Active Switched Antenna Array for a 77 GHz Digital Beamforming Radar

P. Feil* T. Chaloun*

***Abstract* — Imaging radars incorporating digital beamforming (DBF) typically require a uniform linear antenna array (ULA). However, using a large number of parallel receivers increases system complexity and costs. A switched antenna array can provide a similar performance at a lower expense. This paper describes an active switched antenna array with 32 integrated planar patch antennas illuminating a cylindrical lens. The array can be operated over a frequency range from 73 GHz–81 GHz. Together with a broadband FMCW frontend (Frequency Modulated Continuous Wave) a DBF radar was implemented. The design of the array is presented together with measurement results.**

1 Introduction

In recent years, the application of imaging mm-wave sensors at 77 GHz-81 GHz has gained increasing interest. Automotive suppliers in Europe are forced by administrative regulations to shift their wideband short range systems from 24 GHz to this frequency range. Hence, the development and availability of active components has improved and the costs dropped significantly. Also beside the automotive field, there are many industrial applications which can benefit from the large bandwidth and compactness of mm-wave sensors [1, 2].

Switched antenna arrays are proven to be good candidates for high resolution DBF applications [3]. Thereby, switching the transmitting antennas is advantageous compared to a switched receiving array. Amplification stages can easily compensate for losses occurring in the distribution network while the receiver noise figure is not affected. This contribution describes an active switched antenna array with 32 integrated planar patch antennas illuminating a cylindrical lens. The array can be operated over a frequency range from 73 GHz–81 GHz. Together with a broadband FMCW frontend (Frequency Modulated Continuous Wave) a DBF radar was implemented. The design and implementation of the array is presented together with measurement results.

2 Design and Fabrication Technology

A block diagram of the active switched array is shown in Fig. 1. It comprises a five stage SP32T switching network with 31 SPDT switches [4]. After the first stage two amplifiers [5] are inserted to compensate for transmission line and switch insertion losses. 32 transmitting antennas are connected to the network. One receiving antenna is placed on each side of the transmitting array. This configuration forms an equivalent aperture, which is about twice the geometrical size of the array aperture [3]. The mm-wave circuit is implemented on the PTFE based metal backed substrate Taconic TaclamPlus [6]. The height of this substrate is only 0.1 mm. As the required relative bandwidth of the antenna elements is about 10%, the 34 patch antennas are fabricated on an embedded Taconic TLX-9 substrate with a height of 0.38 mm (cf. Fig. 1). The connection is made by wire bonding. Fig. 2 shows the hardware of the switched array. The actual mm-wave circuit is covered by a standard FR-4 PCB providing DC supply and bias for amplifiers and switches. An opening of sufficient size is cut into this PCB to allow the patch antennas radiating

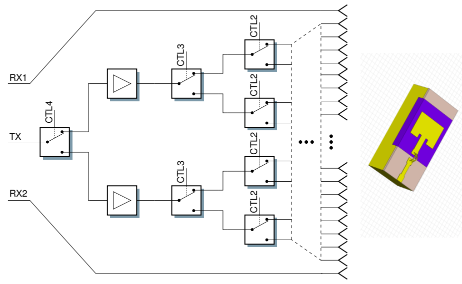

Figure 1: Block diagram of the switched antenna array (left); schematic of embedded patch antenna (right).

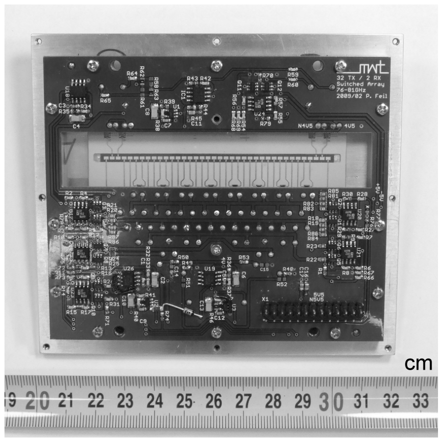

Figure 2: Photograph of the active switched patch array.

*Institute of Microwave Techniques, University of Ulm, Albert-Einstein-Allee 41, 89081 Ulm, Germany, e-mail of corresponding author: peter.feil@uni-ulm.de.

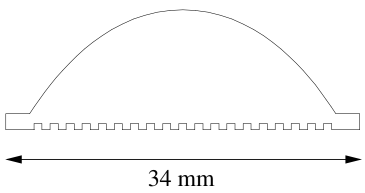

Figure 3: Cross section of the cylindrical lens.

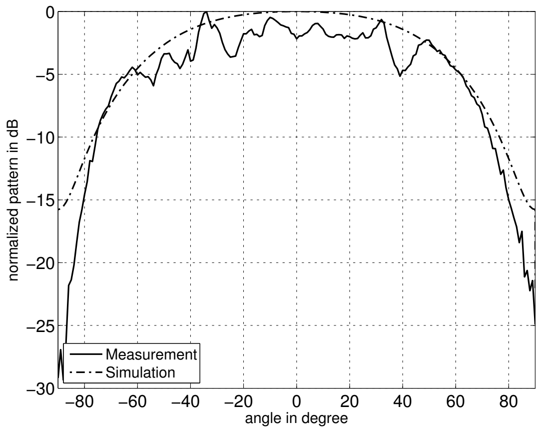

Figure 4: Simulated and measured radiation pattern of a single patch antenna in the H-plane.

without perturbation.

To achieve a narrow beam width in the plane perpendicular to the array, a cylindrical lens was designed, whose cross section is shown in Fig. 3. The gratings on the flat side of the lens are designed to reduce reflections at the air-dielectric interface.

3 Measurement Results

Design and optimization of the embedded patch antenna has been done using CST Microwave Studio. The farfield measurement (Fig. 4) shows a good agreement with the simulated results. The ripple occurring in the measured pattern is caused by the finite substrate size.

The idea of a cylindrical lens design is to preserve the antenna pattern of the primary source in one plane and shape the beam in the perpendicular plane. For thin lenses and a sufficiently large focal length this goal can be met almost perfectly. In case of thick lenses, the spherical wave originating from the primary source is disturbed by the twofold refraction at the air-dielectric interfaces. In the described setup the focal length is very small ($F = 15\,\text{mm}$) and the thickness of the lens is up to $15\,\text{mm}$. Hence, a degradation of the pattern can be expected and is seen in Fig. 5. Due to the reduced 3dB beam width the field of view of the switched array is limited to $\pm 25°$. This may be too small for some applications. One possibility to overcome the effects of a thick lens could be using a Fresnel design.

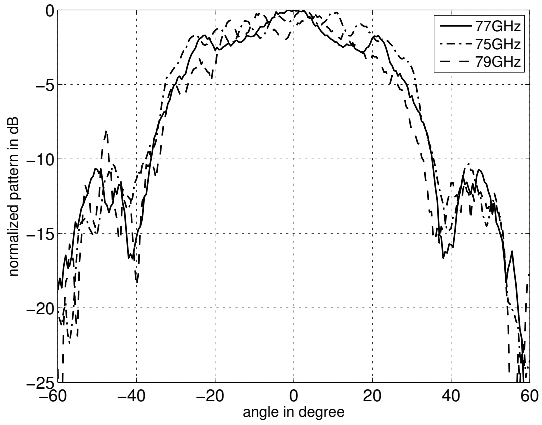

Figure 5: Measured radiation pattern of a single patch antenna illuminating the cylindrical lens (H-plane).

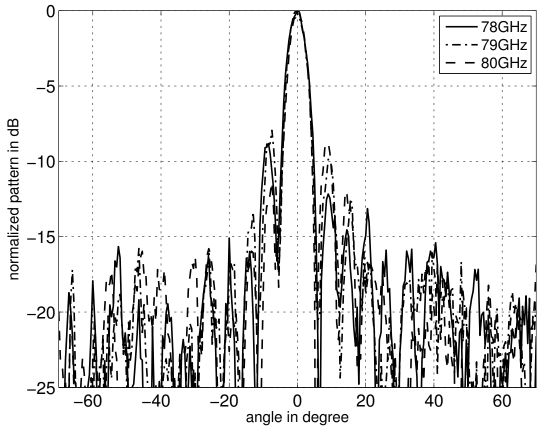

Figure 6: Measured radiation pattern of a single patch antenna illuminating the cylindrical lens (E-plane).

In the perpendicular plane, a narrow beam width of $5°$-$6°$ was achieved (s. Fig. 6). Even tough there is an amplitude tapering down to $-8\,\text{dB}$ at the edges of the lens, the sidelobe attenuation is in the order of 10 dB-13 dB. This is much higher than theoretically expected. The reason may be also found in the large thickness of the lens. In order to improve the antenna pattern in both planes, a redesign of the lens will be a topic of the future work.

As the array is intended to be operated over a wide frequency range, the antenna gain of the active switched array has been measured over frequency. Fig. 7 shows the results of some representative switching states in comparison with a passive patch antenna. In both cases the setup included the cylindrical lens. The passive antenna shows a flat response within the desired range from 73 GHz to 81 GHz. The maximum ripple is $\pm 2\,\text{dB}$. For the active array, the amplifiers almost compensate for the losses occurring within the switching network. A significant drop around 79 GHz is apparent for all states, but the depth strongly depends on the

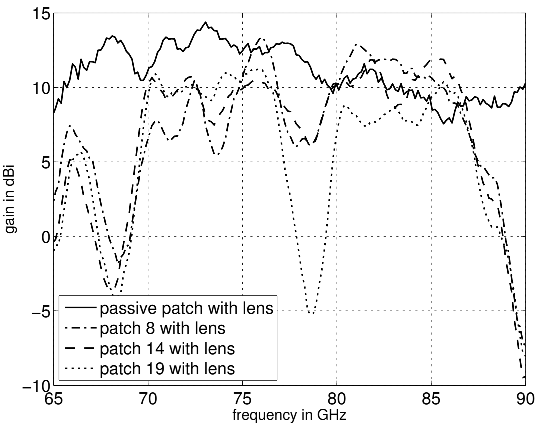

Figure 7: Antenna gain over frequency for all switching states.

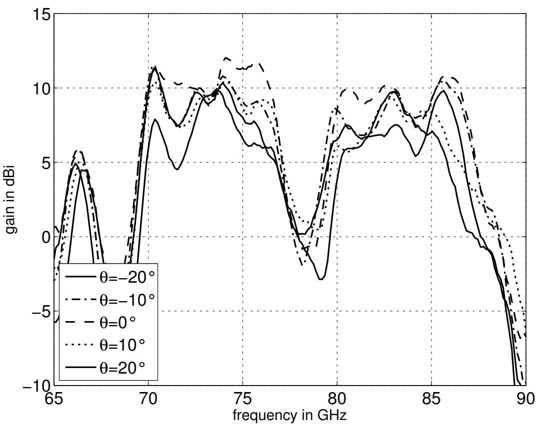

Figure 8: Antenna gain over frequency for different angles θ.

switching state as visible in Fig. 7. As the RF circuit is perfectly symmetric, the switches may be responsible. An imperfect isolation of a switch in stage five would lead to a spurious radiation of the adjacent patch. But in this case the drop in the frequency response would change as a function of the angle. This could not be verified during the measurements (s. Fig. 8). It has been noticed, that the forward bias voltage of the PiN-diodes varies among the switches. This may indicate, that some of them are not operating properly. Additionally, they are designed for narrowband automotive applications from 76 GHz-77 GHz and no wideband scattering parameters are available. However, the problem will be further investigated.

Finally, the switched array has been combined with a broadband FMCW sensor (Frequency Modulated Continuous Wave) as described e.g. in [2]. The sensor can be operated between 73.5 GHz-81 GHz and provides the two receiving channels necessary for the intended system. As a first measurement scenario, three targets have been placed within an anechoic chamber. The bandwidth used in this experiment was 4.8 GHz. The result

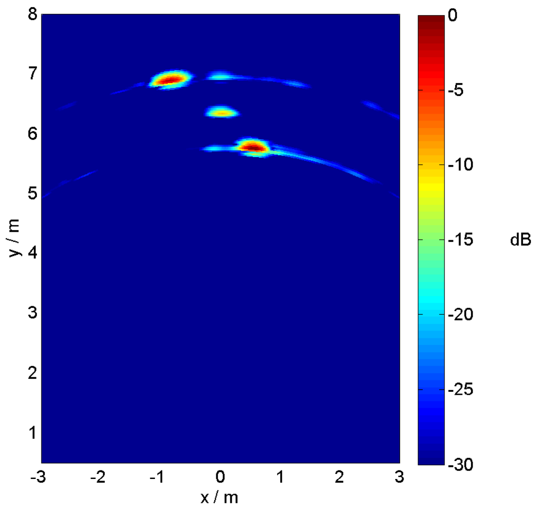

Figure 9: Radar measurement of three objects located within an anechoic chamber.

obtained by delay-and-sum beamforming is presented in Fig 9. The resolution achieved with this beamformer is about 7 cm in range and 2.4° in the angular dimension. This matches the theoretically expected values.

4 Conclusion

This contribution describes the design and implementation of a broadband active switched array for DBF radar at 77 GHz. Even though the overall system is proven to work, there is some room for improvement for the single components. On the one hand a new lens design could increase the field of view. And on the other hand the frequency response of the switching network limits the usable frequency range. Both aspects will be adressed in the future work.

References

[1] K. Nienhaus, R. Winkel, W. Mayer, A. Gronau, and W. Menzel, “An experimental study on using electronically scanning microwave radar systems on surface mining machines,” in *Proc. IEEE Radar Conference*, 2007, pp. 509–512.

[2] P. Feil, W. Menzel, T. P. Nguyen, C. Pichot, and C. Migliaccio, “Foreign objects debris detection (fod) on airport runways using a broadband 78 ghz sensor,” in *Proc. European Radar Conference EuRAD 2008*, 2008, pp. 451–454.

[3] W. Mayer, A. Gronau, W. Menzel, and H. Leier, “A compact 24 ghz sensor for beam-forming and imaging,” in *Proc. 9th International Conference on Control, Automation, Robotics and Vision ICARCV ’06*, 2006, pp. 1–6.

[4] M/A-Com, “MA4GC6773 - 77 GHz GaAs SP2T PIN Diode Switch,” Datasheet v2.00.

[5] Hittite, “HMC-AUH320 - GaAs HEMT MMIC MEDIUM POWER AMPLIFIER, 71 - 86 GHz,” Datasheet v02.0408.

[6] Taconic Advanced Dielectric Division, “A new low loss, laser ablatable substrate for microwave circuitry,” *Microwave Journal*, vol. 47, no. 7, pp. 104–110, 2004.