A 79 GHz Microstrip Grid Array Antenna Using a Laminated Waveguide Feed in LTCC

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Abstract— **This paper presents a novel planar microstrip grid array antenna on low temperature co-fired ceramics (LTCC) with a feeding structure in laminated waveguide technique. The antenna is designed to operate in the 79 GHz frequency range for automotive radar applications. Measured results of a first antenna design show that the antenna is a good candidate for 79 GHz applications and particularly suitable for LTCC integration.**

Keywords- microstrip antenna, grid array, low temperature co-fired ceramic (LTCC), substrate integrated waveguide (SIW)

I. INTRODUCTION

Millimeter wave wireless systems both in the communication (e.g. point-to-point or –multipoint links) and sensor area (e.g. automotive radar) have gained increasing interest during the last decade. For widespread commercial applications, compact, low-loss and low-cost systems are of major interest. With respect to automotive radar, applications such as blind-spot detection, collision warning and pre-crash vehicle preparation shall find their way into compact cars using cost efficient sensors. The long term frequency allocation for future mm-wave short range radar (SRR) sensors has been identified as 77- 81 GHz. A promising technology for such a sensor is a four-channel SiGe radar chip [1] integrated into a low temperature co-fired ceramic (LTCC) substrate. While LTCC provides low-cost 3D-integration and good mechanical stability, the use of multiple channels together with multiple antennas enables techniques such as digital beamforming and space-time adaptive processing (STAP) [2].

This paper will investigate a novel microstrip grid array antenna designed on TDK S39F LTCC substrate. The resulting antenna shows a good bandwidth and pattern stability, making it suitable for the applications mentioned above.

II. MICROSTRIP GRID ARRAY ANTENNA

Grid array antennas were already investigated in 1964 by Kraus [3] and Conti et al. proposed a microstrip version of the array in 1981 [4]. The conventional antenna feed at the end of the grid results in a linearly polarized main beam in a backward angle-fire direction, whereas a center feed leads to a broadside beam [5].

The antenna considered in this paper is shown in Fig. 1 (without feeding network for clarity). It consists of two cascaded arrays of 5 radiating elements each. Both sub-arrays are fed by vias through an aperture in the ground plane.

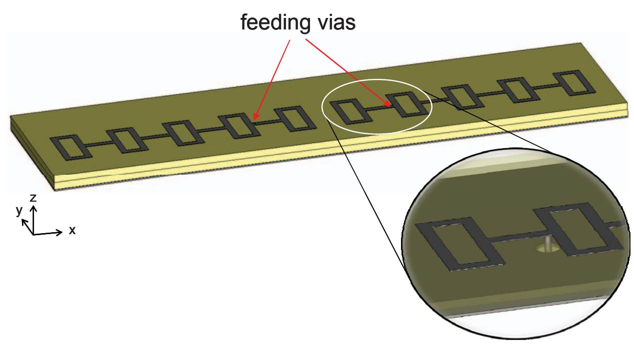


Figure 1. Configuration of proposed grid array antenna.

The antenna shares some geometric similarity with a rectangular-loop type chain antenna presented in [6] with the important difference that the proposed antenna is a resonant structure and not a traveling-wave antenna which would require a matched load at the end.

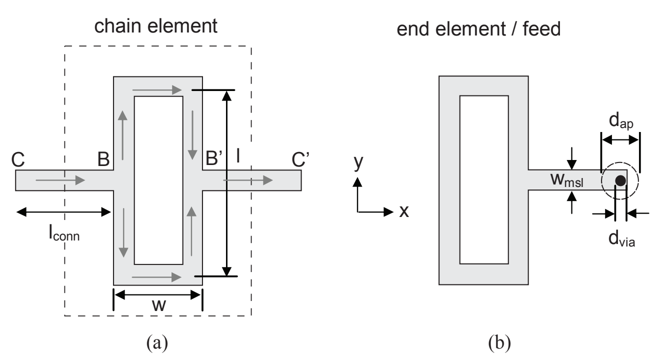


Figure 2. Basic elements of the array:
(a) chain element (b) terminating element.

The basic elements of the antenna are shown in Fig. 2. The rectangular loops have a length of $l = \lambda_m$ and a width of $w = \lambda_m/2$, with respect to the guided wavelength on the microstrip line at the design frequency. The instantaneous currents in the loop indicated by the arrows in Fig. 2 (a) let the horizontally polarized field components (x-direction) combine constructively, whereas the vertically polarized components (y-direction) cancel each other. Using high permittivity LTCC substrate (TDK S39, ε_r=7.4) the antenna becomes very compact in terms of free-space wavelengths. Hence, the antenna can be used in array configurations with an achievable spacing of almost $\lambda_0/2$.

A. Antenna Design

All modeling and simulations were performed using CST Microwave Studio [7]. The methodology for designing the antenna is to optimize its single elements and subsequently assembling them to the complete antenna structure. In the first step, the width of the cell is set to $w = \lambda_m/2$, the lengths l and l_{conn} are adjusted so that the phase difference between B and B' and C and C' (cf. Fig. 2) equals 180°. Using a three port simulation including the feed, the antenna can be subsequently extended with further elements and finally terminated by an end element. The via-diameter available due to manufacturing is d_{via} = 100 µm. Hence, the impedance of the coaxial feed is restricted to a range of up to 27 Ω keeping the outer diameter of the aperture below a quarter-wavelength. Two layers of S39 LTCC, each having a sintered thickness of 118 µm, are used for the antenna. Table I summarizes the optimized parameters.

TABLE I. ANTENNA DIMENSIONS

Label	Value	Description
w	790 µm	width of basic element
l	1670 µm	length of basic element
l_{conn}	870 µm	length of connection line
w_{msl}	180 µm	width of MSL
d_{ap}	330 µm	diameter of aperture
d_{via}	100 µm	diameter of via

Fig. 3 illustrates the z-component of the electrical field below the upper metallization of the antenna at 79 GHz. It can be seen that the radiation is decreasing towards the end elements. Since the two sub-arrays are mirror images of each other, the phase difference between the two feeding ports has to be 180°. The next chapter will show how this can be achieved using a laminated waveguide (LWG) feeding network below the antenna.

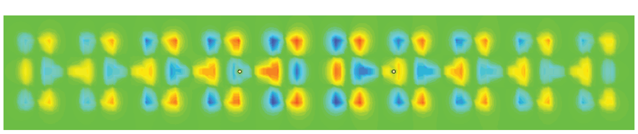


Figure 3. Visualisation electrical field (z-component).

B. LWG Feeding Structures

To feed the antenna sub-arrays, two 3dB power dividers are investigated. The first structure is a laminated waveguide (LWG) T-junction using 5 layers of LTCC with a sintered thickness of 118 µm each. The layer stack is shown in Fig. 4 (a), showing 5 layers for the LWG and 2 layers for the antenna. The phase-difference of 180° at the feeding vias for the antenna is accomplished within the LWG by adjusting the distances l_1 and l_2 with respect to the splitting plane.

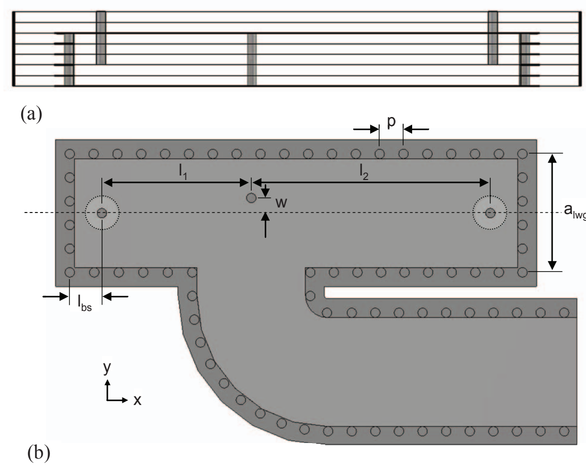


Figure 4. Configuration of the LWG T-junction (a) layer stack, cross-section, (b) top view. Parameters: l_1 = 1580 µm, l_2 = 2530 µm, w = 150 µm, l_{bs} = 330µm, p = 250 µm, a_{lwg} = 1250 µm.

A second investigated feeding structure is shown in Fig. 5 allowing a closer spacing in multiple antenna configurations. It consists of two stacked LWGs using 10 layers of LTCC. Coupling from the lower LWG to the upper one is accomplished by a rectangular aperture. The lower LWG is terminated with a backshort formed by a via-wall placed $l_{bs1} \approx \lambda_g/2$ away from the center of the aperture (λ_g: guided wavelength within the LWG). Since the 180° phase shift is inherent to this aperture coupling, the distances to the feeding vias l_3 are identical. A local reduction of the waveguide height above the aperture helps to improve the bandwidth of the divider.

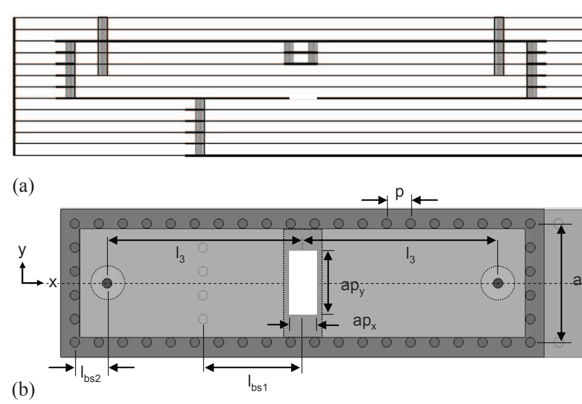


Figure 5. Configuration of the vertical LWG-power divider. (a) layer stack, cross-section, (b) top view. Parameters: l_3 = 2070 µm, ap_x = 260 µm, ap_y = 640 µm, , l_{bs1} = 975 µm, , l_{bs2} = 330 µm, p = 250 µm, a_{lwg} = 1250 µm.

III. Measurement Results

To verify the simulation results, the antenna was fabricated and tested on 7 Layers of TDK S39 including a transition to WR-12 waveguide on the backside. The LWG T-junction (Fig. 4) was used for feeding the antenna. Due to a modified LTCC sintering process the permittivity of the manufactured multilayer is slightly lower than assumed in the simulations. Measurements yielded an actual permittivity of $\varepsilon_r = 7.28$. In Fig. 6 the measured return loss is shown. A 5 GHz impedance bandwidth (for a 10 dB return loss) is obtained.

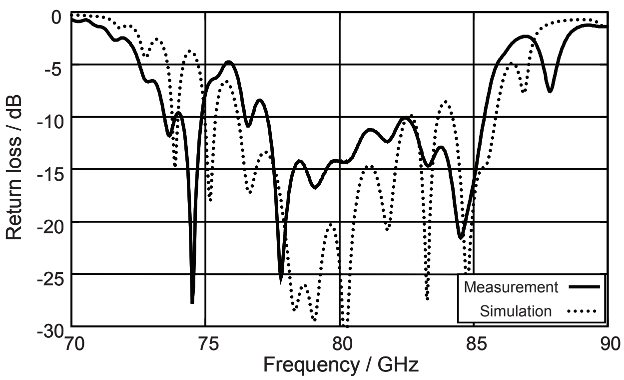
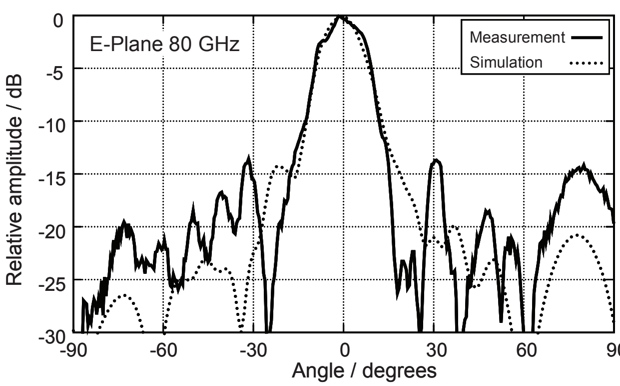


Figure 6. Simulated and measured return loss of the antenna.

Fig. 7 shows the normalized E-plane and H-plane radiation diagrams at 80 GHz. Beamwidths for the antenna are 16° and 54° in the E-plane and H-plane, respectively. A maximum sidelobe level of -13.5 db can be seen in the E-plane. Simulations assuming a permittivity of $\varepsilon_r = 7.4$ predict a stable radiation pattern from 77.5 - 80.5 GHz (cf. Fig. 8). Further simulations taking into account the lower permittivity show an even better agreement with the measurements.



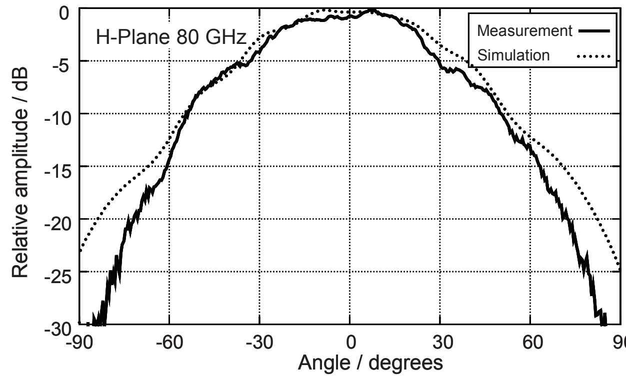


Figure 7. Measured and simulated radiation diagrams at 80 GHz.

Conclusion

A microstrip grid array antenna excited by a laminated waveguide feed network has been presented. The antenna was realized in a low temperature co-fired ceramic multilayer. Although the measured radiation patterns were shifted towards slightly higher frequencies, the antenna did show good pattern stability over a frequency range of about 3 GHz. In future the antenna shall be integrated with an MMIC to build up a radar sensor system.

Acknowledgment

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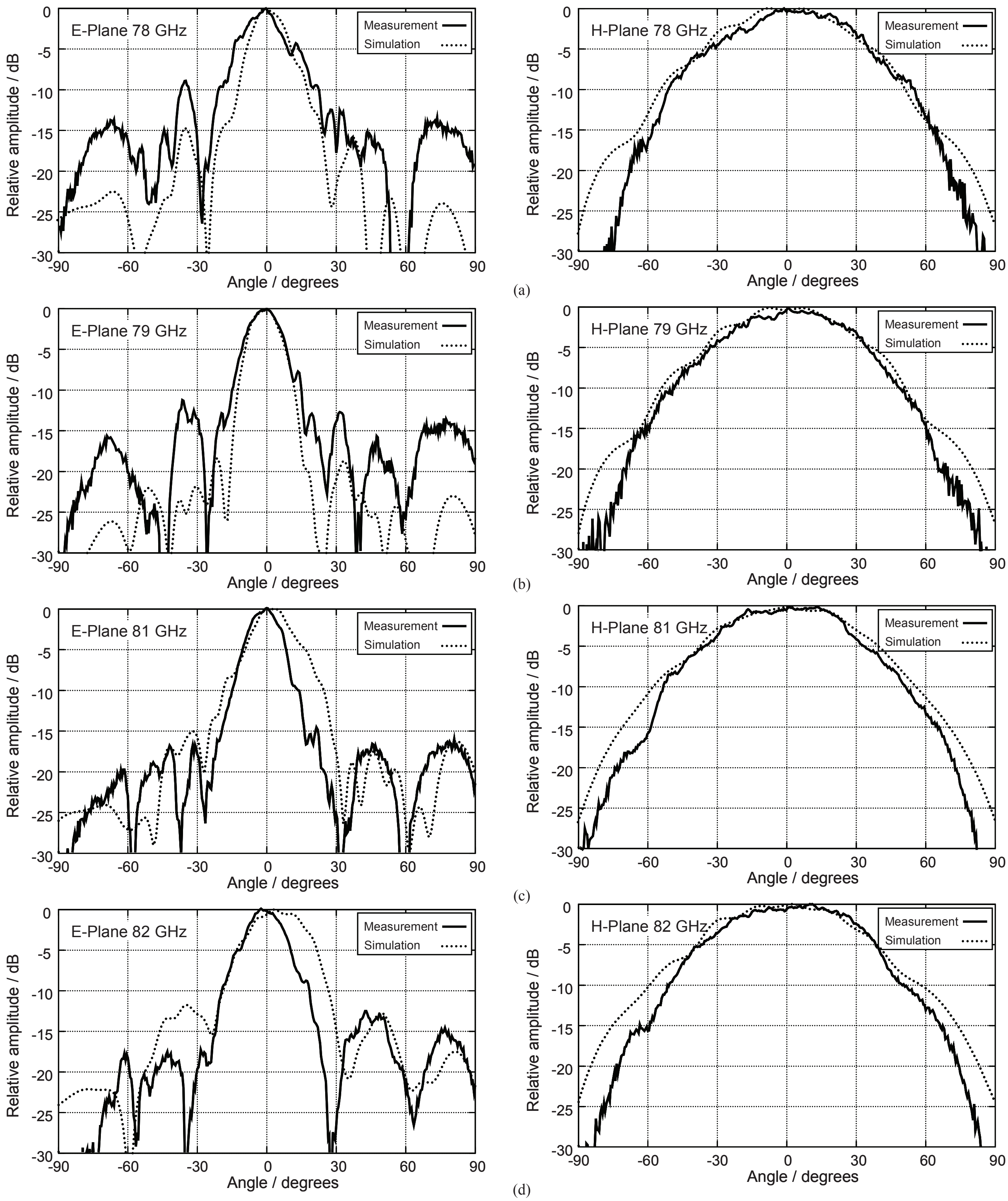

Figure 8. Measured and simulated radiation diagrams at (a) 78 GHz, (b) 79 GHz, (c) 81 GHz, (d) 82 GHz.