap exists, as the complete filter substrate area is covered with the glue with a thickness of 5–10 μm . A variation of the position of the filter chip of $\pm 30 \mu\text{m}$ does not affect the filter performance, probably twice or three times that value are acceptable.

III. RESULTS OF THE FILTER

To be able to do tests of this filter without going through the LTCC fabrication process, a band-pass filter on alumina was designed for a placement on another alumina carrier substrate. Center frequency and bandwidth are 29 and 3 GHz, respectively, and a 0.1-dB Chebychev design was chosen. Both filter and carrier substrate were 0.127 mm thick. Fig. 2 shows a photograph of a carrier substrate with one drop-on filter and another coupling area for such a filter. For the experiments performed at this stage of the work, wax was used to fix the filter to the carrier substrate. Design and experimental return and insertion loss are plotted in Fig. 3. A reasonable agreement between theory and measurement can be stated. The mid-band insertion loss is 1.6 dB.

IV. CONCLUSION

Design and performance of a filter chip on an alumina substrate have been demonstrated. The filter chip simply is placed on top and glued to the LTCC substrate using nonconductive epoxy. A special electromagnetic field coupling is used to provide both the interconnect of signal lines and filter ground. With a special coupling arrangement, tolerance requirement for filter placement and glue thickness have been reduced.

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