Nonradiative Dielectric (NRD) Rotman Lens with Gap-Coupled Unidirectional Dielectric Radiator (UDR)

Jae-Gon Lee, Jeong-Hae Lee, and Heung-Sik Tae*
Dept. of Radio Science & Communication Engineering, Hongik University, Seoul 121-791, Korea
*School of Electronics and Electrical Engineering, Kyungpook National University, Taegu 702-701, Korea

ABSTRACT – In this paper, nonradiative dielectric (NRD) rotman lens with a gap-coupled unidirectional dielectric radiator (UDR) has been presented. Design parameters of UDR such as length of resonator and distance of gap are determined using an equivalent circuit model of an evanescent NRD guide. Experimental prototype is fabricated and measured around 38GHz. The result shows a good agreement with theory. Finally, total beam pattern of NRD rotman lens of multi-beam feed has been obtained using a measured pattern of UDR and array factor of NRD rotman lens. The obtained beam pattern shows remarkably suppressed side lobe

I. INTRODUCTION

Nonradiative dielectric (NRD) rotman lens [1] could be practically utilized as a multi-beam feed of car collision avoidance radar if there is an antenna and a coupled structure suitable for it. Among various dielectric antennas, unidirectional dielectric radiator (UDR) [2] is thought to be the fittest for an NRD rotman lens. For instance, slot array antenna [3] for an NRD rotman lens is complex because output transmission line of an NRD rotman lens is bent. Rod antenna [4] is frailer than UDR on account of projecting out conductor plate. Feeding methods such as aperture coupling and probe feeding were employed in previously reported UDR [2]. However, the above feeding methods cannot be applied to NRD rotman lens structurally. Therefore, this paper presents a gap-coupled UDR that can be applied to NRD rotman lens.

A gap-coupled UDR is designed with an equivalent circuit model, thus, reducing design efforts considerably. An equivalent circuit model of a gap-coupled UDR employs an evanescent waveguide K-inverter circuit using the fact the structure of gap-coupled UDR is similar to that of NRD gap-coupled filter [5]. Design parameters of UDR such as length of resonator and distance of gap are determined using an equivalent circuit model. Position of a resonator from conductor end plate is optimized with High Frequency Structure Simulator (HFSS).

Experimental prototype is designed and fabricated at 38GHz. To launch LSM_{11} mode, the waveguide to NRD transition in the Q-band has been also designed and fabricated. The measured beam pattern of a gap-coupled UDR agrees with that of simulations. Finally, total beam pattern of NRD rotman lens of multi-beam feed has been obtained multiplying a measured pattern of UDR by array factor of NRD rotman lens.

II. A GAP-COUPLED UNIDIRECTIONAL DIELECTRIC RADIATOR

A structure of a gap-coupled UDR and its photograph are shown in Fig. 1 and Fig. 2, respectively. As shown in Fig.1, the length of a resonator, the distance of a gap, and the position of a resonator are denoted as R, G, and P, respectively. These parameters effectively control the center frequency, matching, and effective antenna aperture size, respectively. In addition, Q-band waveguide to NRD transition is connected to a NRD guide to excite LSM_{11} mode. The overall size of prototype UDR in Fig.2 is 90×90×30(mm).

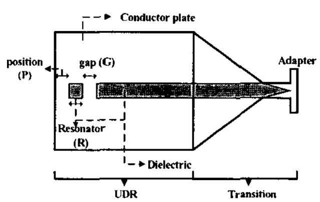

Fig. 1 Structure of a gap-coupled UDR with waveguide to NRD guide transition

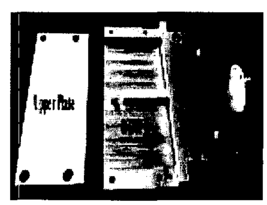

Fig. 2 Photograph of a gap-coupled UDR with transition

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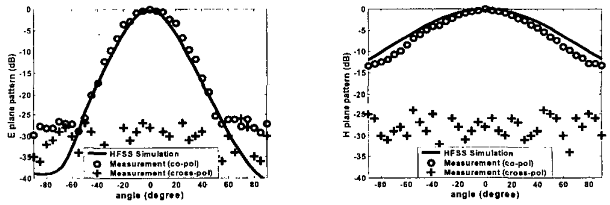
Resonance frequency (Return Loss)	38.45 GHz (-23 dB)	**G**	4.77mm
NRD guide size	a=3.55mm b=3.8mm	**R**	3.34mm
Dielectric	Teflon (ε_r =2.08)	**P**	3.4mm

Table. 1 Designed parameters of a gap-coupled UDR



(a) E-plane (b) H-plane

Fig. 3 Measured and simulated radiation patterns of a gap-coupled UDR

An equivalent circuit model of a gap-coupled UDR is developed in the reference [6]. The model employs an evanescent waveguide K-inverter circuit since the structure of a gap-coupled UDR is similar to that of NRD gap-coupled filter. After calculating gap distance (G) and resonator length (R), position of resonator (P) from conductor end plate is optimized with HFSS for perfect matching since an impedance of an inserted virtual dielectric strip is not exactly the same as that of UDR antenna. At the position of 3.4 mm, the return loss of –23dB has been obtained with the resonance frequency of 38.45 GHz. Table. 1 lists a designed parameter of a gap-coupled UDR.

A gap coupled UDR is fabricated as shown in Fig.2 and its return loss and antenna beam pattern are measured using vector network analyzer (HP 8510C). The return loss of –25dB is measured at the frequency of 38.58 GHz. The 25dBi standard gain horn antenna was utilized for receiving antenna to measure radiation pattern of a gap-coupled UDR. Measurement was performed with 5° step. Fig. 3 plots E-plane and H-plane (co-polar, cross-polar) pattern over –90° to 90°. The measured results show a good agreement with those of HFSS simulation. The resulting half power beam width (HPBW) is 30° in the E-plane and 60° in the H-plane, respectively. As shown in Fig. 3, an isolation of about 25dB between co-polar and cross-polar has been measured. The gain of 13.1dBi has been obtained by comparing difference with Q-band standard horn antenna.

III. TOTAL RADIATION BEAM PATTERNS OF NRD ROTMAN LENS

A structure of an NRD rotman lens [1] together with a gap-coupled UDR is illustrated in Fig. 4. It consists of a parallel-plate guide with an elliptical type dielectric lens inserted between conductor plates. An NRD rotman lens is composed of three input ports, to obtain three output beams, and 29 output ports. Each output NRD guide is coupled to the corresponding UDR through gap as shown in the right hand side of Fig.4. The beam is focused to array output ports provided that incident wave propagates to focal point. The rotman lens is optimized so as to minimize side-lobe of array factor. Array factor is computed using 2-D green function [7] based

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on far-field approximation and 2-D Friis transmission equation after port position and length of output transmission line are determined. Then, an electric field of internal parallel plate is given by equation (1) and (2) using 2-D green function.

$$E(\rho,\theta)=E_0 D\sqrt{\frac{k}{2\pi\rho}}\,\tilde{E}(D,\theta) \tag{1}$$

$$\tilde{E}(D,\theta)=\frac{\cos\theta+\cos\theta_i}{2}\cdot\frac{\sin(\frac{kD}{2}(\sin\theta-\sin\theta_i))}{\frac{kD}{2}(\sin\theta-\sin\theta_i)}\cdot\exp(-jk\rho+j\frac{\pi}{4}) \tag{2}$$

Where, (ρ,θ) is observation point inside lens and D is opening width of tapered output port. ρ_{ij}, ρ_c, and k_c are distance between i[th] input port and j[th] output port, length of output transmission line, and wave number of considering effective permittivity in the transmission line, respectively. A transmission line coefficient between input and output can be derived from 2-D Friis transmission equation. Including ρ_{ij} and ρ_c, complex transmission coefficient from i[th] input port to j[th] output port is derived as equation (3).

$$S_{ij}=\sqrt{\frac{kD_jD_i}{2\pi\rho}}\,\tilde{E}_j(D_j,\theta_j)\,\tilde{E}_i(D_i,\phi_i)\cdot\exp(-j(k\rho_{ij}+k_c\rho_c)) \tag{3}$$

Then, array factor (AF) is represented by

$$AF=\left|\sum C_i\exp(ja_i+jk_0\vec{a_r}\cdot\vec{r_i})\right| \tag{4}$$

Where, C_i and a_i are magnitude and phase of equation (3). $\vec{a_r}$ and $\vec{r_i}$ are unit vector of observation point and position vector of source point, respectively. The procedure for optimization of array factor to obtain minimum sidelobe is shown Fig. 5. Repeating the calculation according to the procedure, optimum of array factor is obtained as depicted in Fig. 6. Note that the detailed NRD rotman lens parameters such as array spacing, focal length, and focal ratio are available in the reference [1].

Total radiation beam pattern of an NRD rotman lens with a gap-coupled UDR has been obtained multiplying a measured pattern of UDR by array factor of NRD rotman lens. Fig. 7 shows total E-plane radiation pattern. HPBW of total beam pattern is 5° in the E-plane. Magnitude of side-lobe is under about –60dB and degradation of side-lobe is remarkable.

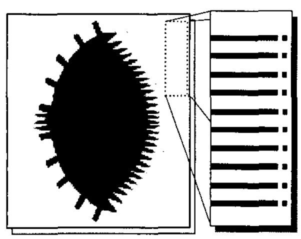

Fig. 4 Structure of an NRD rotman lens with a gap-coupled UDR

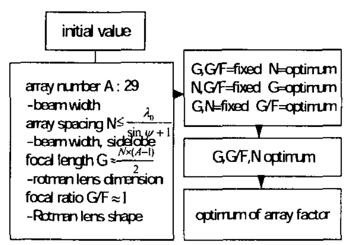

Fig. 5 Procedure for optimization of array factor to obtain minimum side lobe

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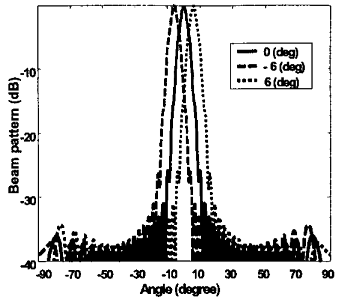

Fig. 6 Optimized array factor (array spacing=5mm, focal length=16 λ_g , focal ratio=0.997, 38GHz

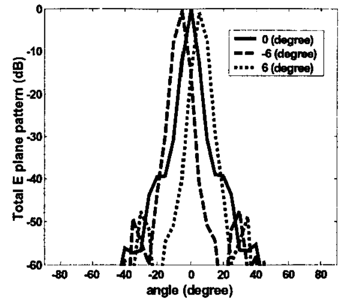

Fig. 7 Total E-plane radiation pattern of rotman lens considering output array (number of array=29,

a=3.55mm, b=3.8mm, G=4.77mm, R=3.34mm P=3.34mm, array spacing=5mm, focal length= 16 λ_g , focal ratio=0.997

VI. CONCLUSION

A gap-coupled UDR suitable for an NRD rotman lens is proposed in this paper. Design parameters of a gap-coupled UDR such as length of resonator and distance of gap are determined using an equivalent circuit model of an evanescent NRD guide. Position of resonator from conductor end plate is optimized with HFSS for perfect matching. This procedure considerably reduced the efforts to design a gap-coupled UDR. Experimental prototype is fabricated and measured around 38GHz. The result shows a good agreement with theory. Finally, total radiation beam pattern of an NRD rotman lens has been obtained multiplying a measured pattern of UDR by array factor of an NRD rotman lens. The obtained beam pattern shows remarkably suppressed side lobe.

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