Design and demonstration of a full polarimetric sensor for surface texture characterisation

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***Abstract*—In this paper, a fully poliametric radarsensor is presented which is feasible to transmit and receive all combinations of linear and circular polarisations. Thus, the scattering matrix of different targets can be measured at once and compared to approaches dealing with circular polarisations. The system is optimized to operate between 76 GHz and 78 GHz and can operate using different modulation schemes. Its design as well as the simulations and measurements of the microstrip antennas will be shown, and an approach using circular polarisation for surface textures characterisation will be discussed. Some exemplary simulations and measurements will finally depict this approach.**

***Index Terms*—Polarimetry, scattering, radar waves, W-band, circular polarisation**

I. Introduction

The usability of several polarimetric approaches for surface characterisation, which have been published in the recent decades, have been validated in several areas of applications. Whereas the calculuses of Mueller and Jones, introduced in the early 1940s, are able to handle circular polarisations, main interest has been arisen on dealing with linear polarisations [1][2]. And, in fact, it is possible to calculate the circular polarimetric scatter matrix from the linear one, but there is one special feature of circular polarisation, which is not integrated in scattering matrices. This is about circular waves changing the polarisation from righthand to lefthand and vice versa during single bounce scattering [3]. By emitting circular polarisation, measuring the reflected magnitudes of both polarisations and comparing these values, a ratio of odd bounce scatters and even bounce scatters can be calculated and used for surface texture characterisation.

To investigate the information gathered from circular polarisation and compare these to conventional scatter matrix approaches, a sensor which is able to transmit and receive horizontal, vertical linear-polarisations as well as right- and lefthand circular polarisations independently has been designed. The architecture of this sensor will be introduced in the first part of this paper. Afterwards, a closer look will be taken at the design of the microstrip antennas. Lastly, an approach for surface texture characterisation will be presented and illustrated at simulations and measurements.

II. System design

The system is based on a multi-static eight channel radar, published in [4]. The transmitter circuit as well as the directional coupler are integrated in commercial state of the art SiGe MMICs, which have been developed and fabricated by *Infineon Technologies*. The system block diagram shown in fig. 1 illustrates the basic set-up of the sensor.

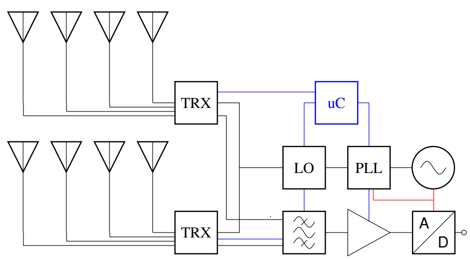

Fig. 1. Block diagram of the presented system

Via SPI-connections, represented in blue, a micro-controller digitally controls the radar MMIC, the PLL, the LO generator, both TRX devices and the characteristics of the bandpass-filter as well as the IF amplifier. The A/D conversion of this demonstrator set-up is done externally by a PCIe converter card. In respect of a proper functionality of operations using FMCW modulations, the clock signal, generated by a highly accurate TCXO, is fed into the PLL and the ADC device simultaneously. The PLL contains an integrated waveform generator, which is feasible to generate linear frequency chirps with programmable modulation bandwidths up to 3 GHz and durations down to 10 µs. The RF board is built in six layers consisting of Rogers 3003 as dielectric laminate between the first two metal layers. The MMICs are soldered using eWLB technique. Therefore complex mounting like gold wire bonding is omitted. The developed PCB is shown in the photography in fig. 2.

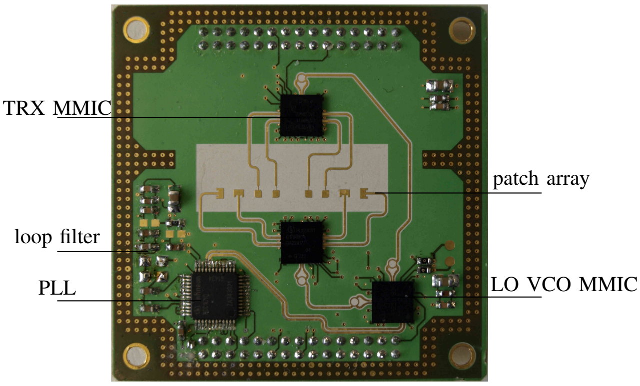

Fig. 2. Assembled radar frontend PCB (based on Rogers 3003 substrate)

Four of the eight microstrip antennas, which are shown in the middle of fig. 2, will be used as transmitting devices, the remaining four antennas as receivers. Both assemblies consist of the same antenna structures which enable sending and receiving linear and circular waveforms independently. The structure of this array supports vertical and horizontal linear polarisations as well as righthand and lefthand circular polarisations. Fig. 3 represents its arrangement. All antennas

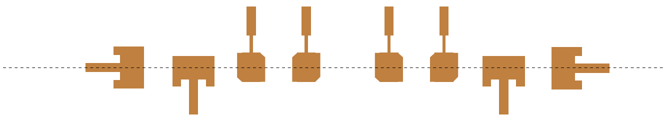

Fig. 3. Layout of the antenna array with patch antenna elements

are centered in the vertical middle of the microwave PCB and therefore of the sensor, which is necessary to enable the usage of a cylindrical lens.

III. System Characterisation

In this section the design of the microstrip antennas as well as their crosstalk will be examined and an insight in the design process of the dielectric lens will be given.

A. Microstrip antennas

The dielectric substrate between the RF ground and the antenna structures is a 0.127 mm Rogers 3003 laminate. Necessary for the planned operations are right- and lefthand circular polarisations as well as horizontal and vertical linear polarisations. While the linear patch can be rotated by 90 degrees to switch polarisation, the structure of the circular antennas has to be adapted to change the direction of rotation.

In the following fig. 4 the dimensions of the linear and the lefthand emitting antenna are drawn. The matching of the

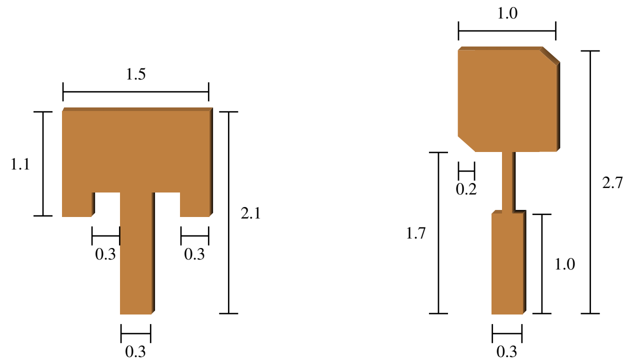

Fig. 4. Sketch of used patch antennas (rounded dimensions in mm)

linear antenna can be optimized by varying the depth and the width of the indent. The direction of polarisation is mainly emitted parallel to the feed.

The matching of the circular microstrip antennas can be influenced by the shape of the patch, the size of the removed corners and the width of the feed, significantly. As it is described in [5] the calculation of the dimensions of a proper working antenna of this kind leads to coarse values, which have to be refined during further measurements and simulations. The measured values of both antennas agree with

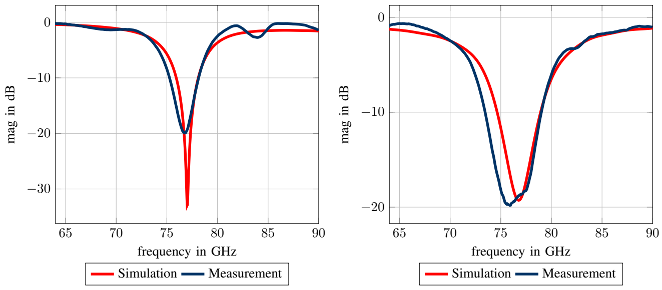

Fig. 5. Comparison of the simulated and measured matching values of the linear polarising (left) and the circular polarising (right) microstrip-antenna

the simulated ones and exhibit a proper matching between 76 to 78 GHz, which can be seen in fig. 5.

Furthermore, and very important for polarimetric investigations, a high level of linear or circular polarisation has to be guaranteed. In order to measure these values, one way antenna patterns have been recorded. A pyramidal standard gain horn antenna has been used as a receiving antenna. The orientation of this device determines which polarisation is received and which one is filtered out [6]. The red graphs in fig. 6 represent the received power with the polarisation of the receiver turned parallel to the feed of the micrsotrip antennas. After revolving the horn antenna around boresight by 90 degrees, the values plotted in blue were measured. The turquoise plots represent the ratio between these two measurements for both antennas over azimuthal direction.

While linear microstrip antennas can be considered as self-polarising, as described in [7], the adjustment of the circular polarisation is more challenging. Values differing slightly in a range of ± 3 dB are desired. These boundaries are marked in fig. 6. As it can be seen, the circular patch antenna satisfies this requirement in azimuthal angles from -20 to 20 degrees.

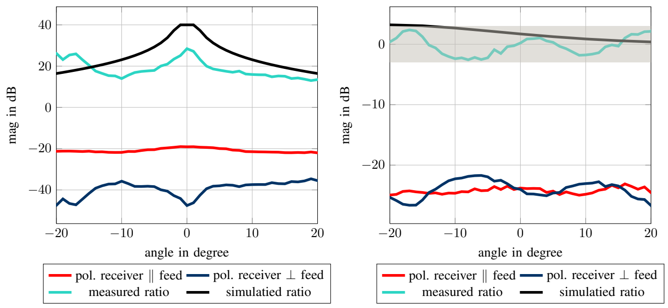

Fig. 6. Comparison of the simulated and measured polarisation values of the linear polarisation (left) and the circular polarisation (right) emitting microstrip-antenna

To ensure that the values obtained before derive from proper polarisations, the receiving horn antenna has been put right in front of the patch antennas successively measuring the incoming power while revolving around boresight. Fig. 7 shows the obtained values gathered from linear and circular polarisation antenna over the angle of rotation.

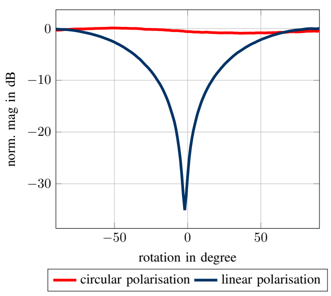

Fig. 7. One way antenna pattern measurement of both microstrip antennas while revolving receiver around boresight

B. Crosstalk

To ensure a sufficiently low blocker, the crosstalk between the antennas has to be minimized. Most important are low crosstalk values between the sending and receiving antennas. Thus, the sending and receiving antennas are separated locally on the PCB as far as possible. Fig. 8 represents the values of the most crucial ones. The values which are not plotted in this figure are far below and are omitted to preserve good visibility. The antennas are numbered from left to right as seen in fig. 3. Highest amount of crosstalk takes place between the circular polarising antennas. However, the values around -30 dB are sufficient for an analysis of the measured signals.

C. Dielectric lens

To achieve a proper focussing of the radar beams, a dielectric planoconvex cylindrical lens out of polyetherimide has

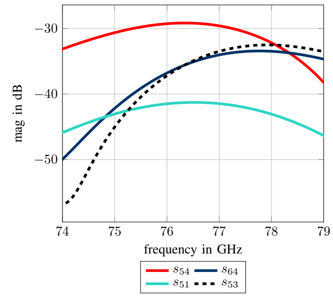

Fig. 8. Simulated results of the crosstalk between the microstrip antennas

been designed . The results plotted in fig. 9 on the left hand side originate from a simulation which has been executed in *CST MWS* in order to optimize the focal point suitable to the distance between the housing of the radar sensor and the patch antennas, which are located in the origin of this coordinate system. The exemplary farfield resulting from the combination of one circular patch antenna and the dielectric lens is plotted beside it. Because the cylindrical lens focuses the emission just in one direction, a narrow strip can be measured at once.

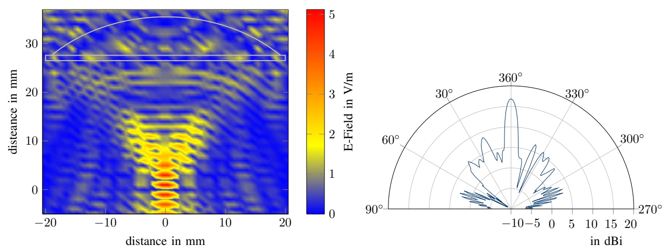

Fig. 9. Distribution electrical field (left), farfield dielectrical lens (right)

IV. Exemplary set-up

On the basis of the theoretical observation that circular polarisations change the direction of rotation at every reflection, this method deals with a comparison of the received magnitudes of the two circular polarisations after sending out one of them. In this way the amount of odd bounces can be compared to those of even bounces.

To prove whether this concept can be integrated in the characterisation of surfaces, simple set-ups have been arranged. The first one deals with the transmission of two righthand circular microstrip antennas radiating towards a plate. This result is compared to the exact same set-up except one antenna being replaced by the lefthand counterpart. In order to create an arrangement in which only double bounces occur, the reflecting object has been replaced by a dihedral angle. Same antenna assemblies as described before have been executed. The two set-ups are depicted in fig. 10.

A. Simulated results

Due to the fact that only one single bounce occurs in the set-up containing the plate, the two way response of equal antennas is far below the simulation with different ones, as it

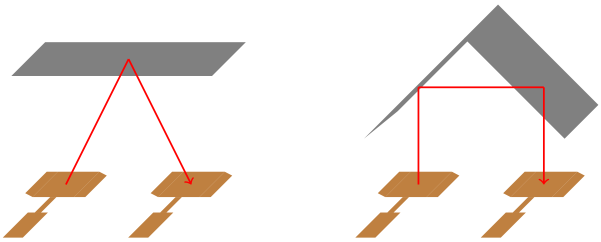

Fig. 10. Sketch of the simulation assembly with the plate (left) and the dihedral object (right)

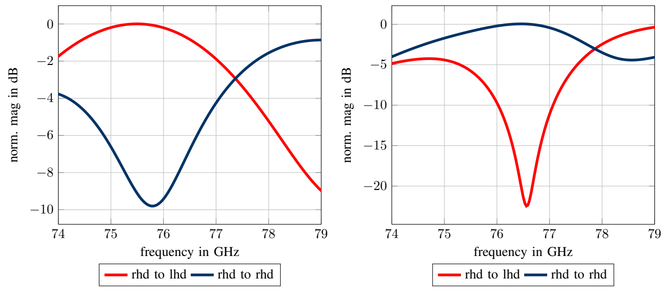

Fig. 11. Simulated results of circular polarisation in righthand to lefthand and righthand to righthand direction of roatation at plate (left) and dihedral (right)

can be seen in fig. 11 at the right hand side. In double bounce situations, transmission values of equal antennas exceed the other ones gathered from the simulation with different antennas plotted on the right. The more increased effect in the right plot can be explained due to the higher crosstalk between two identical antennas. Since the antennas, described in the section before, do not radiate perfectly polarised waves, the results differ slightly from theoretically expected values. However, a distinction can be seen clearly and further information can be accomplished in addition to the conventional scatter-matrix.

B. Measurement results

Measured results can be seen in fig. 12. Both, contrary and similar circular polarisations are plotted in each diagram of the figure, whereas the aim selection is different. On the left hand side, a plate oriented towards the electromagnetic waves is used to create a single bounce situation in about 1.55 m. As expected, a high magnitude of the contrary circular polarisations is achieved in comparison to similar ones.

Next to this plot, opposed results can be seen resulting out of a generated double bounce situation at the same distance, as it has been described in fig. 10. The double bouncing at the dihedral leads to a double change of the direction of the circular polarisation.

V. Conclusion

The architecture of the developed sensor has been presented and the used microstrip antennas has been discussed. The antennas exhibit good matching values in the frequency range from 76 to 78 GHz. The axial ratio of the antennas designed to emit and receive linear polarisation is about 20 dB. The axial ratio of the circular polarised antennas differs slightly

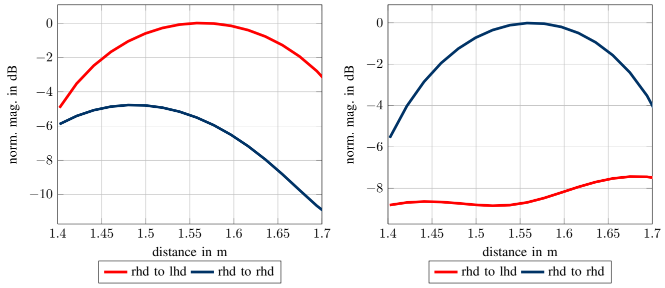

Fig. 12. Measured results of circular polarisation in righthand to lefthand and righthand to righthand direction of roatation at plate (left) and dihedral (right)

in the range of ±3 dB. The values of the crosstalk between the microstrip antennas has been simulated to have a minor impact. In addition, an approach to characterize the condition of surfaces has been introduced and approved by two exemplary set-ups, which have been simulated and compared to measurements. The photo in fig. 13 shows the sensor integrated in a solid metal case with a dielectric plano-convex cylindrical lens.

Fig. 13. Sensor system with a dielectric plano-convex cylindrical lens

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