GeMiC 2009, 16 - 18 March 2009, München, Germany

# Characterization of Reconfigurable LC-Reflectarrays Using Near-Field Measurements

Sabine Dieter*, Alexander Moessinger†, Stefan Mueller†, Wolfgang Menzel*, Rolf Jakoby†

* Institute of Microwave Techniques
University of Ulm,
Ulm, Germany
e-mail: sabine.dieter@uni-ulm.de

† Department of Microwave Engineering
Technische Universität Darmstadt,
Darmstadt, Germany
e-mail: moessinger@mwt.tu-darmstadt.de

*Abstract*— **A new measurement method for characterization of liquid crystal reflectarrays (LC) is presented. The phase and amplitude characteristics are determined by near-field measurements close to the antenna surface, using high resolution probes, which have been developed to resolve individual patches on the reflectarray. Measurement results showed a phase angle range of 280° of individual detected LC patches. The measurement setup and corresponding measurement results at 35 GHz are presented. The procedure used for measurement automation is also explained.**

***Keywords***- *High resolution probe; liquid crystal;, near-field characterization; reconfigurable antenna; reflectarray;*

## I. Introduction

Reflectarrays have attracted an increasing interest due to their advantages of planarity, low cost, low weight, and ease of fabrication [1-2]. The benefits of this principle have also initiated the development of reconfigurable reflectarrays, which make use of varactor diodes, MEM-switches or tunable liquid crystal material (LC), a material which dielectric properties can be tuned by applying a bias voltage [3-5].

The reflection behaviour of the unit cells can be simulated by use of commercial software, where the assumption of an infinite array with uniform unit cells is made.

In addition, however, an experimental way to examine the reflection behaviour of the elements is needed, especially for liquid crystal reflectarrays, where the setup of the tunable unit cells is sensitive to manufacturing tolerances, as reported in [5]. Prototype unit cells can be investigated in a waveguide simulator measurement in order to detect their amplitude and phase characteristics [6]. Besides that, a farfield measurement method is used, where the reflection behaviour over all patches is examined [7]. There is also an interesting method of near-field measurements as a basis for reflectarray antenna design at 15 GHz [8]. It makes use of a monopole probe with the length of $\lambda/16$, which is penetrating from the metallic ground plane below the scatterer elements.

In this paper, the reflection behaviour of each unit cell is characterized individually. For that purpose, near-field measurements are performed a few millimeters above the antenna surface using probes developed for this application.

This work was supported by the DFG-Project “Rekonfigurierbare Millimeterwellenantennen mit steuerbaren hoch-anisotropen Flüssigkristallen”.

## II. Near-Field Measurement Setup

For the detection of the reflected field components, near-field probes with high spatial resolution are needed in order to assign the measurement results to the individual patches. For this purpose, three different near-field probes have been developed using a full-wave simulation tool [9], they are introduced in [10].

The measurement setup can be seen in Fig. 1, it is performed at a near-field measurement x-y-table. The reflectarray patches of the DUT are illuminated by an open waveguide (TX), a near-field probe (RX) is used to detect the reflected field components. The DUT position is controlled automatically during measurement.

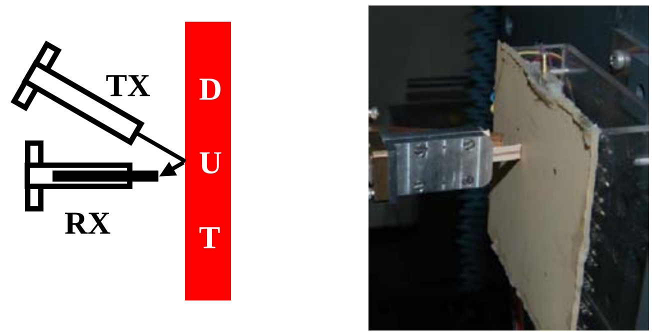


Fig. 1 Near-field measurement setup for reflectarray characterization with a liquid crystal reflectarray as DUT.

The device under test is an electronically reconfigurable reflectarray based on liquid crystal, which has been introduced in [5]. It consists of 16x16 unit cells, both unit cell dimensions are 0.55λ. The cavity between top and bottom carrier is filled with LC-material, acting as a substrate with tunable permittivity. Each row can be controlled individually, by adding a voltage between 0 V and 15 V, respectively. With the control voltage, the effective permittivity of the liquid crystal substrate material changes and with this, the electrical length of the patches in this reflectarray row. Using this method, reflection phase and amplitude characteristics vary, controlled by the supply voltage of the reflectarray rows and therefore, reconfigurable beam-steering in one dimension is possible with this antenna.

In [11], we have shown in principle, that measurement results with spatial resolution are possible with near-field measurements, but there is a need for the development of probes with high resolution. The proposed measurement setup (Fig. 1) and the usage of high resolution probes allow to characterize the reflection behaviour of each patch separately. With this method, a data base for beam adjustment is provided.

## III. Measurement Results With a Dipole Probe

The design of the dipole probe is based on a waveguide with a substrate suspended in the E-plane, as it is shown in Fig. 2. The substrate material is Rogers 3003 with a dielectric constant of 3.0 and the thickness 0.254 millimeters. At the maximum field strength in the center of the waveguide, the field is guided in a finline with a transition to a dipole, which is optimized for 35 GHz. The measured and simulated return loss is shown in Fig. 2.

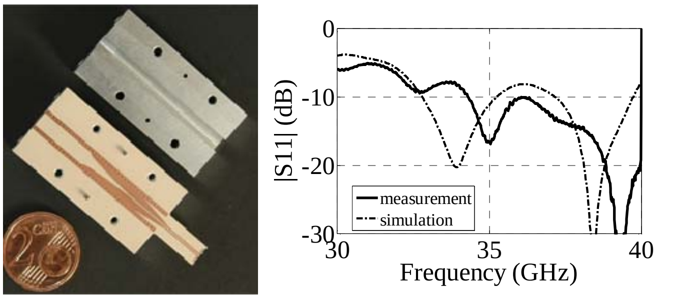


Fig. 2 Photograph and return loss of the dipole probe.

Fig. 3 shows the amplitude result of a near-field scan of one section on the liquid crystal reflectarray antenna; the grid shows the sampling points. For this test all control voltages are set to the same value. This measurement shows good results with respect to the resolution. Each patch can be identified separately, as it can be seen in Fig. 3.

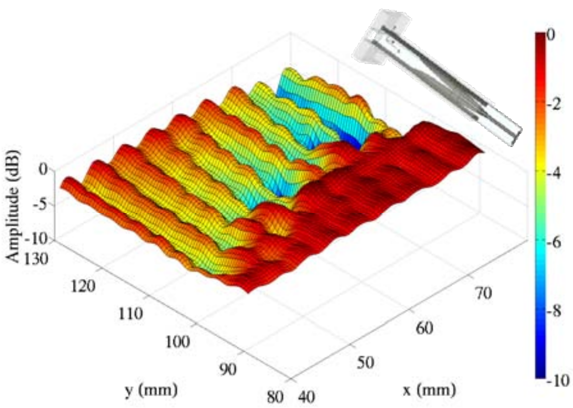


Fig. 3 Measured amplitude near-field scan of liquid crystal reflectarray with the dipole probe.

For the lower y-dimensions, a defective part of the antenna can be located with the probe. The resolution in y-dimension is not as accurate as in the x-dimension due to the geometrical size of the dipole in this dimension. Another problem of this probe is the appearance of crosstalk, a direct signal path from the transmitting waveguide to the probe which leads to a smaller measurement dynamic range and maybe also a complex offset on the results. This disturbing signal can be calibrated by a measurement without DUT and vectorial substraction of this signal.

## IV. Measurement Results With A Substrate-Integrated Waveguide Probe

Fig. 4 shows a substrate-integrated waveguide probe. It consists of a metal waveguide with a transition to a substrate-integrated waveguide [12], metalized on top and bottom and enclosed with vias.

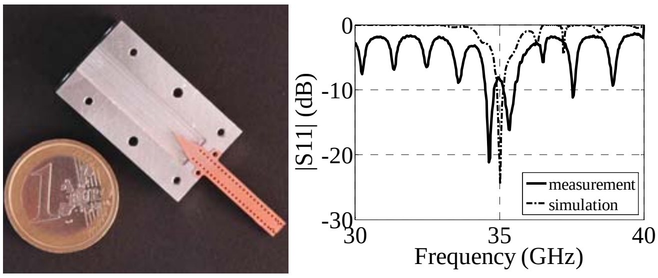


Fig. 4 Photograph and return loss of the substrate-integrated waveguide probe.

The used substrate (Rogers RT 6010) has a thickness of 1.27 millimeters and a high permittivity of 10.8. This high permittivity allows very small waveguide dimensions and therefore a very small tip dimension of less than two millimeters, which leads to a very high resolution.

This substrate implicates, however, a high permittivity step, both at the inner waveguide transition and at the tip of the probe. This leads to reflections, and therefore, further modifications on the design have been made in order to improve matching for the frequency range around 34 GHz to 36 GHz, as it can be seen in Fig. 4.

The substrate-integrated waveguide probe shows very good spatial resolution in both dimensions, see Fig. 5. All patches can be detected individually with this probe, and the setup doesn’t suffer from crosstalk problems. The defective region of the antenna can be located with this probe as well.

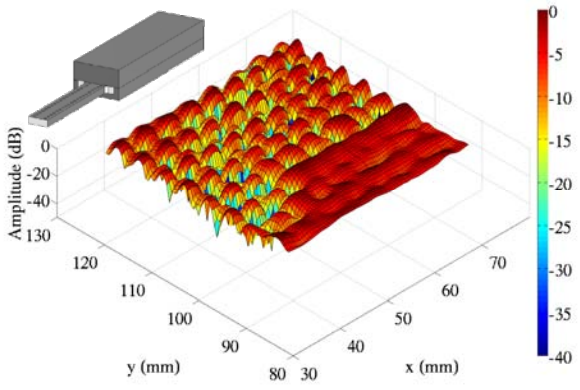


Fig. 5 Measured amplitude near-field scan of liquid crystal reflectarray with the substrate-integrated probe.

## V. Characterization of Individual Patches

In the measurement setup (Fig. 6) the instruments are controlled via GPIB. The RF oscillator creates a signal at a frequency of 35 GHz, both for the test and a reference signal. The LO-signal and the mixers down-convert both signals to a frequency of 4 GHz at the input of the network analyzer (a1 and b1). Transmitter waveguide (TX) and probe (RX) are installed in front of the LC-reflectarray, whose position is controlled by the x-y-table.

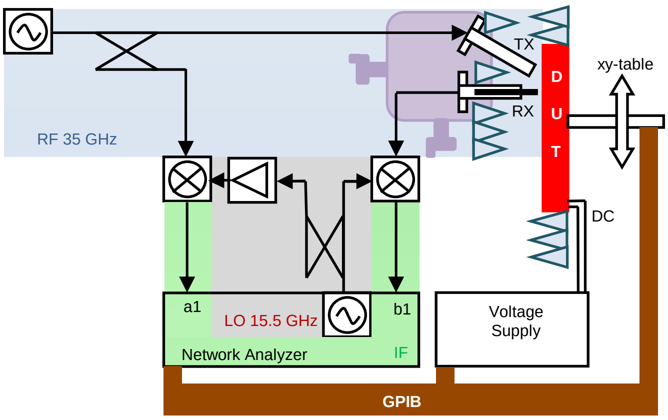


Fig. 6 Measurement setup for automated near-field method.

The voltage supply provides the control voltages for the LC-reflectarray and is also controlled via the GPIB. This allows to characterize the reflection behavior as a function of the control voltage for single patches of the antenna. In Fig. 7 the phase and amplitude result for such a measurement in the LC-filled region of the antenna is shown. The phase angle range is 280°, and there is an amplitude drop of 9 dB at the resonance of the patch at about 3.5V. Almost no hysteresis is observed when tuning on and off.

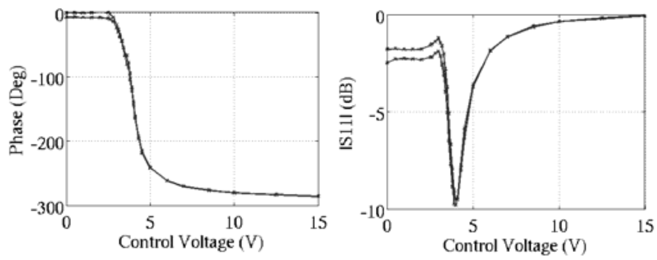


Fig. 7 Measured phase and amplitude characteristics for one patch.

Fig. 8 shows an equivalent measurement of an individual patch, but this time, located in a defective region of the antenna. The small change in amplitude and phase indicates that broken regions of the LC-array can be detected automatically with this method.

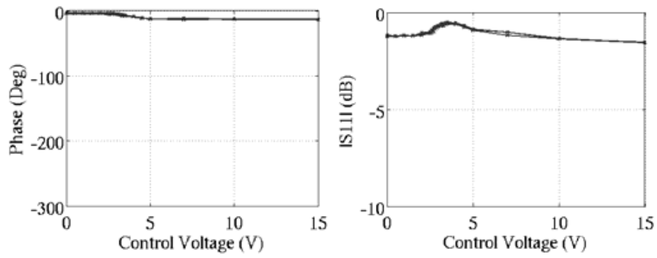


Fig. 8 Measured phase and amplitude for one patch located in the defective antenna region.

## VI. Measurement Automation

In Fig. 9 a block diagram of the automated near-field measurement procedure is shown. In a first step, the whole antenna is sampled, and a code for maxima extraction has been implemented.

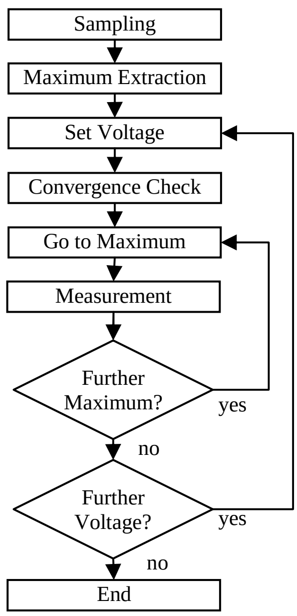


Fig. 9 Block diagram of the automated near-field measurement procedure.

An example for this amplitude result is given in Fig.10, and also the locations of corresponding automatically detected maxima, which are marked with numbers 1 to 64. The part with the lower y-dimension again shows the defective region of the antenna. Maxima detection in this region is difficult, even manually.

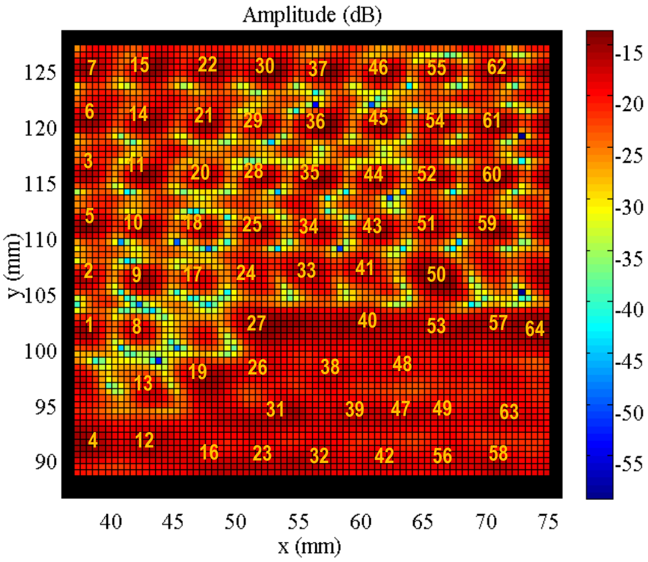


Fig. 10 Sampled nearfield-scan and marked locations of the maxima positions, obtained with automatic detection.

As it can be seen in Fig. 9, the locations of the detected maxima are stored, and then can be automatically approached for each control voltage. As there is some delay from a change of the tuning voltage to the final value of the modified dielectric constant, a convergence check for the measurement results is included in the measurement procedure. So it is made sure, that the switching time of the tunable LC-material is reached and the effective permittivity is constant before the measurement in phase and amplitude takes place. With these data it is possible to use the results for diagram synthesis based on the characteristics of each individual patch.

## VII. Conclusion

In this paper, the reflection characteristic of a LC-reflectarray is measured with a near-field measurement setup. The detection and characterization of individual patches is possible using probes with high spatial resolution developed for this purpose. The amplitude and phase characteristics can be determined automatically for individual patches as well as defective antenna regions.

The performance of two probes has been compared for this purpose, the substrate-integrated waveguide probe shows the best results for this application.

For measurement automation, the steps of the measurement procedure are described, the results of maxima detection and the phase / amplitude performance of individual patches are given. With these characteristics for all individual patches it is possible to use the results for diagram synthesis.

## Acknowledgment

This work has been funded by the German Research Association (DFG).

## References


[1] D. M. Pozar, S. D. Targonski, and R. Pokuls, "A shaped-beam microstrip patch reflecarray," in *IEEE Trans. Antennas Propag.*, vol 47, pp.1167-1173, Jul. 1999.

[2] Ralf Leberer and Wolfgang Menzel, "A dual planar reflectarray with synthesized phase and amplitude distribution," in *IEEE Trans. Antennas Propag.*, vol. 53, no. 11, November 2005, pp. 3534-3539.

[3] S. V. Hum, M. Okoniewski, and R. J. Davies, "Realizing an electronically tunable reflectarray using varaktor diode-tuned elements," *IEEE Microwave and Wireless Component Letters*, vol. 15, 2005.

[4] H. Legay, B. Pinte, M.Charrier, A. Ziaei, E. Girard, and R. Gillard, "A steerable reflectarray antenna with Mems controls," I*EEE International Symposium on Phased Array Systems and Technology*, pp. 494-499, 2003.

[5] A. Moessinger, R. Marin, S. Mueller, J. Freese, and R. Jakoby, "Electronically reconfigurable reflectarrays with nematic liquid crystals," *Electronics Letters*, vol. 42, pp. 899-900, aug 2006.

[6] R. Marin, A. Moessinger, J. Freese, and R. Jakoby, "Characterization of 35 GHz tunable reflectarray unit-cells using highly anisotropic liquid crystal," *German Microwave Conference*, Karlsruhe Germany, March 2006.

[7] R. Marin, A. Moessinger, F. Goelden, S. Mueller, R. Jakoby, "77 GHz reconfigurable reflectarray with nematic liquid crystal," 2nd *European Conference on Antenna and Propagation*, Edinburgh UK, November 2007.

[8] Jean-David Lacasse and Jean-Jacques Laurin, "A method for reflectarray antenna design assisted by near field measurements," in *IEEE Trans. Antennas Propag.*, vol. 54, no. 6, June 2006, pp. 1891-1897.

[9] CST AG: CST Studio Suite 2008, Version 2008.03 , Darmstadt Germany, Jan 2008.

[10] S. Dieter, W. Menzel, „High-Resolution Probes for Near-Field Measurements of Reflectarray Antennas," accepted for publication in *IEEE Antennas and Wireless Propagation Letters*, 2009.

[11] A. Moessinger, S. Dieter, R. Jakoby, W. Menzel, S. Mueller, „Reconfigurable LC-reflectarray setup and characterisation, " accepted for *European Conference on Antennas and Propagation*, Berlin, 2009.

[12] D. Deslandes, K. Wu, "Integrated microstrip and rectangular waveguide in planar form," *IEEE Microwave Wireless Component Letters*, vol. 11, no. 2, pp. 68-70, Feb. 2001.