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Adam Narbudowicz

Technological University Dublin, adam.narbudowicz@mydit.ie

Max Ammann

Technological University Dublin, max.ammann@tudublin.ie

Dirk Heberling

RWTH Aachen University

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On Pattern Reconfigurable Antennas Steered by Modulation Scheme

Adam Narbudowicz^{1,2}, Max J. Ammann¹, Dirk Heberling²

¹ Antenna & High Frequency Research Centre, Dublin Institute of Technology, Dublin, Ireland
 {adam.narbudowicz; max.ammann}@dit.ie

² Institute of High Frequency Technology, RWTH Aachen University, Aachen, Germany
 dirk.heberling@ihf.rwth-aachen.de

Abstract—The paper demonstrates how a modulation constellation can be used to steer the radiation pattern of a reconfigurable omnidirectional circularly polarized antenna. The proposed approach offers the benefit of digital beamforming while using a single antenna: the steering can be executed by low frequency electronics and independently for each frequency channel. In the proposed study, the antenna is excited by a signal generated by two I/Q modulators. By appropriately changing the I and Q components, a phase shift is generated which effectively steers the radiation pattern. The results were achieved using co-simulation between CST Microwave Studio and CST Design Studio.

Index Terms—reconfigurable antenna, MIMO, modulation.

I. Introduction

An antenna's ability to adjust its radiation pattern to changing requirements is a highly desirable feature, offering flexibility and increased information capacity in a radio link [1]. Traditional approaches to reconfigurable antenna rely on switching elements - e.g. pin diodes, MEMS or other - to physically re-route the current in the antenna aperture [2-5]. Although this approach can offer a high degree of pattern reconfiguration, it suffers from many disadvantages. Most notably: since the current is physically re-routed in the antenna aperture, the same radiation pattern must be utilized across the whole bandwidth. This is problematic for practical applications, as many systems use various frequency channels to communicate with different devices. Such devices are typically spaced apart and therefore require different beam directions.

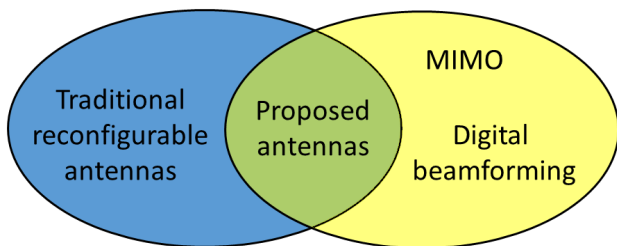


Fig. 1. Motivation for the proposed work. Phase-steered reconfigurable antennas can offer the benefits of multi-antenna solutions, while using only a single antenna.

Another problem emerges from the necessity to correctly steer the switching components. As such components need to be integrated into the antenna aperture, they require additional lines and cables to provide commutating signals. In many cases filtering components are added to separate DC and RF signals. From a system perspective, steering circuitry is required to correctly control the switching sequence of the multiple elements integrated into the antenna.

The above problems do not occur in multiple-antenna systems, such as MIMO or antenna arrays with digital beamforming. However the necessity for multiple antennas significantly increases the required volume and limits applications.

Recently, there is increased interest in multi-port antennas, where the radiation pattern can be steered simply by varying the phases [6-7] or amplitudes [8-9] of the ports. This approach offers several benefits compared to [2-5]. Most notably the beam steering is simplified and can be done independently for each channel. The approach is also compatible with MIMO if every antenna port is considered as a separate input/output channel (and assuming good isolation between ports). For such a case the phase-amplitude steering requires complex weighting that can be adjusted by the MIMO algorithm. From this point of view multi-port reconfigurable antennas offer all the benefits of MIMO and digital beamforming, while using the volume of single antenna. This concept is visualized in Fig. 1.

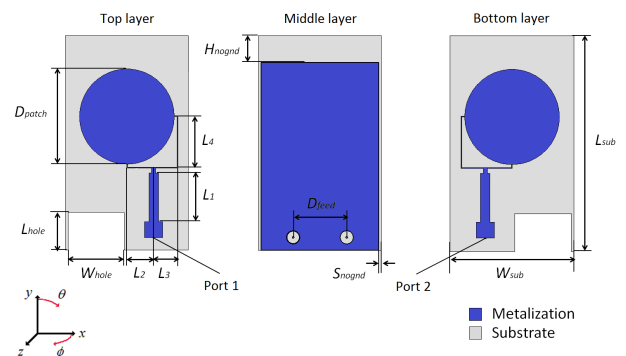


Fig. 2. Design of the omnidirectional reconfigurable circularly polarized antenna [6].

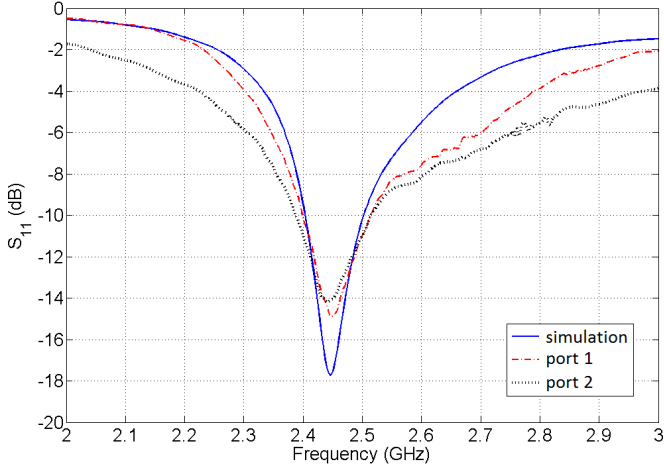


Fig. 3. Measured and simulated S_{11} of the antenna. Due to symmetry only once curve is provided for simulated results.

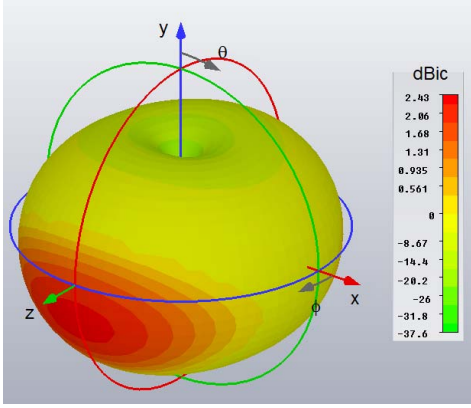


Fig. 4. Simulated RHCP realized gain of antenna [6] fed with $\Delta_{ph} = 0^\circ$. An omnidirectional radiation pattern (with variation below 3 dB) can be seen in xz -plane with two nulls along $\pm y$ -axis. Results shown for 2.46 GHz.

This paper shows how a simple 4-QAM modulation scheme can be used to steer the radiation pattern of a two-port phase-steered reconfigurable antenna. As an example, an omnidirectional Circularly Polarized (CP) antenna introduced in [6] is used. The results were achieved using simulation tools offered within CST Studio Suite package: CST Microwave Studio and CST Design Studio [10]. The antenna element was manufactured and measured [6].

II. Antenna design

Fig. 2 shows the geometry of the proposed antenna. It is a back-to-back coupled circular patch, with right-hand CP realized by 90° phase shift between two orthogonal feeds. Each patch is fed independently, forming a two port antenna. As the patch is fed at the edge, its input impedance is very high. To solve this problem a $\lambda/4$ microstrip section was used to

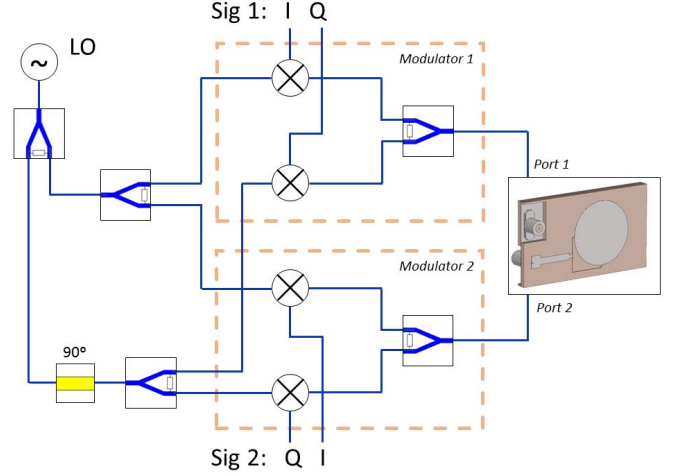


Fig. 5. Circuitry used to steer the radiation pattern with the proposed method.

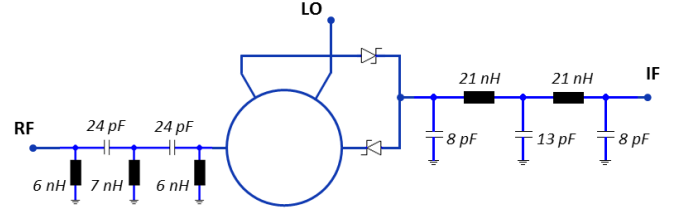


Fig. 6. Circuitry of the rat-race balanced mixer used.

transform the impedance of the microstrip line from 50Ω to 94Ω . Next a simple power divider splits the microstrip into two lines, each of 186Ω impedance (0.2 mm wide). A 90° phase shifter is applied to one of those lines to achieve CP performance and reconfigurability. The structure was milled on a two layers of TaconicTM RF-35 substrate, each layer being 3 mm thick and of relative permittivity $\epsilon_r = 3.5$. Antenna's dimensions are (all in mm): $D_{patch} = 35.4$; $L_{hole} = 14$; $W_{hole} = 21$; $L_1 = 18.5$; $L_2 = 10$; $L_3 = 9$; $L_4 = 19$; $H_{nognd} = 10$; $S_{nognd} = 1$; $D_{feed} = 20$; $L_{sub} = 80$; $W_{sub} = 46$.

Fig. 3 shows the simulated and measured S_{11} of the antenna. As can be seen, it operates within 2.4 - 2.51 GHz bandwidth dedicated for WLAN applications. It generates a right-handed CP torus-shaped radiation pattern (seen in Fig. 4), similar to a pattern of a dipole. It was demonstrated in [6] that by varying the phase shift Δ_{ph} between the two ports, one can rotate the radiation pattern along $\pm z$ axis by angle γ . The relation between the two is linear and for investigated antenna it is:

$$\gamma = \frac{1}{2} \Delta_{ph} \quad (1)$$

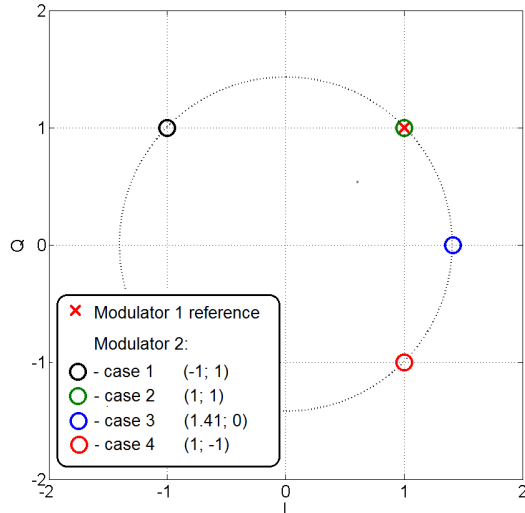


Fig. 7. Modulation of the investigated cases shown in I/Q modulation plane. Dashed circle represents constant amplitude, along which the modulation can be changed while preserving dipole-like radiation pattern of the antenna.

For the coordinate system in Fig. 2, xz -plane is the reference plane with $\gamma = 0^\circ$. Therefore if the phase shift $\Delta_{ph} = 0^\circ$, then an omnidirectional radiation pattern will be produced in xz -plane and two nulls of the torus-shaped dipole-like pattern will be seen along $\pm y$ -axis. This is the case shown in Fig. 4. However for $\Delta_{ph} = 180^\circ$ the plane with omnidirectional radiation pattern will rotate by $\gamma = 90^\circ$, i.e. it will occur in yz -plane. For this case the two nulls are located along the $\pm x$ -axis.

III. Modulator design

For the proposed paper, the antenna was simulated with excitation generated by the circuitry shown in Fig. 5. It incorporates two I/Q modulators, each feeding a signal into different antenna ports. For both In-phase (I) and Quadrature (Q) components 1 corresponds to a magnitude of ± 8 V. The phase shift and consequently pattern reconfiguration is provided by rotating the two modulation constellations with respect to each other. To provide the necessary synchronization, all mixers are fed from the same local oscillator.

Fig. 5 shows detailed design of the mixers incorporated into the modulators. It is a passive balanced mixer employing a rat-race coupler. The Schottky diodes used in CST Design Studio are IDD03SG60C by Infineon. To isolate the RF and IF signals a 5th order Chebyshev filter was used with ripples in the passband not exceeding 0.2 dB: for RF a high-pass with cut-off frequency 1 GHz, for IF a low-pass with cut-off frequency 500 MHz.

IV. Pattern steering

The radiation pattern can be steered by rotating the modulation constellation in one of the modulators with respect

to the constellation used in the other. This is demonstrated using an exemplary 4-QAM modulation at 2.46 GHz. Throughout the course of the presented study, the signal from transmitter 1 was modulated with $(I_1; Q_1) = (1; 1)$ in all investigated cases. The signal from transmitter 2 was modulated with four different signals, all visualized in Fig 7:

1. $(I_2; Q_2) = (-1; 1)$ producing $\gamma = -90^\circ$
2. $(I_2; Q_2) = (1; 1)$ producing $\gamma = 0^\circ$
3. $(I_2; Q_2) = (1.41; 0)$ producing $\gamma = +45^\circ$
4. $(I_2; Q_2) = (1; -1)$ producing $\gamma = +90^\circ$

All those points are located on a circle of unit radius. This is in order to have the same amplitude at both ports and therefore preserve the omnidirectional torus-shaped radiation pattern of the antenna. Increasing amplitude at one of the ports would cause the antenna to radiate stronger in one direction.

V. Results

Fig. 8 shows the radiation pattern in the xy -plane for the four investigated modulation schemes. It can be seen, that the rotation of the radiation pattern has been achieved in accordance with predictions of (1). It is noticed, that the depth of the two nulls is very shallow (only -11 dBic) for case 3 ($\gamma = 45^\circ$). This is because the actual null moved slightly outside of the xy -plane.

It should be noticed, that in the demonstrated plane the radiation is produced by the side of the antenna (which is 6 mm thick), hence the relatively low directivity of 0 dBic. In the $\pm z$ directions (i.e. normal to both patches) the radiation is produced for all investigated configurations and the directivity varies between 3 – 4.8 dBic. This displays a slightly greater variation in the omnidirectional plane, as compared to [6] where antenna was excited using phase shifters.

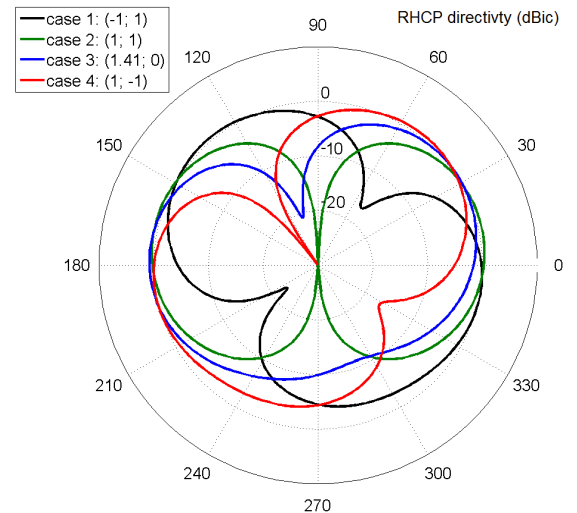


Fig. 8. RHCP directivity in xy -plane simulated at 2.46 GHz. Four modulation schemes used in the study produce radiation in various directions.

VI. Conclusions

It was demonstrated by simulation using CST Studio Suite, that the reconfigurable antenna introduced in [6] can use modulation schemes to steer its radiation pattern. We believe, this is a very potent solution for future communication systems, especially where antenna space is limited (e.g. femtocell base stations or WLAN access points). The method allows easy pattern steering using low frequency electronics and a single antenna. Each frequency channel can be steered independently. The method is compatible with MIMO solutions, such as maximum likelihood combining, however it also offers benefits for environments not supporting multipath propagation. In principle, the method can also be seen as a variation of digital beam forming utilizing single antenna.

Acknowledgment

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