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RADIATION PATTERN MEASUREMENTS OF LTCC-INTEGRATED PATCH ANTENNAS AT 60 GHZ

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ABSTRACT

Low temperature co-fired ceramics (LTCC) integrated patch antennas can be used as components in upcoming wireless communication systems at 60 GHz enabling high data rates. Their radiation pattern and gain were analysed in an anechoic chamber. For this purpose the measurement equipment has been extended to perform frequency converted measurements. Up to now, only return loss measurements were feasible by connecting these planar antennas with coplanar probes. An appropriate 60 GHz waveguide transition was selected to contact planar LTCC antennas to the frequency converting system within the anechoic chamber at Ilmenau University of Technology. Single-radiator and four-patch antenna array configurations have been measured successfully and the results are discussed in this paper.

Index Terms – antenna, measurement, radiation pattern, patch, 60 GHz, LTCC, planar, waveguide transition

1. INTRODUCTION

Within the industry-led R&D-initiative "Enablers for Ambient Systems" (EASY-A), scientists at Ilmenau University of Technology develop antennas for wireless high data rate communication systems. Various applications falling into the unlicensed 60 GHz ISM-band with data transfer rates reaching several Gigabytes per second are conceivable. LTCC-integrated patch antennas, which were designed previously [1], [2], needed to be analysed in an anechoic environment, in order to determine their attributes such as gain and radiation pattern.

It is a technical challenge to contact planar antennas to the measurement equipment in an anechoic chamber at 60 GHz. For this purpose an adequate low-loss and low-radiation waveguide transition is required. At this operating frequency the attenuation of feeding cables in the measurement chamber are crucial, thus, the dynamic range is not sufficient in order to determine the radiation pattern. Up to now, only measurements were feasible, where the LTCC-antennas were connected with coplanar probes on a waferprober. In this manner only a return loss is traceable but this technique did not allow the acquisition of gain, efficiency, and radiation pattern.

Now a new frequency converting measurement system within the anechoic chamber in Ilmenau enables radiation pattern measurements up to an operating frequency of 75 GHz. In order to connect the planar antennas to the frequency converting system, specific waveguide transition elements had to be selected, installed and tested.

2. MEASUREMENT TECHNIQUE

In the used antenna measurement chamber a transmission between an illuminating and a test antenna (AUT) can be determined up to 20 GHz by using a two-port network analyser. For measurements at higher frequencies limits arised due to the used cables and the free space attenuation. Thus, the dynamic range as the difference between test level in main beam direction of the AUT and noise is getting too low. According to that effect it fails to get enough received power into the measurement equipment to obtain a radiation pattern with sufficient contrast between maxima and minima. In such a situation attenuation losses cannot be compensated by power amplifiers with conventional effort. For this reason frequency converters are inserted and directly connected to every antenna in the anechoic chamber (Fig. 1). The up-converter at the input port of the transmitting antenna multiplies the frequency of the feeding signal to the test frequency range and the down-converter at the AUT port reconverts it to a lower range again.

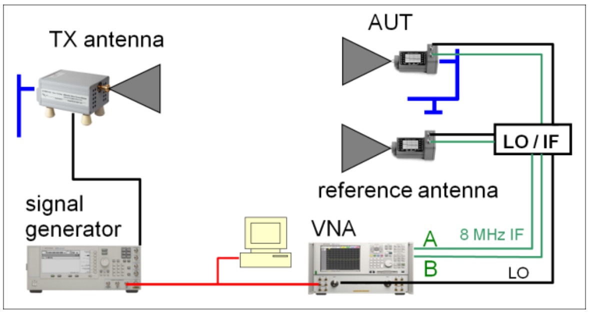

Fig. 1. Sketch of the measurement setup operating in the V band (50-75 GHz).

By using this frequency converting measurement arrangement the network analyser signal and the signal in the transmission path are incoherent.

Therefore a second receiving antenna is required. This so-called reference antenna serves as a reference for the estimation of the magnitude and the phase. Also this antenna is directly connected to a frequency down-converter. Figure 1 shows the RF wiring in the antenna measurement laboratory used at V band frequency range (50-75 GHz). A three-antenna setup within the anechoic chamber is illustrated. It consists of a illuminating TX antenna, a receiving test antenna, and the reference antenna. A computer-aided signal generator within the chamber generates the feeding signal and is connected with a short coaxial cable to the up-converter. The received and down-converted AUT and reference signals attains the so called LO/IF Distribution Unit. This unit gets a local oscillator frequency from the vector network analyser (VNA) and distributes it to both down-converters. The actual measurement signals are distributed to the IF ports A and B of the VNA. The computer-aided VNA creates the ratio of B to A (AUT signal to reference antenna signal). B/A is the dimensionless complex measurement value.

To achieve gain measurement values in dBi it is essential to perform a calibration. It was done using a standard gain horn antenna with known gain G_{CAL} and a gain-transfer method. After measuring the incident power at the standard gain horn $P_{RX\ CAL}$ and at the AUT $P_{RX\ AUT}$ the gain can be calculated. The desired gain of the test antenna G_{AUT} is given for every spherical direction by the following formula:

$$G_{AUT}(\Theta,\Phi) = \frac{P_{RX\,AUT}\,(\Theta,\Phi)}{P_{RX\,CAL}\,(\Theta=0,\Phi=0)} G_{CAL}\,(\Theta=0,\Phi=0)$$

Where Θ is the antenna elevation and Φ characterises the antenna azimuth. If both Θ and Φ equal zero the gain respectively power relates to the main beam direction of the antenna. This existing calibration was done for every measured frequency point and for both linear polarisations of the illuminating antenna.

3. TESTED WAVEGUIDE TRANSITIONS

To obtain an experimental characterisation of 60 GHz patch antennas, a low-loss and low-radiation transition from the antenna under test to a conventional millimeter wave connection standard is needed. Two types of transitions were evaluated by comparative measurements of return losses and antenna patterns. The first one is illustrated in figure 2. It is a surface mounted mini-SMP coaxial connector with a coplanar output geometry which can be soldered to a tapered feeding network of the LTCC patch antenna. This mini-SMP connector requires marginal space for mounting on a substrate and it is intermateable to other conventional connection standards. Such a connection standard would offer an easy and versatile use of our presently being investigated 60 GHz antennas.

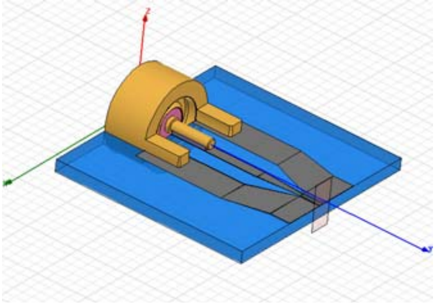

Fig. 2. Three-dimensional model of a surface mounted mini-SMP coaxial connector attached to a coplanar waveguide taper.

The second type of the tested transitions is a previously designed planar LTCC-integrated waveguide-to-microstrip one which provides the direct connection of the back of the LTCC module to the WR 15 waveguide input port of the AUT frequency converter [3]. The waveguide port on the back of the substrate is aligned with pins to the down-converter flange and all is fixed by screws. Since no additional adapters are needed and the signal path on the substrate is relatively short this transition promises a low attenuation. Another advantage is the adjacence of the test antenna to the actual calibration plane which is located on the converters input port. Figure 3 illustrates the three-dimensional model of this transition connected to a four-patch antenna array.

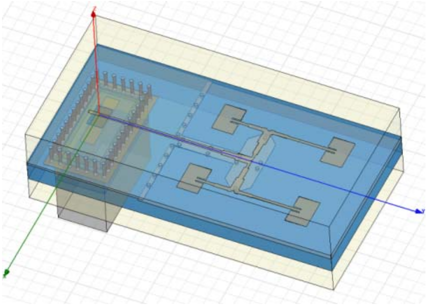

Fig. 3. Three-dimensional model of a planar waveguide-to-microstrip transition integrated in LTCC and connected to a four-patch antenna array.

The feeding microstrip line of a previously designed patch antenna can be connected directly to such a transition. For return loss and radiation pattern measurements a LTCC test module with several realisations of patch antennas directly connected to the shown waveguide-to-microstrip transition was manufactured. This manufactured test array was cut in order to examine each AUT with its waveguide port separately. A disadvantage of this transition structure is the increased space required on the substrate compared to a mini-SMP connector.

4. MEASUREMENT RESULTS

4.1. Usage of a coaxial connector

To investigate the impedance matching of the test antennas, connected to a surface mounted coaxial mini-SMP connector, a return loss measurement in the frequency range between 55 and 67 GHz was performed. Compared to the coplanar probing (wafer-prober measurement) a clear change in behaviour of the return loss is observable. In a wide spectral range a high power consumption exists, but no resonance frequency of the patch antenna is visible. Several tested antennas exhibit a 10 dB input matching over the whole measured frequency range. This indicates an energy loss due to ohmic losses and unwanted radiation but not the behaviour of a resonant antenna.

Regrettably further investigations have shown that the mini-SMP connector exhibits high losses and provides unwanted radiation due to its unshielded coplanar output geometry. This parasitic radiation interferes with the AUT-pattern, thus, no typical radiation pattern of a patch antenna is observable. As shown in Figure 4 only a spoiled and cliffy pattern caused by a superposition of several radiation sources is measureable. This effect appeared during various patch antenna measurements, thus, this connector is preventing a reliable measurement of the desired radiation pattern at 60 GHz.

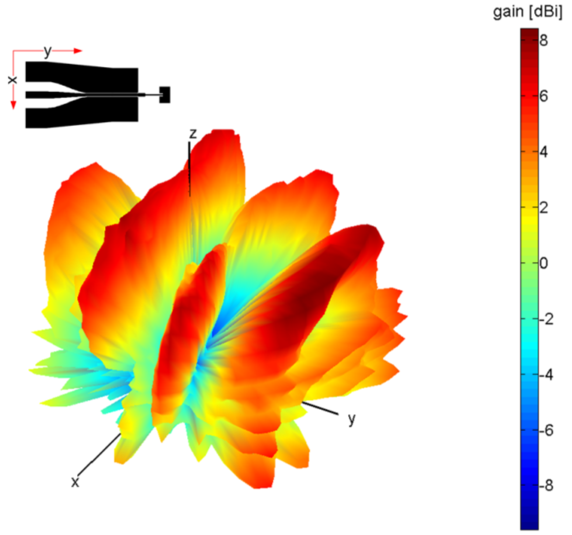

Fig. 4. Representation of the measured three-dimensional radiation pattern of a single-patch antenna using a surface mounted mini-SMP coaxial connector at 60 GHz.

4.2. Usage of a waveguide-to-microstrip transition

Because of the insufficient measurement results the coaxial connector was not further investigated. Instead the previously described waveguide-to-microstrip transition was used to connect the 60 GHz patch antennas. A single- and a four-patch antenna were connected to this transition. Figure 5 and 6 show a measured resonance frequency of 62 GHz for both test antennas and an offset to the minimum of the simulated input matching of about 2 GHz. This offset arises due to shrinking effects occurred during the substrate manufacturing process. The single-patch antenna exhibits a 10 dB impedance bandwidth of 2 GHz with a good agreement to the simulation results. Figure 6 shows the bandwidth of the four-patch antenna array. Compared to the simulation trace the bandwidth increases by 1 GHz. Such a positive effect results from manufacturing geometry tolerances of several patches that have slightly shifted resonances.

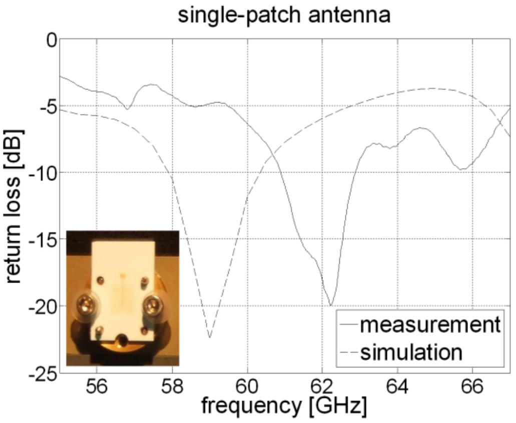

Fig. 5. Return loss measurement and simulation of a single-patch antenna connected to a waveguide to microstrip transition.

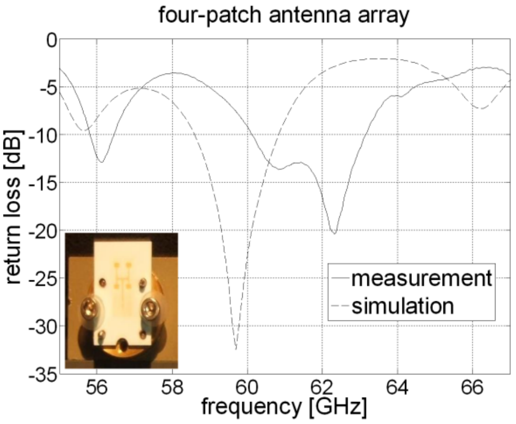

Fig. 6. Return loss measurement and simulation of a four-patch antenna array connected to a waveguide to microstrip transition.

Using a planar waveguide-to-microstrip transition integrated in LTCC, gain and radiation pattern measurements at 60 GHz could be performed successfully. Figure 7 represents our first measured three dimensional radiation pattern of a four-patch antenna array at 62 GHz. The main beam direction is located along the z axis. A maximum of realised gain of 11.8 dBi is located at an elevation of 5 degrees. The figure shows also a deformation of the radiation pattern due to parasitic radiation sources. Compared to the coaxial measurements these unwanted sources are not longer dominant, however, they are causing a relatively strong side lobe in the E-plane at an elevation of about 60 degrees. The gain is about 5 dBi for this direction. A reason for unwanted radiation could be the open end of the feeding microstrip line on the LTCC surface. This effect can be generated by geometry tolerances which result from the manufacturing process.

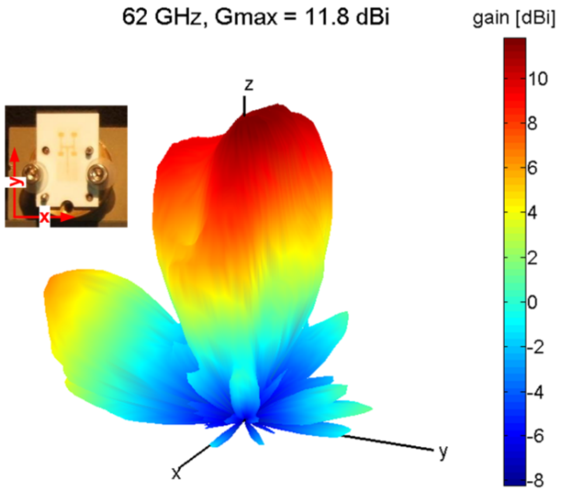

Fig. 7. Representation of the measured three-dimensional radiation pattern of a four-patch antenna array connected to a waveguide-to-microstrip transition at 62 GHz.

To minimise unwanted radiation further measurements were performed while the AUT environment has been manipulated with absorber materials. A piece of absorber was fixed at the lower edge of the LTCC module. This absorber was not directly placed on the microstrip line and did not cover the main beam direction of the AUT pattern. Figure 8 and 9 illustrate the E- and H-plane radiation pattern measurement and the simulation of the four-patch antenna array.

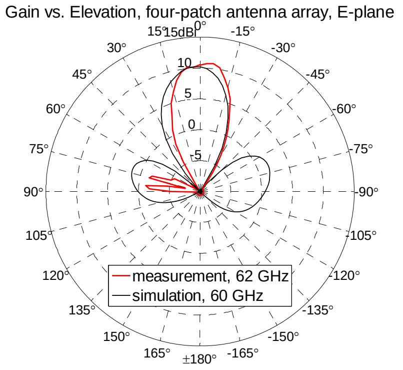

Fig. 8. Measured and simulated E-plane radiation pattern of a four-patch antenna array connected to a waveguide-to-microstrip transition.

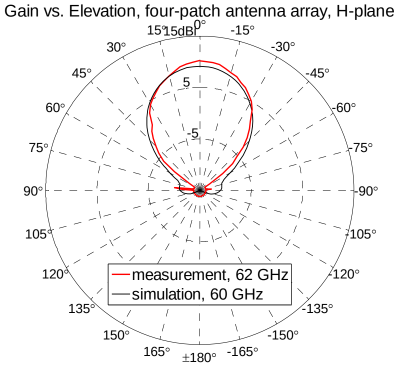

Fig. 9. Measured and simulated H-plane radiation pattern of a four-patch antenna array connected to a waveguide-to-microstrip transition.

Due to the use of absorber material the 5 dBi side lobe is suppressed. Shielding parasitic radiation sources also improves the pattern in main beam direction. The deformation in main beam direction was significantly minimised and the measured pattern agrees well with the simulation pattern. The polar plots are showing a maximum realised gain of 10.9 dBi for a four-patch antenna array. A spectral observation of this measurement data reveals a gain of at least 9 dBi over the whole matched frequency range from 60 to 63 GHz.

The numerically calculated maximum directivity of a four-patch antenna measurement is 14.8 dBi. This value degrades due to the partial coverage by absorber materials and by the influence of the positioner in the anechoic chamber. This tends to result in a too low total radiated power, thus, the value of the measured directivity is slightly too high. This distortion affects less if the test antenna mainly radiates in the upper hemisphere. In this case the AUT pattern is not covered by the antenna positioner. A minimum radiation efficiency of 41 percent is obtained due to the ratio of measured gain to directivity at 62 GHz. Patch antennas generally offer a relatively low radiation efficiency, mainly caused by dielectric and ohmic losses. This measured efficiency takes account of the AUT input matching and corresponds to the measurement of the realised gain.

Furthermore, radiation pattern measurements of a single-patch antenna connected by a waveguide-to-microstrip transition were performed successfully. As previously described even this test antenna was measured using absorber material to cover parasitic radiation sources. One piece of absorber was located at the upper edge, a second one at the lower edge of the LTCC substrate. Figure 10 and 11 show the results of the measurement compared to the simulation of the E- and H-plane radiation pattern. The different plotted frequencies are selected due to the difference of the measured and simulated input matching minimum (Fig. 5). Despite the use of absorbers still slight deformations remain in the radiation pattern of the single-patch antenna and there is only a moderate agreement between measurement and simulation results. A maximum realised gain of about 6 dBi was measured at an elevation of 20 degrees in the E-plane. The frequency response of this single-patch measurement data reveals a boresight gain of at least 3 to 4 dBi over the whole matched frequency range from 61 to 63 GHz. Using the measured directivity of 9.5 dBi a minimum radiation efficiency of 45 percent could be verified at 62 GHz.

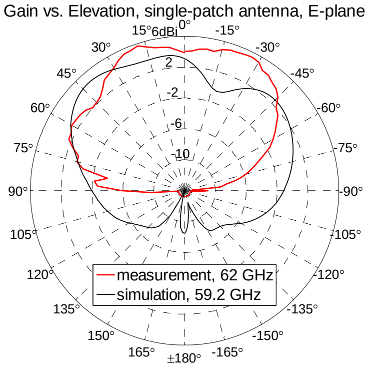

Fig. 10. Measured and simulated E-plane radiation pattern of a single-patch antenna connected to a waveguide-to-microstrip transition.

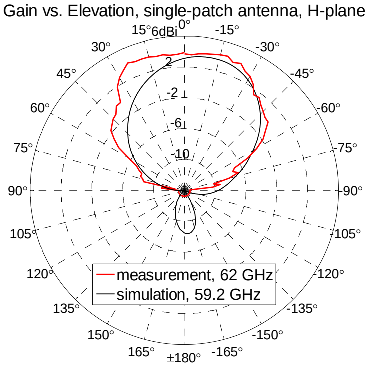

Fig. 11. Measured and simulated H-plane radiation pattern of a single-patch antenna connected to a waveguide-to-microstrip transition.

5. CONCLUSIONS

Two types of 60 GHz transitions were evaluated by comparative measurements of return losses and antenna patterns. A surface mounted coaxial connector exhibits high losses and provides unwanted radiation due to its unshielded coplanar geometry connected to the feeding network of the patch antenna. This parasitic radiation interferes with the AUT-pattern, thus, preventing a reliable measurement of the radiation pattern. By using a planar waveguide-to-microstrip transition integrated in LTCC, first gain and radiation pattern measurements at 60 GHz could be performed successfully. The calibration was done using a reference antenna with known gain and a gain-transfer method.

For a matched frequency range of 61 to 63 GHz, a single-patch antenna reached a realised gain of 3 to 4 dBi in the direction of the main beam. Furthermore, an array of four patch antennas achieved at least 9 dBi over a frequency range of 60 to 63 GHz. The maximum gain at the centre frequency of the matched range amounted to 11 dBi. Both antennas investigated were connected by a waveguide-to-microstrip transition and exhibited a minimum radiation efficiency of 41 to 45 percent, as derived from gain and directivity measurement data.

The results of this contribution are a good basis for further experimental characterisations of planar antennas for wireless high data rate communication applications at 60 GHz.

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