Design of a Non-Reciprocal Reconfigurable Phase Shifter for Phased Array Applications

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***Abstract*—A novel non-reciprocal reconfigurable phased shifter feed network is proposed in this paper. The feed network is a one-input-four-output network for the steerable antenna application. The proposed novel concept has two main paths for transmitter and receiver in which each path has a different independent phase shifter. Varactor diodes with different bias voltages have been used in this study to generate different progressive phase shifts for transmitter and receiver. The measurement results show non-reciprocity results as well as reconfigurability for each output.**

I. Introduction

The demand for smart antennas for different applications such as IoT devices has increased intensively for the past decade [1-4]. Steerable antennas are one of the key elements for such demand. Non-reciprocity and non-reciprocal electromagnetic systems have gained a surge of interest due to its unique capability in wave engineering. Non-reciprocal array antennas are presented in [5],[6] as a novel concept of wave engineering. In this paper, we propose a non-reciprocal reconfigurable feed network by leveraging unique properties of phase-gradient transistor-loaded non-reciprocal phase shifter in which a varactor diode is used to tune the phase shifter. In contrast to the previously reported non-reciprocal structure, the power amplification is used in the proposed structure which basically cancel-out all the insertion loss introduces by the power splitter which is highly desirable in the array antenna design. Furthermore, the proposed nonreciprocal feed network (NFN) structure is compatible with any planar circuit board technology.

II. Design of a Reconfigurable Non-Reciprocal Feed Network Structure

Figure 1 (a) shows a single unit of the proposed NFN and figure 1 (b) shows the implemented proposed NFN systems consists of the four single-unit. Every single unit consists of two Wilkinson power/combiner to split and combine the signal into two paths (i.e. transmitter and receiver), a unilateral amplifier, and a reconfigurable phase shifter. A Gali-2 gain block from Mini-Circuits Inc. is used in the design for two purposes, first to amplify the signal and second to isolate the signal from the other path (i.e. if the amplifier is in the receive path it will block the transmit pass and vice versa). Figure 2 (a) and 2(b) depicts the two type of reciprocal phase shifter (i.e. a low pass T-type and a high pass T-type filter phase shifter) integrated into the proposed design, respectively. The low pass T in figure 2(a) introduces a

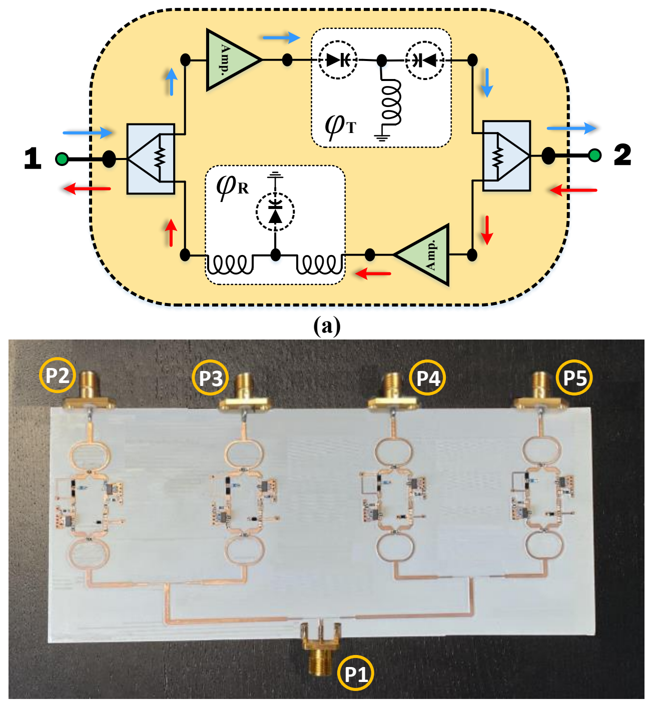

Fig. 1. (a) A single unit of a reconfigurable non-reciprocal phase shifter (b) the implemented proposed non-reciprocal feed network.

negative transmission phase shift whereas the high pass T in figure 2(b) introduces a positive phase shift. A varactor diode is used as the capacitor to change the transmission phase responses and as a result, a reconfigurable phase shifter (i.e. reconfigurable positive and negative phase shifter) is achieved. If the ABCD matrix of a conventional transmission line with the characteristic

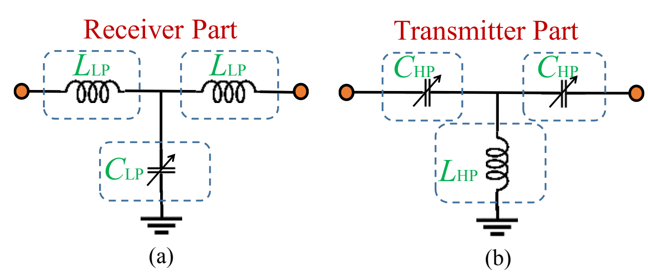

Fig. 2. Reciprocal T-type phase shifter (a) Lowpass filter, (b) High pass filter.

impedance of Z_0 and angular frequency ω be equal to the ABCD matrix of the T-type phase shifter, one can calculate the required inductor and capacitor values for any given phase shift (φ). These Values for the Tee high pass filter are,

$$L = \frac{Z_0}{\omega \sin\varphi} \quad \& \quad C = \frac{\sin\varphi}{\omega Z_0 (1-\cos\varphi)}, \qquad (1)$$

And for the Tee lowpass filter are,

$$L = \frac{Z_0(1-\cos\varphi)}{\omega \sin\varphi} \quad \& \quad C = \frac{\sin\varphi}{\omega Z_0}, \qquad (2)$$

As a result, for any desired phase response we have calculated the inductor and capacitor values. It should be noted that varactor diodes are used with different bias voltages to replicate different capacitor values.

III. Results and Discussion

For a steerable antenna application, one needs to meet the progressive phase requirement. Figure 3 (a) shows a measured example of a progressive phase response of +30-degree and figure 3 (b) shows an example of a measured progressive phase response of –15-degree corresponds to transmit and receive mode, respectively. It should be noted that different bias voltages were applied to have the desired progressive phase response. Three different progressive phase response for the transmit mode (i.e. +10, +30, and +45) and two different progressive phase response for the receive mode (i.e. -15, and -25) are measured by applying different bias voltages. It should be also noted that the inductor value is fixed for all measurements and as a result the circuit it completely reconfigurable based on the bias voltages.

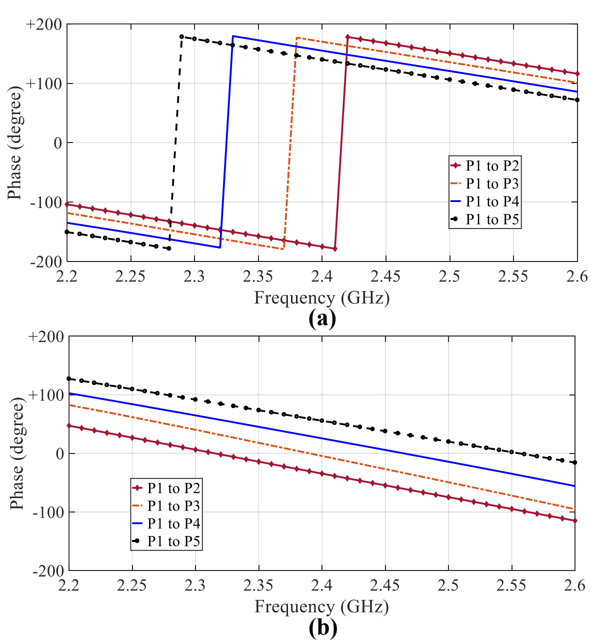

Fig. 3. progressive phase response for (a) +30 degree for the transmit mode (b) -15 degree for the receive mode (Different bias voltages are used for each path in the NFN structure).

Figure 4 (a) and (b) shows the measured return loss and insertion loss responses of the proposed NFN. The circuit is designed at the 2.4 GHz and as it can be seen from figure 4 (a), a return loss better than -10 dB has been achieved for all measurement. Figure 4 (b) depicts the insertion losses response between port 1 (input port) and ports 2 to 5 (output ports) for a case of +30-degree transmit mode and -15-degree receive mode.

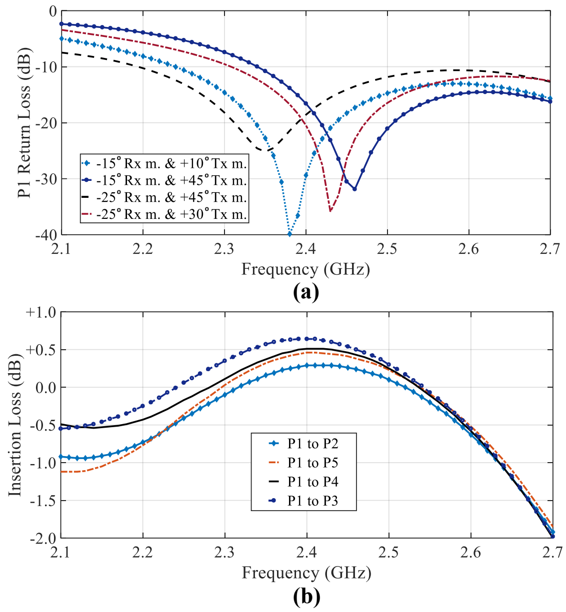

Fig. 4. Measurement results of the (a) return loss and, (b) insertion loss for some samples of different cases of progressive phase response.

IV. Conclusion

A novel non-reciprocal tunable feed network array structure is presented in this paper. Different progressive phases for both transmit and receive states by applying various bias voltages are achieved. The results show the proposed network can be an ideal candidate for non-reciprocal phased array applications.

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