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Direction of Arrival Estimation for Retrodirective Rotman Lens Antenna Array

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Abstract. A retrodirective array based on simplified direction-of-arrival estimation algorithm is presented. A beamforming network based on Rotman lens providing the direction of arrival estimation as well as the beam steering is proposed. Retrodirectivity is provided by analysing an interrogating pilot signal, which allows retrieving a data to estimate the source position and then steering a beam in response of a pilot signal. The proposed retrodirective array test system was fabricated and measured for operation at 5.85 GHz central frequency. Designed retrodirective Rotman lens-based antenna array forms eight beams with beamwidth of 10° to cover the scanning angular range from -40° to 40° . The evaluation of the direction of arrival by measuring the power level of the received signal depending on the port index for the different angle of incidence of the pilot signal source is experimentally demonstrated.

1. Introduction

As it is known, retrodirective antenna arrays reflect an incident wave towards the source without any prior information about its location. Such systems are widely used in radar, satellite, wireless communications, radio-frequency-identification (RFID), tracking systems, microwave power transmission applications etc. A retrodirective array is composed by analog circuitry that steer their beams automatically without any phase shifters or complex digital-signal-processing components in response to an interrogating signal [1].

However, well known direction of arrival (DoA) estimation algorithms could bring to the retrodirective arrays more flexibility. For example, it would allow implementing gain calibration, DoA correction techniques [2]. As a result, such algorithms are often used in wireless communications to increase the capacity and throughput of a network [3]. Typically, they are based on time-of-arrival, received signal strength, time-difference-of-arrival, or angle-of-arrival measurements determined from the mobile terminal signals received at the base stations [4].

This paper is focused on design of the retrodirective array based on simplified DoA estimation in order to steer the beam towards the location of electromagnetic source. The proposed architecture is based on a Rotman lens, which is used as a beamforming network of an antenna array to provide the DoA estimation as well as the beam steering.

2. Retrodirective Array Architecture

A general block diagram of the proposed retrodirective Rotman lens-based antenna array with DoA estimation is presented in Fig. 1. It consists of an antenna array, a Rotman lens, a RF switch, an



amplitude power detector and a microcontroller, which is used to implement control of the system and perform a DoA estimation algorithm.

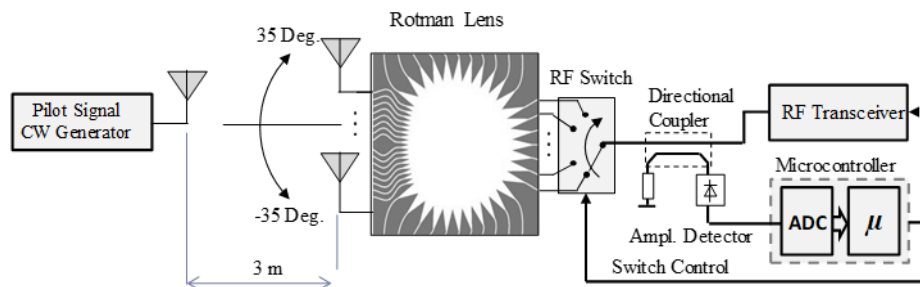


Figure 1. Block diagram of the retrodirective Rotman lens-based antenna array with DoA estimation.

The operational principle of the proposed architecture is based on receiving an interrogating pilot signal, which is used to retrieve the information about source location. It was decided to use a *Time-Division Duplexing* (TDD) mode because it has some advantages for this specific application. First of all, there is asymmetry of the uplink and downlink data rates, because for a DoA estimation algorithm a simple pilot signal is sufficient, while during the data transfer other signals are preferable for higher data rates. The Rotman lens (RL), which has M input (beam) ports and N output (array) ports, is used as a beamforming network (BFN) for a linear antenna array. In a transmitting mode, an individual beam port is fed that results in excitation of antenna elements with a certain phase distribution, defined by a position of the beam port relative to the lens symmetry axis. The beam steering is realized by switching between different beam ports. An ideal Rotman lens is a reciprocal device. It means that in the receiving mode, an incident wave, which arrives with time delays across the linear array, is summarized in phase mainly at one of the beam ports. This fact can be efficiently used for a passive method of DoA estimation.

So, during the receiving time slot, a microcontroller performs a sequential switching between its M output ports for measuring the signal power levels at all beam ports using an amplitude power detector, which is connected to the switch through the coupled port of a 10-dB directional coupler, while the through port of the coupler is connected to a transmit chain. All measured values are analyzed by a microcontroller and the DoA of the received signal is estimated. In the simplest scenario, the DoA is defined by an index of the beam port, where the highest power level is detected. Based on the algorithm output, the microcontroller sets up the required state of the switch and during the transmitting time slot, the antenna array transmits the signal in the required direction.

3. Experimental Results

To demonstrate the DoA estimation operation of the proposed retrodirective array a test system was fabricated and measured for operation at 5.85 GHz central frequency. The antenna array consists of 8 series-fed 1×8 linear patch arrays, where a beam steering was realized in azimuth plane (Fig. 2a). Such aperture dimensions provide the main beam width of 10° . The antenna array was fabricated on a Rogers RO4003 substrate ($\epsilon_r = 3.55$, $h = 1.52$ mm). The size of 8×8 patch sub-array was 220×250 mm². According to the measured reflection coefficient its bandwidth covers the range from 5.5 to 6 GHz.

The Rotman lens was designed for scanning in the range $[-40^\circ; 40^\circ]$ with a step of 10° using Remcom Rotman Lens Designer (RLD) tool [5] (Fig. 2b). It includes 8 beam ports, 8 array ports and 16 dummy ports, which were introduced to reduce the amount of multipath interference within the lens. Dummy ports are loaded by 50 Ohms SMD chip resistors. The prototype Rotman lens was fabricated on the Arlon AD1000 substrate ($\epsilon_r = 10.2$, $h = 1.27$ mm). The dimensions of the lens are 260×280 mm².

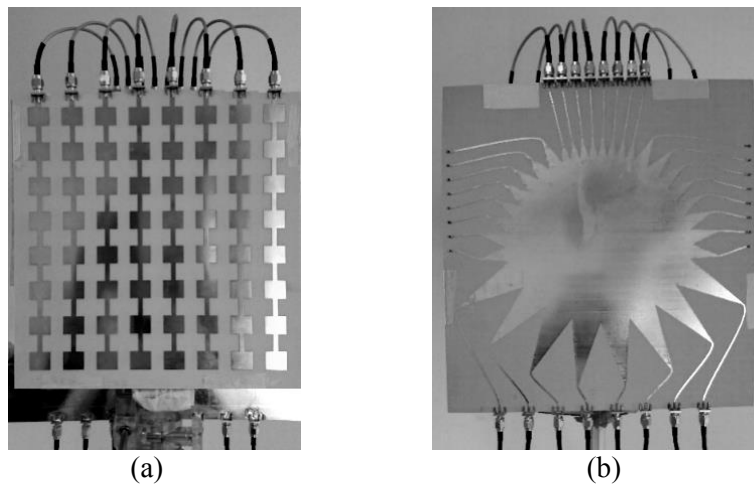


Figure 2. Fabricated antenna array (a) and Rotman lens (b) composing the retrodirective Rotman lens-based antenna array.

The scattering parameters of the Rotman lens were measured and used for simulating radiation patterns. The normalized radiation pattern simulated at 5.85 GHz based on measured Rotman lens S-matrix is shown in Fig. 3a. As one can see, eight formed beams with beamwidth around 10° cover the angular sector from -40° to 40° . The gain of the antenna arrays drops by 2.5 dBi for the outermost direction of the beam.

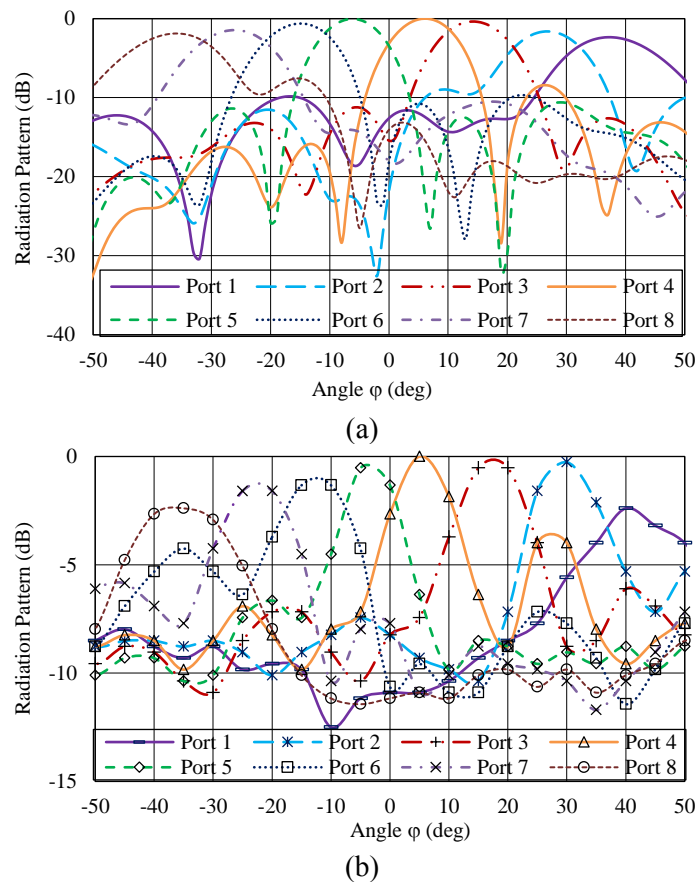


Figure 3. Normalized radiation pattern simulated based on the measured Rotman lens S-matrix data (a) and measured received signal power level (b).

The most critical part of the system is DoA estimation of an interrogating pilot signal because it has a direct impact on the direction of the transmitted signal afterwards. Thus, the retrodirective array test system presented in Fig. 1 was experimentally studied to evaluate DoA of an incident pilot signal. The continuous wave (CW) used as the pilot signal was radiated by a single 1×8 linear patch array. The distance between the retrodirective array and the pilot signal antenna is fixed at three meters. The azimuth angle of the Rotman lens-based antenna array was varied from -50° to 50° . For each position of an antenna array, the microcontroller changed the state of the *SP8T* HMC321LP4 switch [6] and recorded the voltage level at the amplitude detector ADL5906 [6] output every 150 msec. Thus, each receiving cycle was a little bit more than 1 sec. The absolute power is calculated using the measured dependence of the voltage level on the input power level for specified amplitude detector. As a result, the normalized values of the detected power at each beam port are presented in Fig. 3b as a function of the azimuth angle φ .

As can be observed, when the signal is coming from the specific direction the power level at a certain beam port is higher in comparison with power level at other ports by 3 - 6 dB. This dynamic range is sufficient to detect the received signal and estimate DoA by comparison the power levels. However, the dynamic range tends to decrease at the edges of the incident wave angular ranges. In order to achieve a high angular resolution between beams, a number of beam ports of the Rotman lens should be increased.

In general, Rotman lens array provides multiple beams toward different directions simultaneously. So, the functionality as well as operation rapidity of the system can be improved if M single pole single throw (*SPST*) switches will be used instead of one single pole M -throw switch. Therefore, several beam ports power level can be analyzed and fed simultaneously making the retrodirective array more flexible in the case two or more signals are coming from different directions.

4. Conclusion

In this work, the retrodirective array based on Rotman lens to steer beams towards the pilot signal sources is proposed. The simplified direction-of-arrival estimation circuitry allows extending a functionality of the proposed retrodirective array. The Rotman lens array antenna is designed to provide an 80-degree angular sector coverage. The evaluation of the direction of arrival by measuring the power level of the received signal depending on the port index for the different angle of incidence of the pilot signal source is experimentally demonstrated. The results of this study demonstrate that the Rotman lens can separate incident waves coming from different discrete directions providing a sufficient dynamic range to perform DoA evaluation. To achieve a high angular resolution between beams, beam ports number of the Rotman lens could be increased.

Acknowledgment

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