

Phase Shifter Using an Artificial Magneto-Dielectric for Phased Array Antenna Application

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Abstract

A phase shifter using artificial magneto-dielectric material for phase array antenna application is proposed. The miniaturization was achieved using an artificial magneto-dielectric, realized using a split ring resonator (SRR). By using superstrates with split-ring resonators (SRRs) on a T-junction power divider, a phase shift can be implemented over the Mobile-WiMAX band (2.3 GHz ~ 2.4 GHz) due to the high permeability property of the SRR. The SRR superstrate provides the low insertion loss and compact size for a phase shifter.

Keywords : Phase Shifter, Artificial Magneto-dielectric material(AMD), Split-Ring Resonator (SRR)

1. Introduction

A phase shifter is one of the key elements in wireless communication systems including electronically steered phased array radar, surveillance, sensing and tracking. When the antenna positions are stationary, the beam steering should be achieved by phase controlling, and the phase shifter is generally applied to control the beam [1]. Modern phased array systems, such as array antenna, require a large number of phase shifters, thus, low-insertion loss and low-cost microwave phase shifters are required to ensure the antenna performance and to reduce the cost of overall microwave systems [2]. For array antennas, in order to avoid the grating lobes, the distance between adjacent antennas in the array cannot be greater than half wave-length; therefore, compact size phase shifters are required. Several phase shifters have been reported for phased array antenna using various materials of dielectric [3], ferrites [4], and pin diode [5]. To achieve phase shift, various materials can be used to change the permittivity, permeability or the electrical length. However, it has large size, high fabrication cost and insertion loss. Recently, a microstrip phase shifter using complementary split-ring resonators (CSRR) has been reported [6]. However, it has control problem because CSRRs are printed on the ground plane and are cannot control the phase precisely.

In this paper, we propose a phase shifter using an artificial magneto-dielectric, which is realized using SRR, is inserted to reduce the size and low insertion loss.

2. Phase Shifter Design and Analysis

2.1 Phase Shifter Design

The proposed phase shifter is shown in Fig.1. The proposed phase shifter consists of a T-junction power divider, ground plane, and artificial magneto-dielectric substrate. A 4:1 T-junction power divider was printed on the top side of Taconic TLY substrate ($\epsilon_r=2.2$) with the dimension of 130mm×130 mm×1mm. The AMD substrate is a Tacocnic CER ($\epsilon_r=10$)with the thickness of 0.5mm and size of 12mm×5mm. It is placed on the T-junction power divider in sub#1. The AMD is realized using SRR structure. The SRRs, which printed on the top and bottom side of a 0.5mm thickness Taconic CER (sub#3) with dimension of 12mm×5mm, were placed on sub#2. The SRRs on the top and bottom sides are connected using via holes. Different number of AMD substrate with SRRs are arrayed on the T-junction power divider. The ground plane is printed on the bottom surface of the first Taconic TLY substrate.

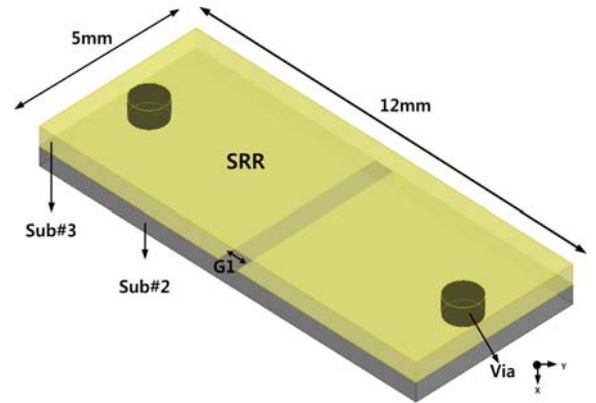
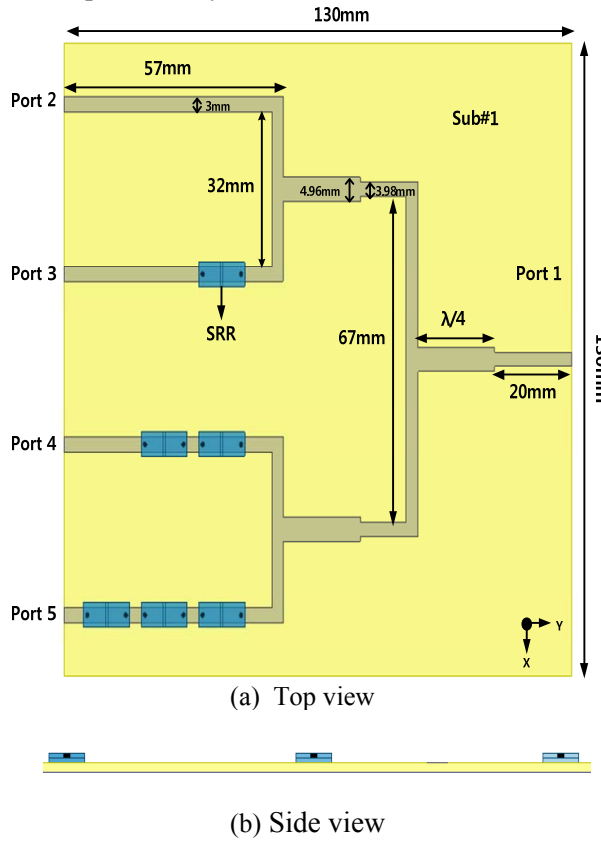
The performance of phase linearity and time response of power divider are important for the feeding network of the antenna array. The relationship between the input and output ports is given by equation (1)

$$V_0 = V_{in} e^{-jkl}, \quad (1)$$

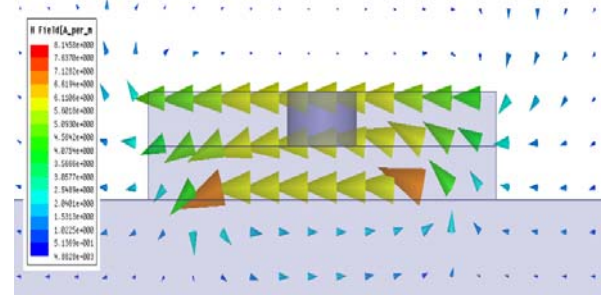
where $-kl$ is the phase change of microstrip line. $k = 2\pi / \lambda_g$ is the propagation constant. λ_g is the guide wavelength of microstrip line and can be expressed in terms of permeability and permittivity as

$$\lambda_g = \lambda_0 / \sqrt{\mu\epsilon} \quad (2)$$

Eq.(2) shows that the phase of a microstrip line can be controlled by adjusting the permeability and/or permittivity.



(a) Geometry of AMD structure



(b) Magnetic Field of SRR

Figure 1: Geometry of the proposed phase shifter

Figure 2: Geometry and magnetic field of SRR

2.2 Artificial Magneto-dielectric material design

The split ring resonator (SRR) array structure was used as an artificial magneto-dielectric in Ref. [7]. The SRR structure stores magnetic energy so that the magnetic field exists perpendicular to the surface of the ring, which acts as an inductor. The gap in the SRR structure acts as a capacitor to store electric energy. Therefore, the SRR can be equivalently modeled as an LC resonant circuit. Once the resonance frequency is determined by the capacitance and inductance of its geometry, the SRR structure can be adjusted to provide high permeability at a specific frequency band. Fig.2 (a) shows the configuration of the proposed SRR structure. The SRR structure is placed on the sub#2. Fig.2 (b) shows the magnetic field of the proposed SRR structure. When magnetic field is vertically incident on SRR structure, the effective permeability of the medium can be larger than one near the resonance frequency of the SRR. If the T-junction power divider is directed along the y-axis,

magnetic field is induced along the x-axis. Thus, if the SRR is placed on the T-junction power divider as show in Fig.1, the magnetic field is vertically incident on the SRR so that the effective permeability of the T-junction power divider can be larger than one over the specific frequency region. Fig.3 shows the return loss and transmission coefficient. The designed SRR has return loss higher than 10dB from 1.5 GHz to 2.4 GHz. The resonant frequency is dependent upon the width and gap distance of the capacitance area of the SRR structure. Fig.4 show the permeability for various G1 value of SRR.

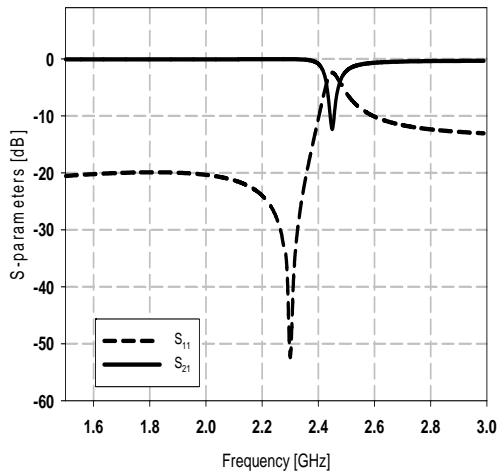


Figure 3: Simulated S-parameters of the SRR

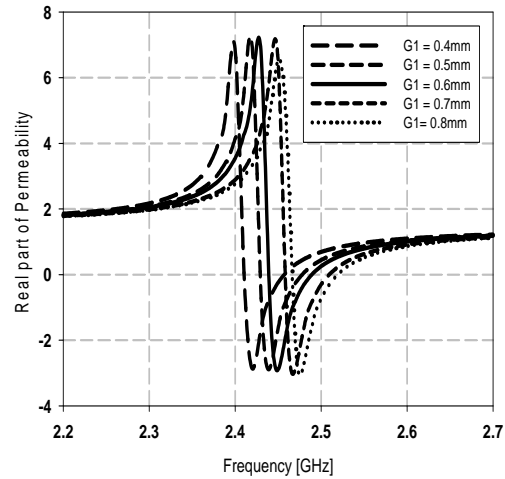


Figure 4: Simulated Real part of permeability

3. Simulated Result

The simulated S-parameters of the proposed phase shifter using AMD substrate are illustrated in Fig. 6. The designed phase shifter has a 10 dB return loss and transmission coefficient of less than -7 dB from 1.8 GHz to 2.4 GHz. The simulated phase change of the proposed phase shifter using AMD substrate are illustrated in Fig. 7. The total phase change between port 2 and port 5 are 524 degree , 557 degree, 584 degree and 636 degree, respectively at 2.4 GHz. The maximum phase shift are 112 degree and the maximum beam scan angle is 10 degree at 2.4 GHz.

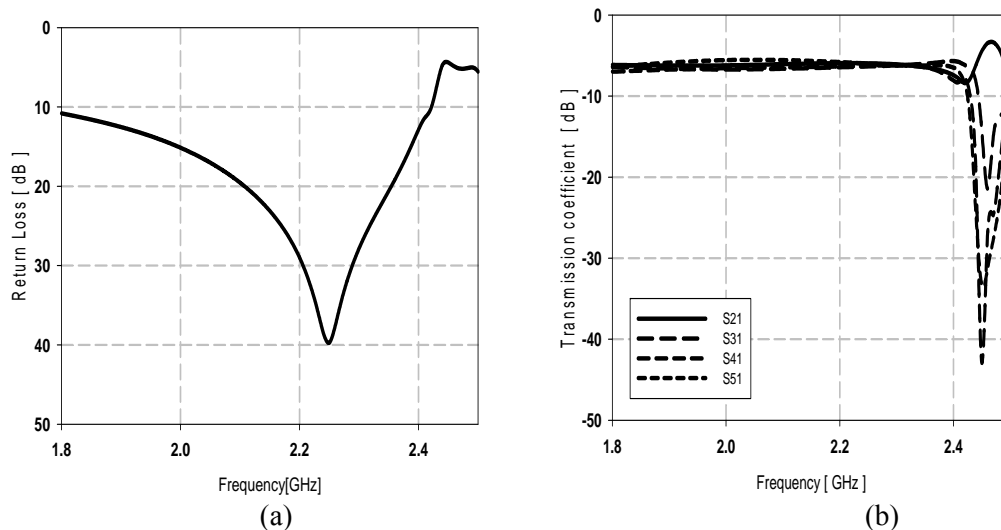


Figure 6: Simulated S-parameters of the proposed phase shifter
(a) Return Loss, (b) Transmission coefficient

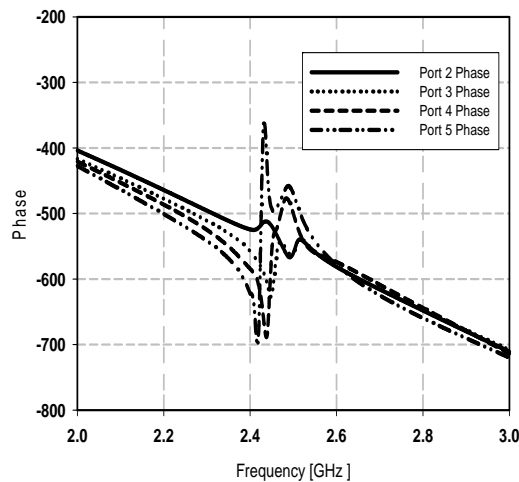


Figure 7: Simulated phase respond of the proposed phase shifter

4. Conclusion

In this paper, a phase shifter using AMD substrate for phase array antenna application is proposed. The phase change is improved by the AMD substrate with SRR. The size of the proposed phase shifter is about 50% smaller than that of a conventional phase shifter by AMD substrate. The maximum phase shift are 112 degree and maximum beam scan angle is 10 degree at 2.4 GHz.

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Acknowledgments

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