

Circularly polarised digital beam forming transmitting array for mobile satellite communications

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Abstract: This paper presents a circularly polarised Digital Beam Forming (DBF) antenna array. The array consists of 4×4 elements (Fig. 2), and forms a building block for high gain DBF arrays for mobile satellite communications at 30 GHz (Fig. 1). After a general introduction, the antenna element and interconnect design will be discussed. Subsequently, the transmitter architecture will be introduced to illustrate the complexity of the whole system. Finally, measurements of the electronically steered array are presented.

I. Introduction

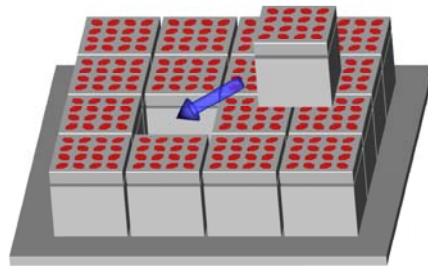


Fig. 1: Modular concept of the high gain DBF antenna array.

Satellite communication systems offer unique possibilities to connect mobile users to data networks and multimedia services. In order to satisfy the ever increasing demand for higher bandwidth the attention of system providers will move to highly adaptive antenna systems operating at Ka-Band. Antennas employing digital beamforming, which offer capabilities such as fast and flexible beamsteering, are the most promising solution. The design presented here is based on earlier studies ([1],[2]) that suggest a modular approach to build up a high gain DBF antenna array as depicted in Fig. 1.

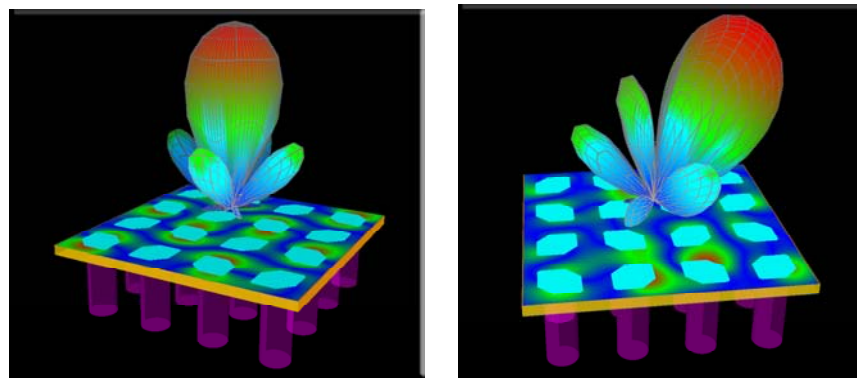


Fig. 2: Far field patterns of 4x4 antenna array, set at two different radiation directions simulated with FDTD simulator EmpireTM [6].

II. Antenna and interconnect

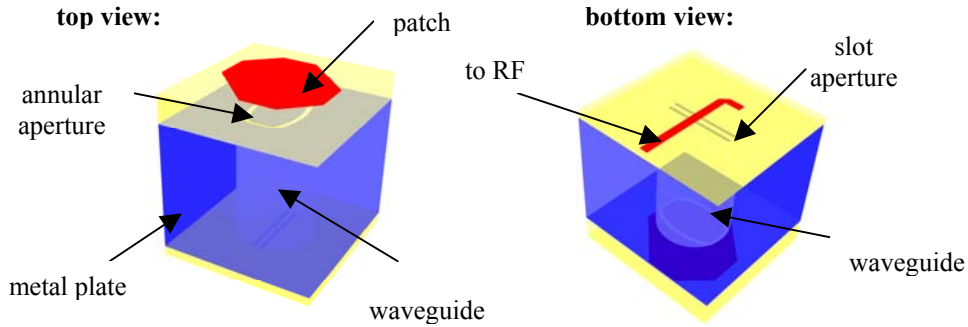


Fig. 3: Circularly polarised antenna element and waveguide interconnect.

The DBF antenna array consists of circularly polarised patch elements with truncated corners, operating in the range of 29.5 to 30.0 GHz. This element type only requires a single substrate layer, thus providing low cost and easy manufacturing of the antenna array. The antenna layer is mounted on a thick metal plate as shown in Fig. 3. On its bottom side, this metal plate supports the RF-circuitry. A dielectrically filled circular waveguide ($\epsilon_r=8$) provides the interface from the RF-layer to the antenna layer. The waveguide transitions are field coupled by apertures in the ground plane of the RF-circuit as well as in the ground plane of the antenna.

The shape of the annular aperture is complex since there are two different parameters to be matched, the return loss of the antenna and the axial ratio of the element. Furthermore, the required resonance length of the aperture would exceed the available dimensions of the waveguide if a usual slot was used. The selected aperture shape is optimised to fit in the small area provided by the waveguide diameter of 2.3 mm. Similar shapes have been reported in [3].

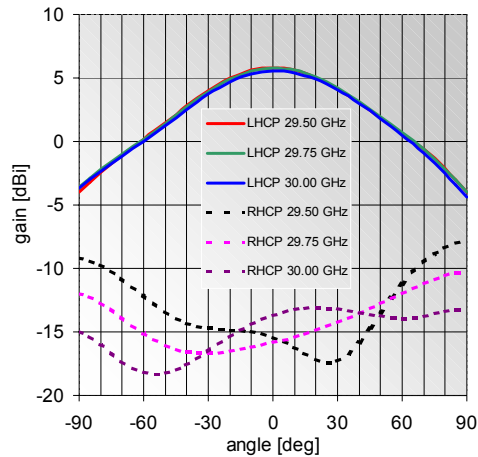


Fig. 4: Antenna gain of a single patch element.

The calculated far field pattern in Fig. 4 shows a satisfactory polarisation behaviour and gain level over the complete operating frequency range. Over the angle range of $\pm 45^\circ$, the cross polar suppression is 15 dB. In order to achieve an even better polarisation performance of the array, the antenna elements are sequentially rotated [4].

Thorough FDTD simulations [6] of the 4×4 antenna array including the waveguide feed were performed to calculate the far field pattern of the array while considering all mutual coupling effects between the elements. Field visualisations for two different steering angles are exemplarily depicted in Fig. 2. This model serves also as a basis to predict far field patterns of larger arrays (e.g. 64×64 elements) [5].

III. Transmitter Architecture

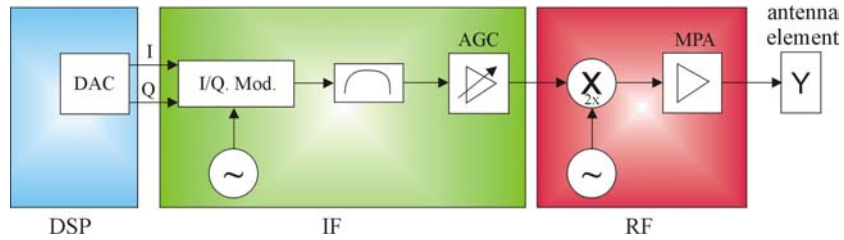


Fig. 5: Transmitter architecture for a single DBF antenna element.

The principle of DBF is based on an up- (down-) conversion of the transmitted (received) signal of each single antenna element. The amplitude and phase parameters of these signals are set on a digital level. The major advantage of digital beamforming is a high flexibility in the generation of the antenna pattern. For example, it can enable the suppression of interferences or the generation of multiple beams, e.g. for satellite handovers. However, DBF requires a high system complexity, since each antenna element has to be equipped with its own transmitting (receiving) circuitry, as shown in Fig. 5.

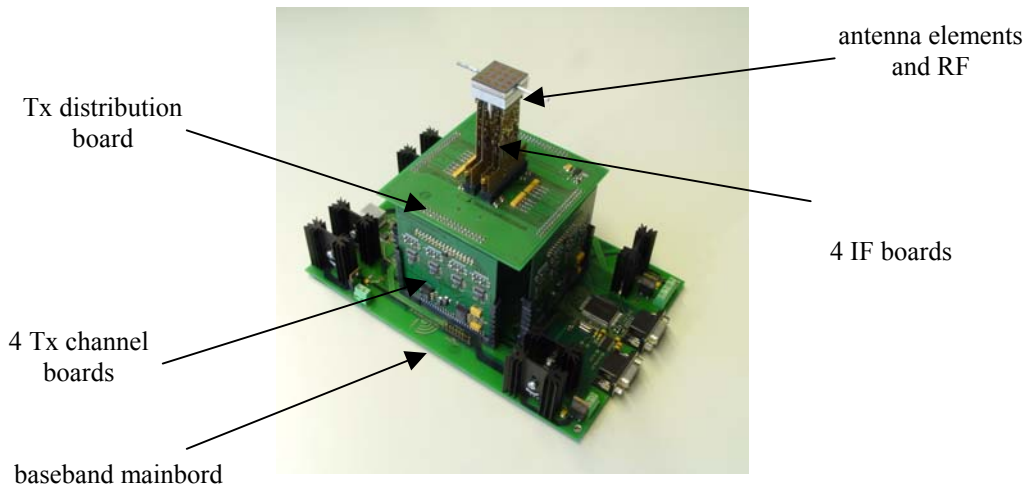


Fig. 6: Complete transmitter module.

Fig. 6 shows a photograph of the fully assembled transmitter module. The baseband mainboard provides the interfacing to a PC, on which control and steering software is running, and handles the digital data stream (e.g. I/Q symbol mapping). The I/Q signal generation takes place on the Tx channel boards, which are plugged perpendicularly onto the baseband mainboard. Each Tx channel board handles four data streams. The Tx distribution board routes all signals to the IF boards. Here, the digital signals modulate an 880 MHz carrier. The power level of the modulated signal can be controlled by means of a gain control amplifier, which is steered via the baseband mainboard. Again, each IF board handles four data streams. So far, the assembly followed a brick-architecture. The following RF circuitry is arranged in a tile-architecture [1]. For signal routing to the RF circuitry a special distribution PCB and miniaturised vertical interconnects are used [2]. Each RF channel converts the corresponding IF signal up to the specified transmit band (29.5 to 30.0 GHz). The RF circuitry consists of standard MMICs (one subharmonic mixer and one medium power amplifier), which are mounted on the backside of the metal plate. The assembly techniques and results of the RF performance of the single channel are reported in [2]. The output of each channel is fed to the waveguide interconnect described in the previous section. All necessary LO signals are generated externally and fed to the IF modulators and RF mixers first by miniature coaxial cables and on the PCBs by dedicated power divider networks. To dissipate the heat generated by the amplifiers on the RF frontend (nominal 10 W), the metal block carrying the antenna patches on the topside and the RF circuitry on the bottom side is provided with a straight duct for water cooling.

IV. Module Measurements

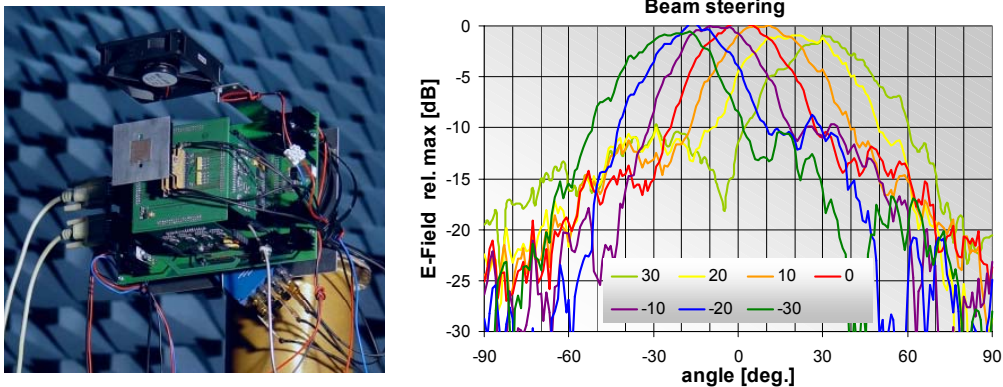


Fig. 7: Antenna under test and radiation patterns of the antenna at selected steering directions.

The far field patterns of the complete digitally steerable 4×4 antenna module have been measured in the active transmit mode according to Fig. 5. Fig. 7 shows the antenna under test in the anechoic chamber and the respective antenna patterns at selected steering directions. The measurement results validate that each element is digitally addressable in amplitude and phase, and also calibrated successfully.

Summary

The successful design of a circularly polarised DBF antenna array for mobile satellite communications at 30 GHz has been presented. The measurements of the antenna in the active transmit mode validate not only the functionality of the antenna itself, but also the functionality of the complete transmitter chain.

Acknowledgement

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References

- [1] A. Dreher, D. Heberling, S. Holzwarth, C. Hunscher, A.F. Jacob, N. Niklasch, H. Pawlak, L. Richard, A. Schroth, L.C. Stange, and M. Thiel, "Ka-band DBF terminal concepts for broadband satellite communications", 25th ESA Antenna Workshop on Satellite Antenna Technology, Noordwijk, The Netherlands, Sept. 2002, pp. 95-102.
- [2] Leif C. Stange, Holger Pawlak, Achim Dreher, Sybille Holzwarth, Arne F. Jacob, Oliver Litschke, Michael Thiel, "Components of a Highly Integrated DBF Terminal Antenna for Mobile Ka-Band Satellite Communications", International Microwave Symposium, Philadelphia, USA, Vol. I, June 2003, pp. 583-586.
- [3] J. Barbero Sanchez, C. Martin Pascual and J. Vassl'lo Sanz,, "Circular Patch With Feeding Through A Circular Slot", Jina 1998.
- [4] Teshirogi, et al., "Wideband circularly polarised array antenna with sequential rotations and phase shift of elements", International Symposium on Antennas & Propagation Proceedings, Japan, 1995, pp. 117-120.
- [5] L.Baggen, S.Holzwarth, W.Simon, O.Litschke,"Phased Array using the sequential rotation principle: analysis of coupling effects", IEEE Phased Array Systems and Technology, Boston, Oktober 2003, pp. 571-576.
- [6] IMST GmbH, "User and Reference Manual for the 3D EM Time Domain Simulator Empire", <http://www.empire.de/empire.pdf>, November 2003.