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Non-Reciprocal Phased Array antenna

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Abstract

A nonreciprocal phased array antenna is proposed in this paper. compare to a conventional phased array antenna, here the proposed structure has two independent paths for transmit and receive state which makes the antenna a perfect candidate for full-duplex application. The two paths have achieved by a Wilkinson power divider in which it divides the signal on one side and combine it on the other side. Each path consists of a unilateral amplifier as well as a phase shifter. Two types of phase shifter were utilized to generate both positive and negative phases. The phase shifters were designed based on a T-type filters and by using varactor diodes in which it can be reconfigurable by different bias voltages. A 1×4 feed network based on the proposed non-reciprocal idea were implemented and measured. The measured scattering parameters shows a better than -15 dB return loss and validate our claim on the non-reciprocity response of the proposed feed network by measuring the phase responses. A 2×4 patch antenna also integrated into the proposed feed network and implemented. The proposed phased array antenna provides power amplification as well as the ability to steer the transmit and receive signal independently.

1 Introduction

Beam steering and multi-beam techniques largely facilitate the design of beam-directional high gain antennas, and phased array antennas in more specific have aroused the interest of many researchers because of its agility and integrability, which has broad application in military and commercial communication systems [1]– [3]. Designing beam switch antennas based on Butler matrices is one of the best solutions for such requirements [4]. However, conventional phased-array antennas are limited by the Lorentz reciprocity theorem, where the antenna has identical properties for transmission and reception states (e.g., identical radiation pattern, gain, input matching, etc.). Nonreciprocal electromagnetic and electronic systems, on the other side, have gained a surge for the past couple of years due to its unique capability for wave engineering and controlling electromagnetic wave propagation and as a result, numerous literatures paid attention to this idea and application. A nonreciprocal leaky-wave antenna is reported in [5], that is a magnetic ferrite based nonreciprocal structure. Some nonreciprocal metasurfaces can be found in [6],[7]. Space-time modulated media [8]

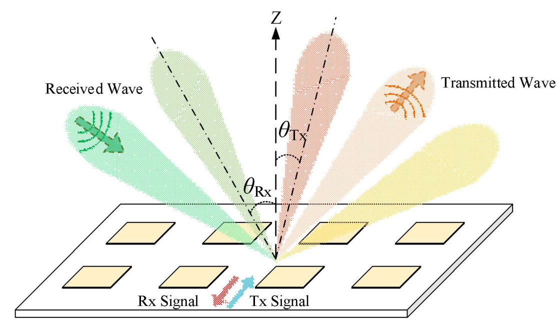

Figure 1. Functionality of the nonreciprocal radiation patterns for the proposed phased-array antenna.

and transistor loaded metamaterial-based metasurfaces [9] are other reported nonreciprocal antenna structures. The transistor loaded antenna has several advantages over other nonreciprocal technologies mostly because it needs less design complexity, power amplification and high efficiency. A nonreciprocal phased-array antenna is reported in [10].

In this paper, a nonreciprocal phased array antenna is investigated by using the nonreciprocal tunable phase shifter. Compare to other reported phased array antennas [2]-[8] which experience severe drawbacks, here the presented feed network provides high efficiency, power amplification, high isolation, and capability to produce different symmetric or asymmetric radiation beams for both reception and transmission states and therefore make the proposed structure a very good candidate for full-duplex application.

2 Theory and Concept

Figure 1 shows the operational principle of the nonreciprocal phased-array antenna. For the radiation state, the antenna receives the signal from the input of the antenna and transmits it at the angle of θ_T while for the receiving state, the antenna receives the maximum gain from the incoming wave at the angle of θ_R.

The concept of the non-reciprocal phased array antenna is very similar to of a conventional phased array antenna with this difference that to realize a nonreciprocal array factor, the antenna feed network should introduce two separate phase-gradient responses by employing a nonreciprocal phase shifter for each element.

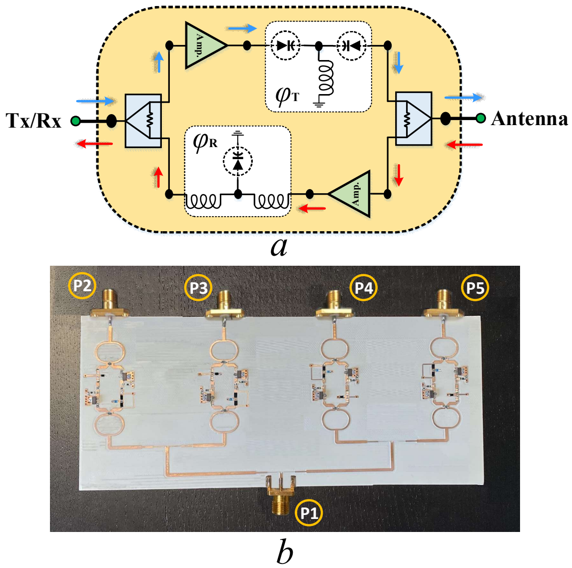

Figure 2. (a) Single unit of the tunable nonreciprocal phase shifter, (b) Implemented proposed nonreciprocal feed network.

Here, for the proposed antenna, we consider four elements, each of which introduces a nonreciprocal phase shift for the incoming and transmitted waves. Figure 1 shows the operational principle of the proposed nonreciprocal phased array antenna. Three different transmitting state phase responses (i.e.–110, –85 and –60 degree) and two different receiving state phase responses (i.e., +110, and +85 degree) are designed and measured.

Figure 2(a) shows a schematic representation of the transistor-based nonreciprocal phase shifter network and figure 2(b) shows a fabricated non-reciprocal feed network (FN). The proposed structure is constituted of two unidirectional amplifiers (i.e., Gali-2+ from Mini-circuits Inc.), two Wilkinson power dividers/combiners, and two lumped element phase shifters. Two power splitters/combiners ensure a full-duplex operation of the transmission and reception states and the unidirectional amplifier provide amplification as well as isolation between the Tx/Rx states. Two types of the reciprocal phase shifter, that are low pass T-type and high pass T-type are used for the receiver and transmitter traces. Basically, the low pass T-type phase shifter gives a negative phase shift, whereas the high pass T-type phase shifter presents a positive phase shift. A varactor diode from Skyworks Solution Inc. (SMV1234-079) is utilized as a tunable capacitor (i.e., the capacitance changes by different bias voltages) to change the transmission phase response and as a result, a tunable phase shifter is achieved.

3 Results

The fabricated FN were analyzed and calibrated for different progressive phase responses. Figure 3(a) depicts the scattering parameters of the fabricated FN for four sample modes of Tx/Rx with different progressive phases.

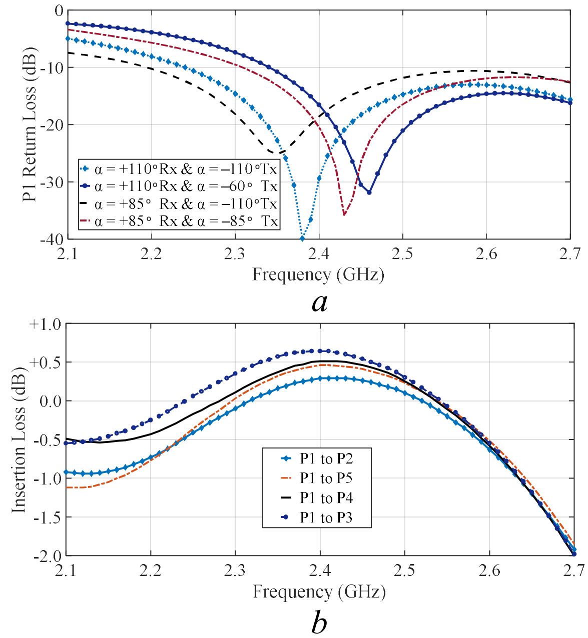

Figure 3. Measurement results of the (a) return loss and, (b) insertion loss for some samples of different cases of progressive phase responses.

Three progressive phases for the transmitter and two progressive phases for the receiver are designed and measured. Different bias voltages are applied to the varactor diodes to meet the phase response requirements. The FN is designed at 2.4 GHz. The results in figure 3(a) show a return loss better than -15 dB has been achieved for all scenarios, and figure 3(b) shows a positive insertion loss or in other words a transmission gain.

A 4×2 microstrip patch antenna array is integrated into the designed FN to evaluate the nonreciprocity of the proposed concept. The antenna is designed at the frequency of 2.4 GHz using eight microstrip patches distributed with the distance of d = λ/2. For initial states, an upward phase progression is considered for the transmission state with -110^0 phase difference, and a downward phase progression is assumed for the reception state with $+110^0$ phase difference between every two adjacent radiation elements. As a result, the initial transmission and reception antenna beams, at around $\theta_{TX} = 50^0$ and $\theta_{RX} = 50^0$, are achieved.

Figure 4(a) depicts the transmitting radiation patterns (i.e., upward direction) correspond to three different progressive phases of –110, –85, and –60 degrees and Figure 4(b) also shows the receiving radiation patterns (i.e., downward direction) correspond to two different progressive phases of +110 degree (initial receiving state) and +85 degree (tuning the diodes' bias voltages),

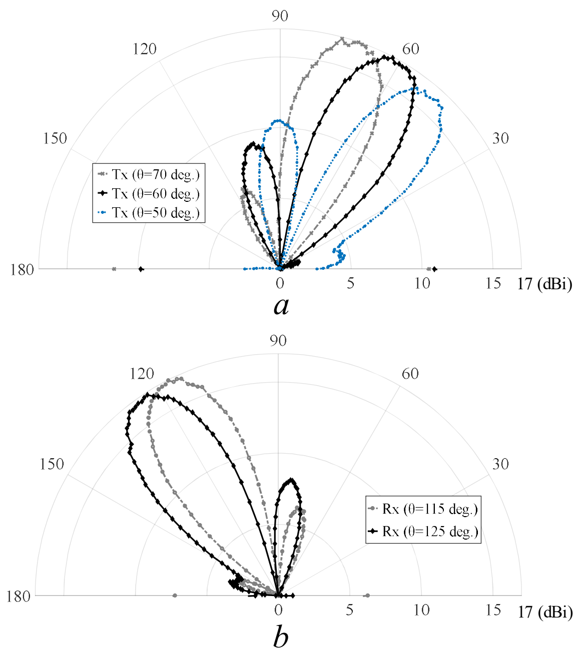

Figure 4. Experimental results for the designed nonreciprocal beam phased-array antenna based on the implementation scenario (a) Transmission (Tx) radiation beams, (b) Reception (Rx) radiation beams.

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