Propagation Characteristics of Periodic Metal Strips on Dielectric Layer in Parallel Plate Waveguide

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1. Introduction

In a phased array antenna, the phase shifters, T/R modules, and beam-steering control circuitry account for the major hardware cost. Therefore, the phase shifters are being actively investigated for realizing the low cost phased arrays [1]. The Radant lens, which is one of the phase shifters, reduces many of the fabrication problems that increase the cost and the transmission loss associated with the conventional implementation of a passive phased array [2].

The Radant lens is constructed from a set of parallel metal plates. In between each set of plates is dielectric layers on which are two periodic strips of metal cross-connected by a set of the diodes. The operating principle of the Radant lens is that the phase shift through the lens changes when the diodes in one layer are turned on or off. The amount of the phase shift per dielectric layer can be controlled by varying the structure of the metal strips [2].

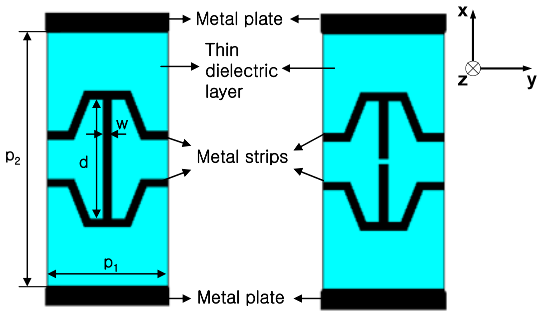
In this paper, 11.25^o, 22.5^o and 45^o layers, which can be used for X-band 4-bit Radant lens phase shifter [2], are simulated by using CST's MWS(Microwave Studio). The diode ON and OFF states are regarded as the short and open circuit, respectively, in the simulation. Also, the equivalent circuit of each layer is found and simulated by using Agilent's ADS(Advanced Design System). Validity of the equivalent circuit is verified by comparing the simulated results with the measured ones.

2. Structure and equivalent circuit of metal strips on dielectric layer

Fig. 1 shows a unit cell of metal strips on dielectric layer between the parallel metal plates. Figs. 1(a) and (b) show the shorted and opened structures which represent the diode ON and OFF states, respectively. The vertical boundaries of the unit cell are regarded as the magnetic walls to analyze S-parameters of the periodic structure using CST's MWS.

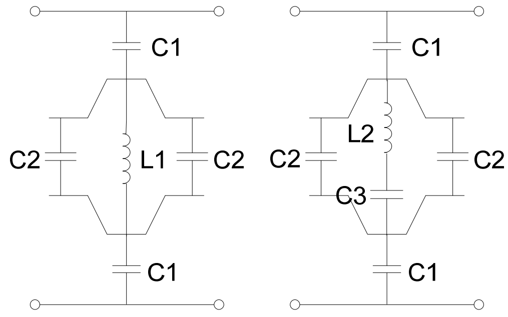
When a vertically polarized wave is propagating in the z-direction in Figs. 1(a) and (b), the equivalent circuits can be expressed as Figs. 2(a) and (b), respectively. In Fig. 2(a), L1 is due to the magnetic field caused by the metal strip parallel to the electric field and C1 is due to the electric field between the metal plate and the horizontal metal strip. These L1 and C1 cause a series resonance. Also, C2 is due to the electric field between two horizontal strips. This C2 causes a parallel resonance with L1. In Fig. 2(b), C3 is due to the electric field in the opened gap. Since C3 is connected with C1 in series, L2 causes a series resonance with smaller capacitance than C1 in Fig. 2(b). Therefore, the series resonance of the opened unit cell occurs at higher frequency than that of the shorted unit cell.

Because the equivalent circuits between the shorted strip and the opened strip are different, the transmission phases are also different. Therefore, the differential phase shift between the shorted and opened metal strips can occur.



(a) Shorted unit cell (Diode ON)   (b) Opened unit cell (Diode OFF)

Figure 1: Unit cell of metal strips on dielectric layer between parallel metal plates.



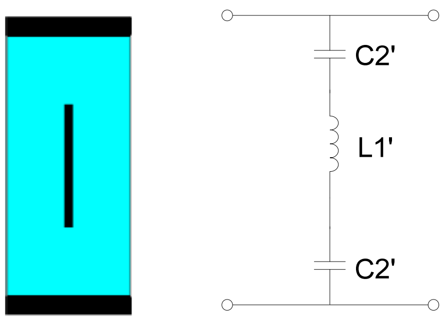
(a) Shorted strip   (b) Opened strip

Figure 2: Equivalent circuit of metal strips on dielectric layer

3. 11.25°, 22.5°, and 45° layers

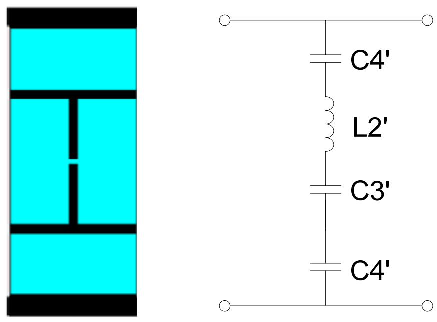
A 4-bit Radant lens consists of 22.5°, 45°, 90°, and 180° bits. Each bit can be implemented using 11.25°, 22.5°, and 45° layers. These three layers can be designed by controlling the width and length of the metal strips on dielectric layer between the parallel metal plates in Fig. 1.

Fig. 3 shows the unit cell and its equivalent circuit of a vertical strip on dielectric layer. The field-simulated results for a vertical strip unit cell are compared with the circuit simulated results in order to obtain the approximate value of L1 in Fig. 2(a). Also, the approximate values of C1 and C2 in Fig. 2(a) are calculated from the field-simulated series and parallel resonance frequencies. Similarly, the approximate value of L2 in Fig. 2(b) can be found following the same procedure for the unit cell in Fig. 4(a). Also, the approximate value of C3 in Fig. 2(b) is calculated from the field-simulated series resonance frequency. The inductance for the oblique metal strip is neglected.



(a) Unit cell   (b) Equivalent circuit

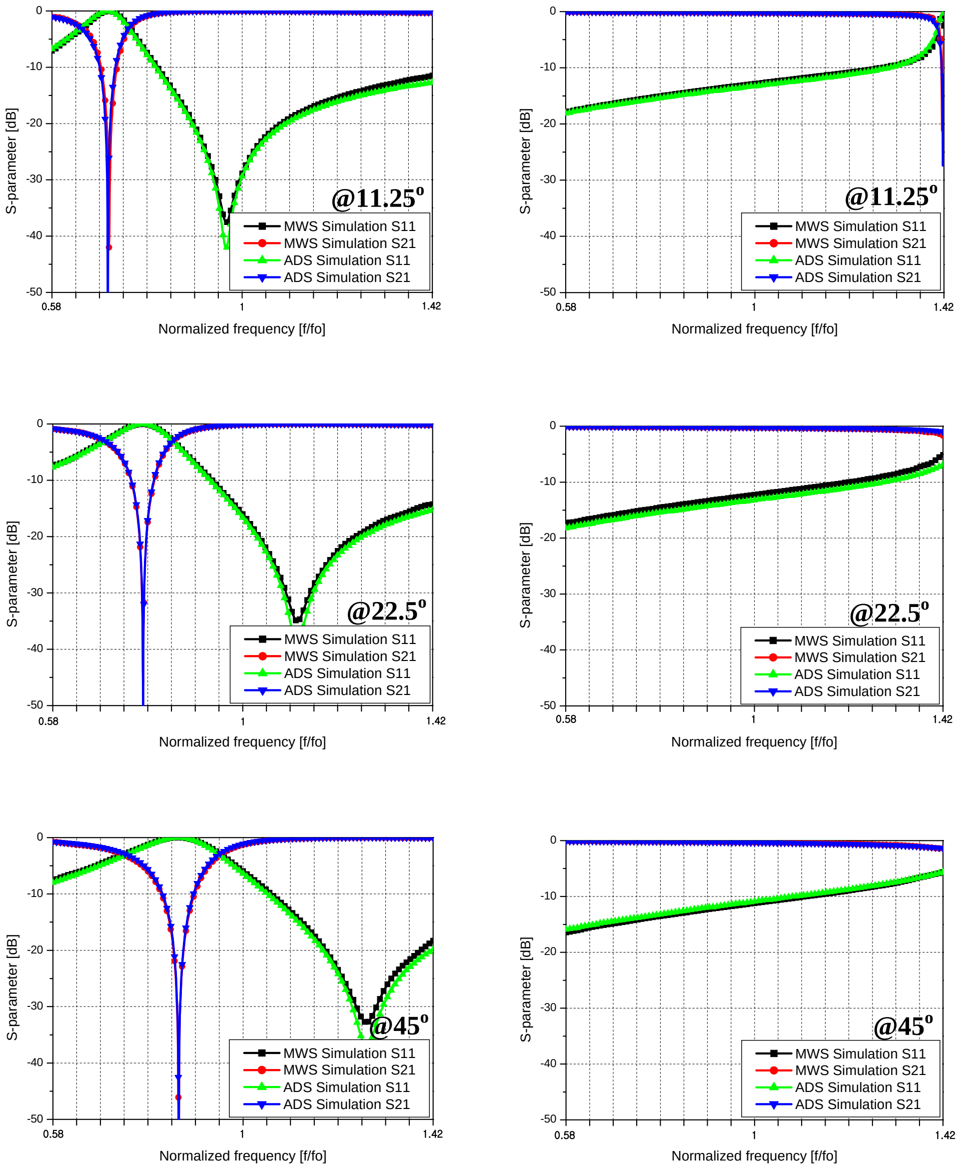
Figure 3: Unit cell and equivalent circuit of a vertical strip on dielectric layer between parallel metal plates



(a) Unit cell   (b) Equivalent circuit

Figure 4: Unit cell and equivalent circuit of a I-bar strip having gap on dielectric layer between parallel metal plates

Fig. 5 shows the simulated insertion and return losses for metal strip on dielectric layer having the differential phase shift of 11.25°, 22.5°, and 45°. Note that the MWS-simulated results are in good agreement with the ADS- simulated ones. Fig. 6 shows the simulated differential phase shift for 22.5° layer. The differential phase shift at the center frequency is 23.2°. The MWS-simulated differential phase shifts for 11.25°, 22.5°, and 45° layers at the center frequency is indicated in Table 1.



(a) Shorted unit cell (b) Opened unit cell

Figure 5: MWS- and ADS-simulated insertion and return losses.

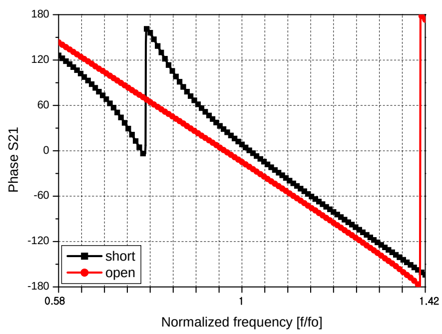


Figure 6: MWS-simulated differential phase shift

4. Measurements

Fig. 7 shows the fabricated 22.5^o dielectric layer, the assembled layer in the metallic waveguide, and the differential phase shift measurement setup. Styrofoam is used to vertically locate the dielectric layer between the parallel plates. Dielectric layer has nine periodic metal strips instead of a magnetic wall. The measurement setup consists of the WR-90 waveguide adapter, the tapered waveguide section, and the assembled layer section.

Table 1 shows the measured differential phase shift for the three different layers at the center frequency. The simulated and the measured results are in reasonably good agreement.

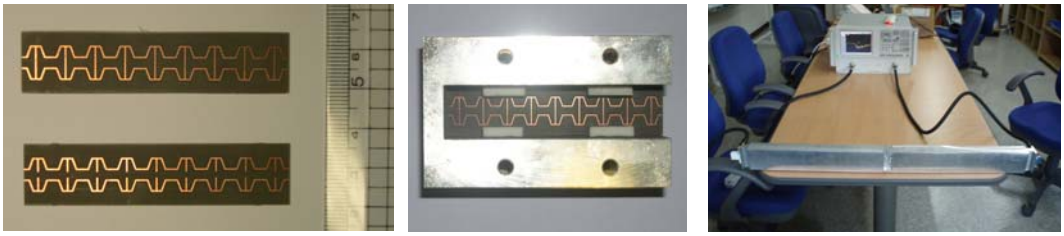


Figure 7: Fabricated dielectric layers and the differential phase shift measurement setup.

Table 1: MWS-simulated and measured differential phase shift

	11.25^o layer	22.5^o layer	45^o layer
Simulated	11.28^o	23.2^o	46.22^o
Measured	9.6^o	22.4^o	43^o

5. Conclusions

11.25^o, 22.5^o, and 45^o dielectric layers are considered to investigate a 4-bit Radant lens. The insertion and return losses of these dielectric layers are simulated by using CST's MWS and compared with those of the equivalent circuits simulated with Agilent's ADS. Also, the measured differential phase shifts are compared with the MWS-simulated ones. The equivalent circuit we obtained can be applied for the design of a more complicated 4-bit Radant lens.

Acknowledgments

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References

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