Power Distribution Networks in Multilayer LTCC for Microwave Applications

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Abstract* — Divider networks are key modules for feeding antenna elements in microwave applications like RADAR sensors for space (SAR: Synthetic Aperture Radar, remote sensing of earth), avionic, military, automotive, ISM bands and others. The RF power at the input port is distributed equally to an arbitrary number of output ports. The most important specifications of these divider networks are the phase and amplitude balance stability at the output ports, the isolation between different output ports as well as the VSWR. Multilayer LTCC has several advantages in comparison to standard microwave boards: Divider network and patch antenna array can be fabricated in the same module, separated by an inner ground mesh; large divider networks can either be on the top or bottom of the substrates in microstrip configuration or in inner layers as shielded triplate waveguides. The main component of such a circuitry is the Wilkinson divider, which splits the input power equally to two output ports. With a cascade of Wilkinson dividers an arbitrary 1:n power distribution network can be realized. Such circuits have been designed, fabricated and evaluated by the authors.

Keywords: LTCC, Multilayer, Divider Networks, RF Circuits, Antennas

I. INTRODUCTION

The investigated modules consist of divider networks, which distribute the power from the input port equally in phase and magnitude to the radiating antenna elements at the output ports. Figure 1 shows such a circuitry with a 1:4-distribution network.

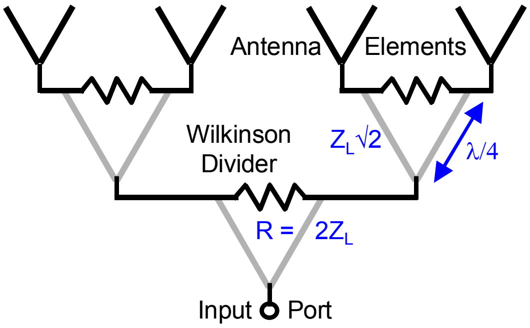

Fig. 1. Parallel feeding network with antenna elements

Different technologies and applications have been investigated and will be compared in this paper. The work starts with the development of the Wilkinson coupler as the most basic element in such modules. Test circuits on thinfilm Alumina [2], PTFE composite substrates [5] as well as multilayer LTCC [1,3] have been designed an evaluated. In a next step the transitions to the antenna elements have been designed and optimized. In case of single layer PTFE and Alumina substrates SMA connectors were used to connect the divider network with the antenna elements. In case of multilayer LTCC antenna patches and divider network are fabricated on the same substrate: network on the one side and patches on the opposite side fed through an aperture in the inner ground layer. The latest development shows two stacked divider networks in multilayer LTCC. The RF waveguides are buried between a top and bottom ceramic layer and are fabricated as shielded triplate lines. This requires buried screen printed resistors, which are available for the LTCC system 951 from DuPont.

II. WILKINSON COUPLER

The Wilkinson divider is the basic component of each distribution network. Special designs have been developed for each application, frequency range and technology. This element consists of two parallel branches with a length of $\lambda/4$ and a line impedance of $Z_L\sqrt{2}$. A resistor with $R = 2Z_L$ combines the two output ports. Corresponding to the used technologies such resistors are made as thin-, thickfilm or SMD components. Each one has its own advantages and disadvantages. SMD resistors with the size 0201 (0.5x0.25mm) and a tolerance of 1% have been chosen. However, the parasitic effects of the packaging and the solder caps are not neglectable in the frequency ranges of interest (20 – 30GHz). Printed thickfilm and thinfilm resistors are not trimmable in a Wilkinson divider, because both terminations are short-circuited. Thus, tolerances up to 30% have to be taken into account. Simulations could proof, that the Wilkinson divider is not sensitive against such tolerances as long as the ports are terminated with an ideal impedance. This can become a problem in applications like phased array antennas, when active phase shifters and amplifiers or attenuators are connected between divider network and antenna elements. The failure of one module might destroy the symmetry of the network. This influence has to be investigated in the future. The figures 2 and 3 show the simulated and measured S-parameters of a Wilkinson coupler (Z_L =50Ω) on top of LTCC (Ferro A6-M). Different 100Ω resistors have been fabricated: A) a co-fired and B) a post-fired screen printed resistor (20% tolerance), C) a thinfilm resistor trimmed to 5% tolerance and flipchip mounted, and D) a SMD resistor 0201 with 1% tolerance. The resistivity has been measured at 5 and 25GHz at one 100Ω resistor to ground and two 100Ω resistors in parallel. Table 1 summarizes the results.

	100Ω		100Ω // 100Ω	
	5 GHz	25 GHz	5 GHz	25 GHz
A	89 Ω	116 Ω	39 Ω	48 Ω
B	94 Ω	110 Ω	44 Ω	50 Ω
C	98 Ω	98 Ω	49 Ω	**38** Ω
D	101 Ω	**138** Ω	50 Ω	**62** Ω

Tab. 1 Measured resistor values

The frequency dependence of the mounted resistors in C) flipchip and D) SMD despite the better tolerances becomes evident. The screen printed resistors A) and B) show acceptable results at the desired frequency of 25GHz. Similar investigations have been made on PTFE substrates at 10GHz, where tuning is made by soldering SMD resistors in parallel [5]. The investigation of buried triplate Wilkinson couplers in LTCC is just running [3].

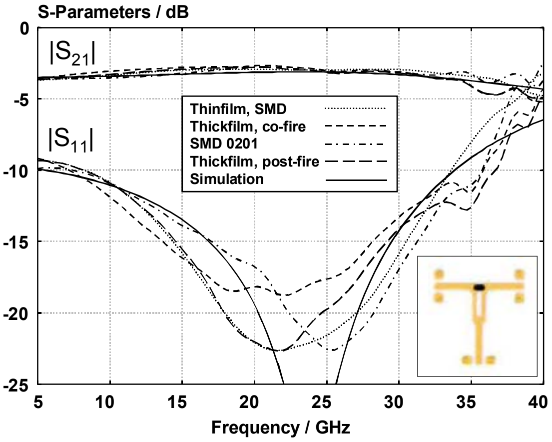

Fig. 2. Comparison of simulated and measured return- and insertion losses of a Wilkinson coupler

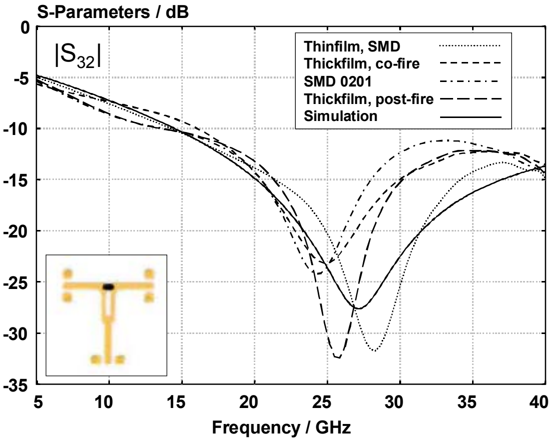

Fig. 3. Comparison of simulated and measured isolation of a Wilkinson coupler

III. DIVIDER NETWORK AND ANTENNA

Two antenna modules for 24.125GHz with 2x2 and 4x4 rectangular patches on one substrate side and the feeding network with Wilkinson dividers on the opposite side have been developed [1,3,4]. The RF energy is coupled through an aperture in the inner ground plane from the branches of the divider networks to the patches. Figure 4 shows the backside of one of the antenna modules. 15 Wilkinson couplers are used to get a 1:16-divider module. The inner conductor layer is a ground grid, with solid rectangular areas and a small aperture under the antenna patch. A conductor grid is necessary to avoid delamination of the ceramic layers. Again, screen printed, thinfilm flipchip and SMD 100Ω-resistors have been fabricated to investigate the electrical behavior of the antenna module. The following parameters have been measured: a relative 10dB bandwidth of 5% for the 4x4 and the 2x2 antenna; an efficiency of 65% and an antenna gain of 14.5dBi for the 4x4 and 8.2dBi for the 2x2 patches.

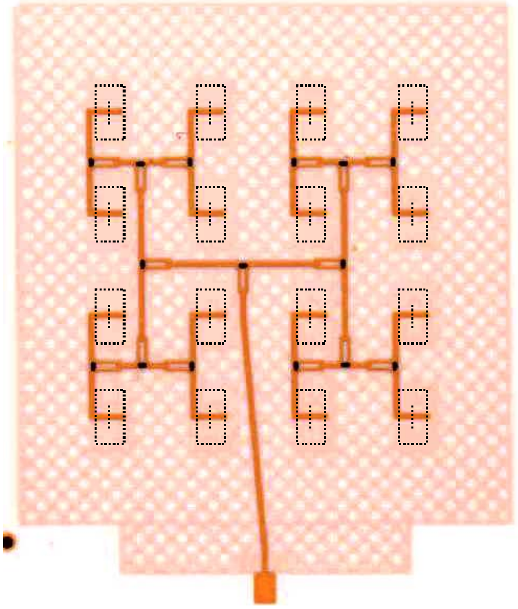

Fig. 4. 1:16-divider network with Wilkinson couplers and screen printed resistors; inner layer: ground mesh with aperture; backside with antenna patches (see dotted lines); size: 35 x 35 mm^2

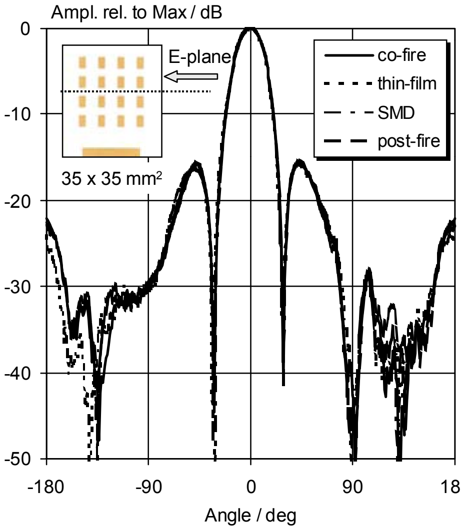

Fig. 5. Measured far-field characteristic of 4x4 antenna

Figure 5 shows the measured far field characteristic (E-plane) of the 16-patches antenna with different resistor technologies in the Wilkinson coupler. The results are in excellent agreement with the predicted calculations. Some asymmetry in the measurements can be observed in the E-plane of the antenna arrays. A causal reason for this effect can be an amplitude and phase error resulting from the meshed ground plane. However, this effect is independent form the resistor technology. These modules are suitable for low cost ISM-band applications like RADAR sensors at 24.125GHz. A next step could be the integration of a frontend circuit in the same LTCC laminates.

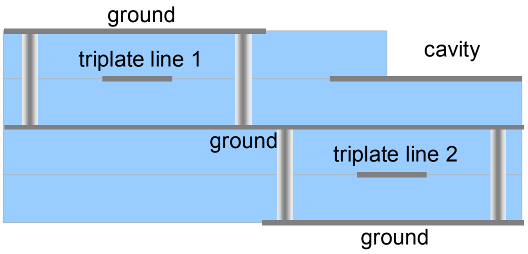

Fig. 6. Multilayer LTCC setup for stacked distribution networks with shielded triplate waveguides

A further R&D activity is the development of stacked distribution networks with shielded triplate waveguides in multilayer LTCC [3]. Figure 6 illustrates the cross section of such a configuration. A conductor line is fabricated between two ceramic layers and covered by a top and button ground plane or wide ground strip. A fence with metalized vias is placed in sufficient distance on the left and right side of the center line to increase the shielding to neighbor waveguides and to avoid the excitation of higher wave modes. Buried resistor technology is required to use Wilkinson couplers in inner layers. Such pastes are offered by DuPont for their LTCC tape 951. The ports will be contacted in cavities. These transitions have been optimized with 3D full wave analysis (in-house tool: EMPIRE^{TM}) for the operating frequency at 20GHz. Figure 7 shows the optimized return and insertion losses of the transition from a 50Ω microstrip line in a cavity to a 50Ω triplate line, buried in LTCC. Via fences and all ground connections were taken into account. All other important transitions have been designed likewise: triplate 1 to triplate 2, triplate 2 to port, 50Ω triplate to 30Ω triplate …

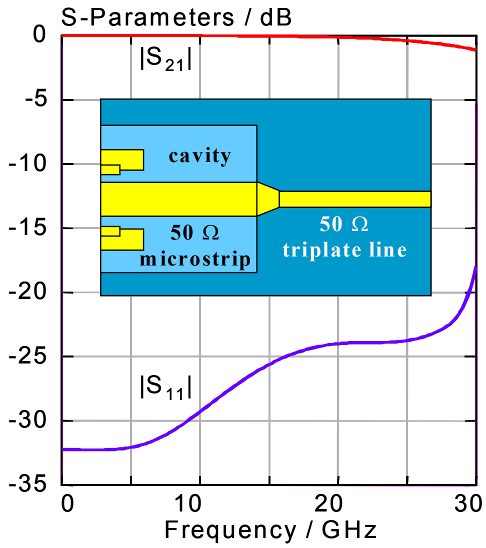

Fig. 7. Multilayer LTCC setup for stacked distribution networks with shielded triplate waveguides

	LTCC: DuPont 951	PTFE Composite: RT/Duroid
waveguide	triplate: thickfilm Au	microstrip line: Cu
permittivity	7.8	3
50Ω-line width	425 µm	1950 µm
line loss factor	0.24 dB/cm	0.038 dB/cm
line length	46 mm	144 mm
total line losses	1.1 dB	0.55 dB
outer dimensions $^{+}$ [mm]	58 x 24 x 0.7	176 x 67 x 0.8* 200x 90 x 14**
weight $^{+}$	3.2 g	≈ 215 g
TCE [ppm/K]	LTCC: 5.8	16* 24**

$^{+}$ no connectors, * PTFE substrate, ** Al housing

Tab. 2 Comparison of 1:8-divider networks in LTCC and PTFE technology for 10GHz

A technology for conventional space applications is described in [5] and has been realized on PTFE composite substrate with copper conductors, aluminum housing and SMA connectors. LTCC multilayer ceramic is seen as a reliable and cost-effective alternative to the conventional technology. Advantages of LTCC are smaller dimensions, lower weight, low TCE, high environmental robustness, simpler packaging, excellent shielding resulting in a good phase and amplitude balance stability. A drawback are the slightly higher line losses coming from the smaller conductor width and the higher dissipation factor as long as a non RF substrate is used (here: DuPont 951). Table 2 compares two 1:8-divider networks, one in LTCC with triplate waveguides and the other with microstrip lines on PTFE in an aluminum package. The LTCC solution has been designed with GPPO connectors from Gilbert, while the PTFE module was build up with SMA connectors.

IV. CONCLUSION

Different kinds of power distribution networks have been developed for feeding (phased) antenna arrays. All modules utilize the Wilkinson coupler as a basic power splitting element. A resistor is necessary in each splitter, therefore different resistor technologies have been investigated: screen printed co- and post-fired, thinfilm flipchip mounted and SMD components. Screen printed resistors show good properties and are available as buried elements, which gives LTCC some advantages over conventional technologies. The performance of such a module has been demonstrated with a 4x4 patches antenna module, fed by a distribution network and aperture coupled transitions on a 4 layer LTCC substrate.

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