Ka-Band Power-Distribution Networks on Multilayer LTCC for Broadband Satellite Multimedia Applications

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Abstract — **Broadband satellite multimedia application is one of tomorrow's information and communication technologies with great benefits for subscribers and providers. The satellite systems will require new and challenging technologies to fulfil ambitious demands like high and flexible bandwidth or reconfigurable coverage of ground zones with multi-beam antenna systems. The German Space Agency supports several activities for the development of the required satellite hardware. Within the EASTON project a power-distribution module for Ka-band down-link (17-21 GHz) has been optimized, fabricated and evaluated. LTCC has been chosen to stack two distribution networks (each with 1 input and 4 output ports) on top of each other within multilayer ceramic. Each network consists of 3 Wilkinson dividers with buried screen printed resistors as well as several optimized waveguide transitions. Stripline technology has been utilized, while via chains suppress cross-talk from one part of the circuit to another. The final module demonstrates the benefits LTCC: compact size, low cost and reliable performance.**

I. INTRODUCTION

High frequency power divider/combiner networks are fundamental circuitries in today's and tomorrow's reconfigurable communication and earth observation satellite systems. Especially the next generation of multimedia and telecommunication satellite payloads are expected to support a high number of beams to be implemented into phased antenna array systems. Independent of the utilized frequency band (e.g. Ku/Ka-band) power distribution networks require one divider module for each beam (e.g. n beams in case of a transmit system) with m output ports connected with amplitude-/phase shifters, power amplifier and antenna element. This results in a network of ($n \times m$) RF ports with n nearly equal divider modules. Current networks are typically made of rectangular waveguides, finline or multilayer PCB/PTFE boards. The first two one have excellent high frequency properties with low losses and high reliability. Waveguides are heavy, large and expensive. Single or multilayer PCB/PTFE boards with Wilkinson dividers are an other solution with advantages for large area boards [1]. However, the substrate material is expensive and has a high density which makes the networks heavy. New approaches are envisaged to reduce the costs and the weight at the same level of performance. The basic idea is to concentrate the power divider elements within a multilayer ceramic substrate. At lower frequencies where the wavelength requires longer lines, printed inductors and capacitors could be used to achieve small Wilkinson dividers. The multilayer ceramic modules could be connected with standard waveguide technologies to shape the whole network. At higher GHz-frequencies and networks with limited port numbers the entire divider/combiner can be fabricated on a single multilayer ceramic. This has been demonstrated in the EASTON project, where two stacked power dividers have been realized in a multilayer LTCC environment at 20 GHz.

II. NETWORK REQUIREMENTS

The specifications for the power divider network came from the ESA study HIFE, where a Ku/Ka-band communication system between satellites and earth terminals has been investigated [2]. The phased array antenna demonstrator consists of 4 input ports for 4 different beams. There are also 4 output ports available to feed 4 antenna radiators. Fig. 1 illustrates the block diagram of the module. Two divider networks are required to distribute the 4 input signals (beams) to the different branches of the control circuit, where phase and amplitude shifters modify the signals to achieve the desired distribution on the radiator array. Solid-state power amplifiers (SSPA) ensure, that sufficient output power is generated. A main task within the EASTON project was to design and manufacture the required divider networks on multilayer LTCC material. The only difference between network A and B is, that module B needs four additional transmission lines from its left to the right side. These waveguides have been realized as a microstrip lines on top of the ceramic. Two divider networks for beam 3 and 4 have been buried into inner layers using stripline or triplate line technology. Fig. 2 illustrates the cross section of this multilayer ceramic board. Each waveguide level is separated by ground planes. It was forced that all input and output ports had to be at the same level of height. The most promising solution was to use "Triplate 1" as port level. However, that required the design and optimization of reliable transitions from the top and bottom waveguides to triplate 1 in the frequency band from 17 to 21 GHz.

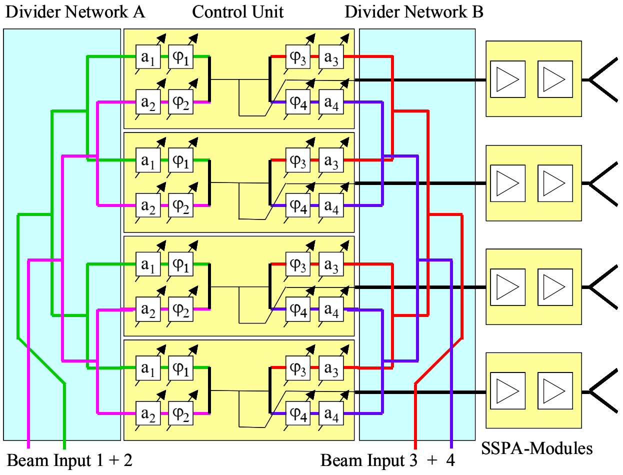

Fig. 1. Block diagram of multibeam phased array antenna; Divider Network B represents the module, which has been realized in multilayer LTCC.

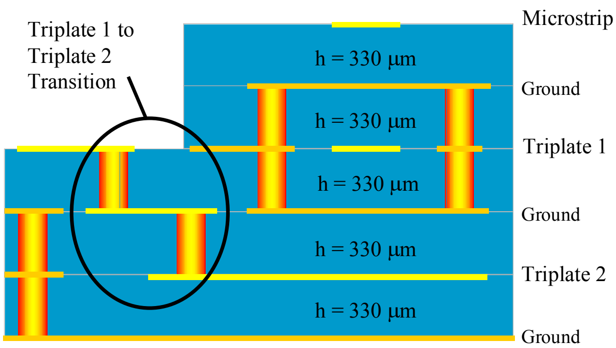

Fig. 2. Cross view of multilayer ceramic stack with microstrip line on top, shielded triplate lines in different levels.

III. CIRCUIT DESIGN AND OPTIMIZATION

The consortium decided to work with the LTCC system 951 from DuPont, which has a dielectric constant of 7.8. One reason for the selection was the huge experience in manufacturing this material even under difficult design requirements. However, the most important point was the availability of pastes for buried screen printed resistors. This technique was mandatory to realize the buried Wilkinson dividers, which where the core components of the networks. Each Wilkinson divider requires one resistor to decouple the output ports. First investigations of these elements have been performed in [3], while detailed information about the dividers of this module will be published in [4]. The current paper concentrates on the waveguide transitions. Three different kinds of transitions have been designed and optimized for signal paths within the LTCC substrates and further two for the transition from the LTCC to the housing and the connectors:

1. Microstrip 50Ω ↔ Triplate ↔ Port in Cavity 50Ω
2. Triplate 1 30Ω ↔ Port in Cavity 50Ω
3. Triplate 2 30 Ω ↔ Triplate ↔ Port in Cavity 50Ω
4. Ground-signal-ground wire-bonds:
   Port in Cavity ↔ substrate in housing
5. Substrate in housing ↔ GPPO connectors

The preliminary design task was to find a transition from the 50 Ω microstrip line (w = 390 µm) on top of the LTCC to the ground-signal-ground port in cavity. It becomes necessary to introduce a first step from microstrip to triplate level followed by a via connection from triplate to microstrip configuration within the cavity of the port. As illustrated in Fig. 3 a complicated routing of the ground conductors and vias has been preferred. This gives additional degree of freedom to optimize the whole transition in matter of matching. Furthermore ground strips and via chains improve the shielding of this part against other circuit branches. Cross-talk can be minimized this way.

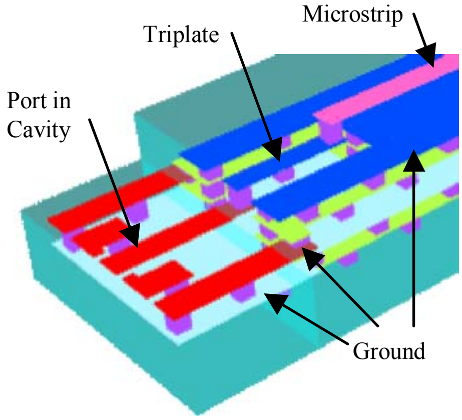

Fig. 3. Transition with shielding structures to minimize cross-talk: Microstrip ↔ Triplate ↔ Port in Cavity.

The graphs in Fig. 4 represent the high frequency behavior of 2 transitions of type 1. Insertion loss $|S_{21}|$ and return loss $|S_{11}|$ are shown in a comparison of measured and simulated data. All simulations have been performed with the 3D Finite Differences Time Domain (FDTD) method, which is implemented in the software tool EMPIRE^{TM}. The agreement is excellent, which demonstrates the reliability of the performance's forecast. The transition shows a broadband behavior in the desired frequency range. Transmission losses are lower 1.3 dB.

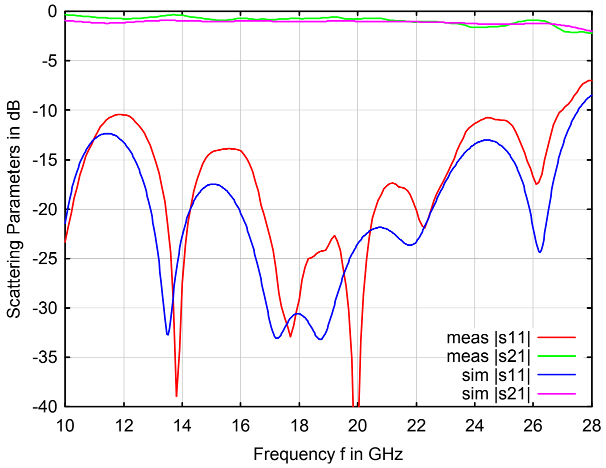

Fig. 4. Comparison of measurement and simulation; 2 transitions of: Microstrip ↔ Triplate ↔ Port in Cavity.

The triplate waveguides for the buried divider networks have been designed with a line impedance of $Z_L = 30\ \Omega$ (w = 425 µm). This was necessary, because the branches of the Wilkinson divider require a line impedance of $Z_L\sqrt{2} = 42.4\ \Omega$. In a $50\ \Omega$ (w = 145 µm) environment the triplate line width for the Wilkinson branches ($Z_L\ \sqrt{2} = 70.1\ \Omega$, w < 100 µm) would become too small for a standard screen printing process so that a lower impedance with a wider line width was favored. An other advantage of wider conductor lines is the reduction of the ohmic losses. However, the 30 Ω environment makes a transformation to 50 Ω necessary at the output ports. Such a transformation is included into the second transition. This structure is the most simplest one due to the fact, that the shielded triplate line at conductor level "Triplate 2" requires no vertical step to another conductor level. The measured and simulated results as a function of the frequency are summarized in Fig. 5. Return losses are below 20 dB in the desired frequency range and the insertion losses are acceptable with values lower than 1.3 dB.

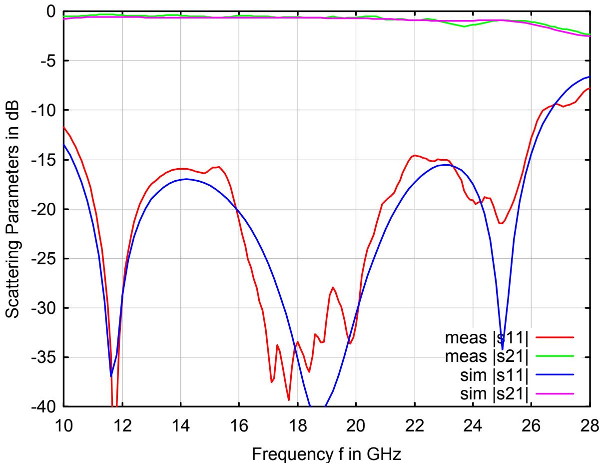

Fig. 5. Comparison of measurement and simulation; 2 transitions of: Triplate 1 ↔ Port in Cavity.

More complex is the final transition. Two vertical steps from conductor level "Triplate 2" to the port in cavity became necessary. Also included is again the impedance transformation from 30 Ω to 50 Ω. Fig. 6 illustrates the cross-view of the center line routing. Two steps with filled via connections have been introduced to pass the triplate waveguide to the port level. Again, transition and impedance transformation are guided by a top and button ground strip as well as a shielding via chain on the left and right hand side of the center line. 3D simulations have shown, that this effort is mandatory to avoid cross-talk to neighbored branches. The success of the shielding configuration becomes evident, when the electrical field distribution in Fig. 6 is considered. Only low field concentrations can be found outside the ground cage. In the cavity on the left side of the graph the e-field is certainly higher. Ground strips beside the ground-signal-ground pads of the port avoid coupling with neighbored ports (see Fig. 8).

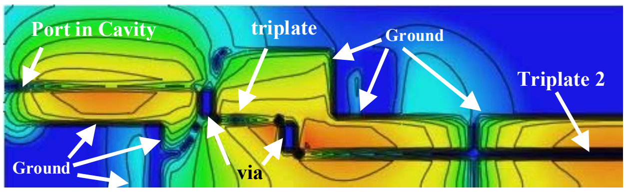

Fig. 6. Simulated electrical field in transition: Triplate 2 ↔ Triplate ↔ Port in Cavity.

The measured and simulated results of two transitions (type 3) including two impedance transformations are shown in Fig. 7. Slight deviations in the curves can be observed. Several measurements lead to the assumption, that manufacturing tolerances might have influence in the RF behavior of this complex transition. But again, return losses are below 15 dB in the desired frequency range.

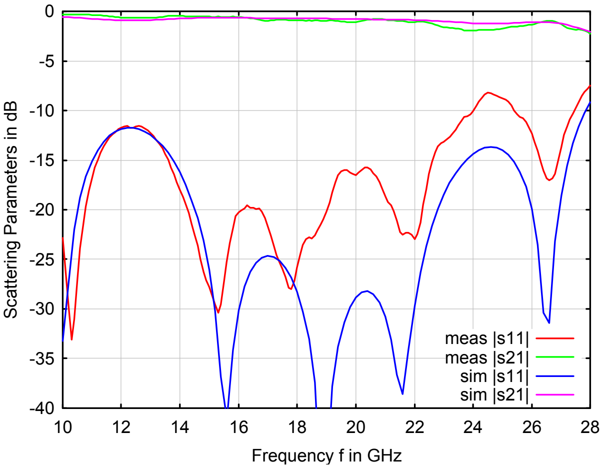

Fig. 7. Comparison of measurement and simulation; 2 transitions of: Triplate 2 ↔ Triplate ↔ Port in Cavity.

The photograph in Fig. 8 is a zoom of the module's corner. It shows the gold-plated DISPAL housing (an aluminium-silicon alloy) with embedded GPPO connectors (Gilbert). Small ceramic substrates in thinfilm technology with contact pads for the GPPO connector pins on the one side and ground-signal-ground bond-pads for the LTCC ports on the opposite side are inserted into the package. Three wire bonds per port connect the multilayer LTCC board with its environment.

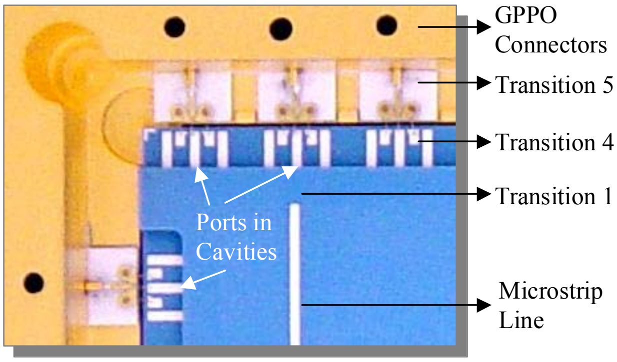

Fig. 8. Zoom of module's corner.

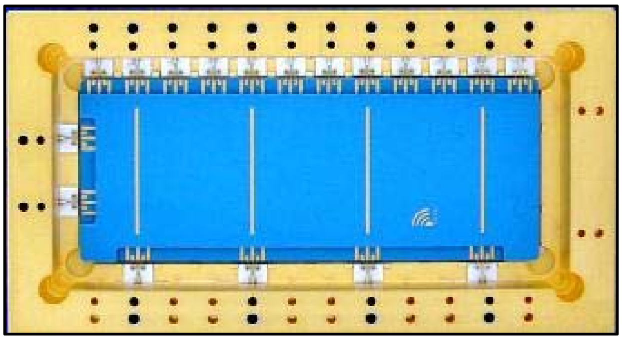

Fig. 9. Photo of divider module utilizing multilayer LTCC in a gold-plated DISPAL housing.

VI. CONCLUSION

The photo in Fig. 9 represents the entire distribution module with two buried 1/4 - divider networks and microstrip transmission lines on the top of the multilayer LTCC substrate. The authors have designed and optimized the divider networks, the Wilkinson combiners as well as all transmission waveguides, transitions and impedance transformations. The analysis has been executed with the 3D Finite Differences Time Domain method implemented in the software tool EMPIRE. Partners from the Technical University of Ilmenau have manufactured the LTCC tiles made of the DuPont tape 951. Silver and gold conductor paste systems have been utilized for two different modules. They have also optimized the buried screen printed resistors, which were necessary for the Wilkinson combiners [4] and [6]. TESAT Spacecom has designed and manufactured the DISPAL housing and has mounted and assembled the LTCC board into the package. The total size of the module is 6.5 x 3.5 cm.

RF measurements have been performed at IMST in a frequency range up to 40 GHz. The measured S-parameters agree very well with the simulated data. This has been demonstrated in the current paper for all core transitions within the multilayer LTCC. It could be shown, that the specified return and insertion losses could be met in the desired frequency band from 17 to 21 GHz. Complex shielding effort has been made to minimize cross-talk among the divider and transmission line branches. As main result of this R&D project it could be stated, that LTCC is a reliable substrate technology for space applications at GHz-frequencies.

ACKNOWLEDGEMENT

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