Broadband Gap-Coupled Unidirectional Dielectric Radiator (UDR) in the Millimeter Wave Band

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ABSTRACT

Gap-coupled unidirectional dielectric radiator (UDR) is proposed in this paper. Especially, multi-pole gap-coupled UDR is employed to obtain broadband characteristic. Design parameters of UDR such as length of resonator and distance of gap are determined using an equivalent circuit model of an evanescent nonradiative dielectric (NRD) guide. The proposed UDR has advantages of planar integration due to good union between antenna and NRD guide, simple structure, easy design procedure, and low cost. Prototypes of gap-coupled UDR are designed and measured around 38GHz. The measured result shows a good agreement with simulation data.

INTRODUCTION

Aperture coupling and probe feeding [1] are previously reported as feeding methods for unidirectional dielectric radiator (UDR). These feeding methods cannot, however, integrate antenna with device of NRD guide easily. In this paper, a gap-coupled UDR is proposed for planar antenna suitable for device with NRD guide. Furthermore, multi-pole UDR is designed to obtain broadband characteristics.

A gap-coupled UDR is designed with an equivalent circuit model to reduce design efforts. 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 [2]. 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 further optimized with High Frequency Structure Simulator (HFSS). Experimental prototypes are designed and fabricated around 38GHz. To launch LSM_{11} mode, the waveguide to NRD transition in the Q-band has been also designed and fabricated. The measured beam patterns of a gap-coupled UDR agree with those of simulation.

EQUIVALENT CIRCUIT MODEL OF A GAP-COUPLED UDR

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).

An equivalent circuit model of a gap-coupled UDR is developed in this paper. 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. Fig. 3 shows that a schematic diagram of a gap-coupled UDR. If an UDR is well matched, all input power will go through an air without any reflection. To model the above matched condition, a virtual dielectric strip is inserted as shown in Fig.3. Then, a gap-coupled UDR could be considered as a gap-coupled NRD filter. Since an impedance of an inserted virtual dielectric strip, however, is not the same as that of URD antenna, the position (P) is further optimized with HFSS to complete a matching as will be discussed later.

At first, height and width of NRD guide are calculated using the following equation (1a) and (1b) since distance of two parallel conductor plates is smaller than half a wavelength in free space [3].

$$a/\lambda_0 \approx 0.45 \quad (1a)$$

$$(b/\lambda_0)\sqrt{\varepsilon_r - 1} \approx 0.4 \sim 0.6 \quad (1b)$$

where a, b, and ε_r are dielectric height, dielectric width, and permittivity, respectively.

The air gap region in Fig.4 can be represented by impedance K inverter of an evanescent waveguide since the NRD guide has a similar structure with a dielectric-filled metal waveguide. The resulting impedance (K) inverter constructed by a gap is shown in Fig. 4. Then, using half-wavelength resonators the values of K and ϕ are given by the equations (2),(3), and (4) [4].

$$\frac{K}{Z_g} = \left| \cosh \alpha G \sin \phi + \frac{1}{2}\left\{ \left(\frac{Z_e}{Z_g} + \frac{Z_g}{Z_e} \right) + \left(\frac{Z_e}{Z_g} - \frac{Z_g}{Z_e} \right) \cos \phi \right\} \sinh \alpha G \right| \quad (2)$$

$$\phi = \tan^{-1}\left(\frac{2\coth \alpha G}{Z_e/Z_g - Z_g/Z_e} \right) - \pi \quad (3)$$

where $Z_e = \omega\mu/\alpha$, $Z_g = \omega\mu/\beta$.

$$\frac{K_{01}}{Z_o} = \sqrt{\frac{\pi}{2}\frac{\omega_\lambda}{g_o g_1 \omega_1'}} \quad (4a)$$

$$\left.\frac{K_{j,j+1}}{Z_o}\right|_{j=1,\ldots,n-1} = \frac{\pi\omega_\lambda}{2\omega_1'}\frac{1}{\sqrt{g_j g_{j+1}}}$$

$$\frac{K_{n,n+1}}{Z_o} = \sqrt{\frac{\pi}{2}\frac{\omega_\lambda}{g_n g_{n+1} \omega_1'}}$$

$$\omega_\lambda = \left[\frac{\lambda_{g1} - \lambda_{g2}}{\lambda_{g0}} \right] \approx \left(\frac{\lambda_{g1}}{\lambda_0} \right)^2 \left(\frac{\omega_2 - \omega_1}{\omega_0} \right) \quad (4b)$$

$$\lambda_{g0} = \frac{\lambda_{g1} + \lambda_{g2}}{2} \quad (4c)$$

where $g_0, g_1, \ldots, g_{n+1}$=element value of low pass filter, ω_1'=normalized cutoff frequency, ω_0=center frequency of filter, ω_1, ω_2=lower and upper frequency of pass-band, λ_0= free space wave length, $\lambda_{g0}, \lambda_{g1}, \lambda_{g2}$=guide wavelength at frequencies at $\omega_0, \omega_1, \omega_2$.

By comparing equation (2) with equation (4), gap distance (G) can be calculated. Resonator length (R) is also calculated using equations (3) and (5).

$$R = \frac{[\pi + 0.5(\phi_1 + \phi_2)]}{\beta_0} \quad (5)$$

MEASUREMENT RESULTS

Table. 1 lists designed parameters of one-pole and three-pole gap-coupled UDR. One-pole gap coupled UDR is fabricated as shown in Fig.2 and its return loss and antenna beam patterns 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. 7 and Fig. 9 plot 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. Fig. 7 and Fig. 9 also show an isolation of 25dB between co-polar and cross-polar. The gain of 13.1dBi has been obtained by comparing difference with Q-band standard horn antenna. Three-pole gap-coupled UDR is simulated with HFSS. As shown in Fig. 6, bandwidth of UDR is 2.5%. The resulting HPBW is 35° in the E-plane and 100° in the H-plane in the 38.5GHz, respectively. Three-pole gap-coupled UDR is being fabricated and its measured results will be presented at the conference.

CONCLUSIONS

A gap-coupled UDR is proposed in this paper. Multi-pole gap-coupled UDR is employed to enlarge bandwidth. 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.

Acknowledgement
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References

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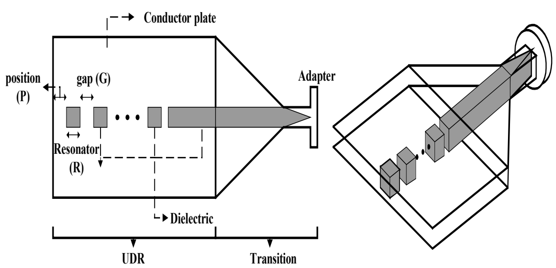

Fig. 1 Structure of a gap-coupled UDR with waveguide to NRD transition

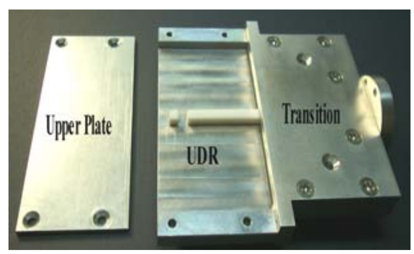

Fig. 2 Photograph of a gap-coupled UDR with transition

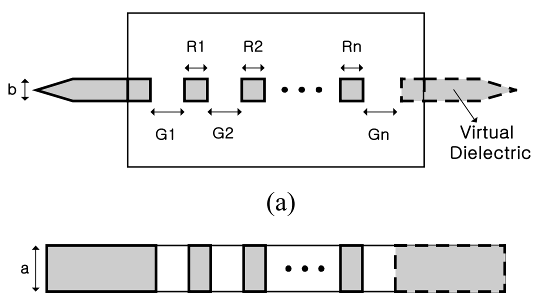

Fig. 3 Schematic diagram of a gap-coupled UDR (a) Top view (b) Side view

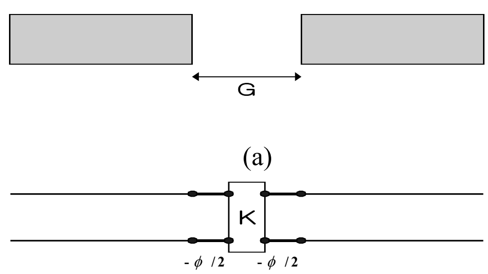

Fig. 4 (a) Dielectric pair separated by gap (b) Equivalent circuit of K-inverter

(mm)

	G_1	G_2	G_3	R_1	R_2	R_3	P
1-pole UDR (a=3.55mm, b=3.8mm)	4.77	•	•	3.34	•	•	3.4
3-pole UDR (a=3.55mm, b=4.175mm)	2.37	4.9	4.9	2.92	2.87	2.92	2

Table. 1 designed parameters of one-pole and three-pole gap-coupled UDR (Center frequency=38GHz, ε_r=2.08)

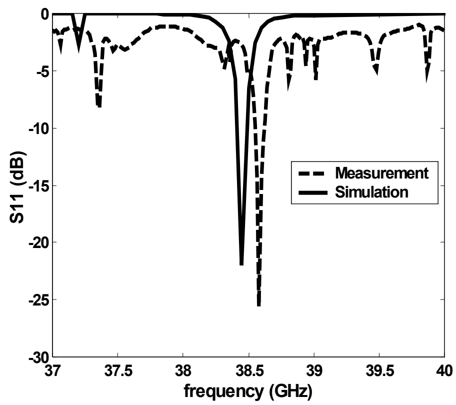

Fig. 5 Simulated and measured S_{11} of one-pole gap-coupled UDR

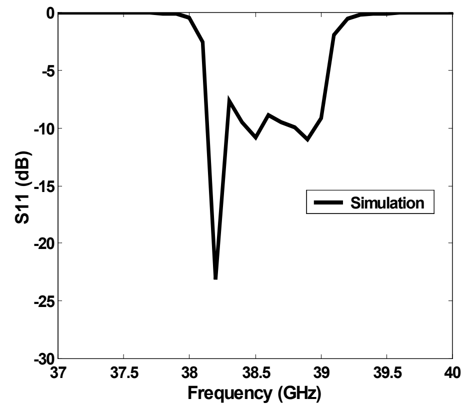

Fig. 6 Simulated S_{11} of three-pole gap-coupled UDR

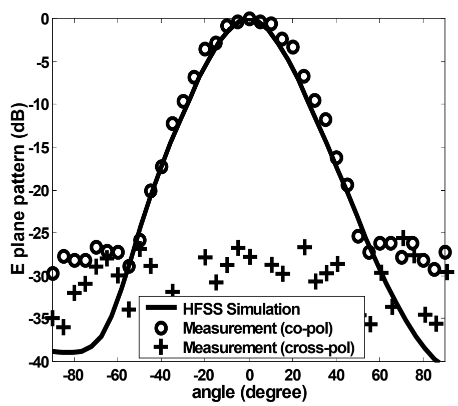

Fig. 7 Simulated and measured E plane patterns of one-pole gap-coupled UDR

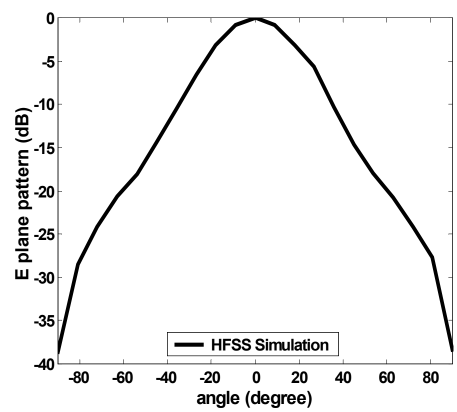

Fig. 8 Simulated E plane pattern of three-pole gap-coupled UDR

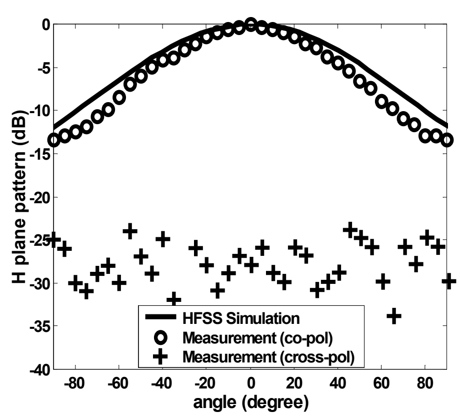

Fig. 9 Simulated and measured H plane patterns of one-pole gap-coupled UDR

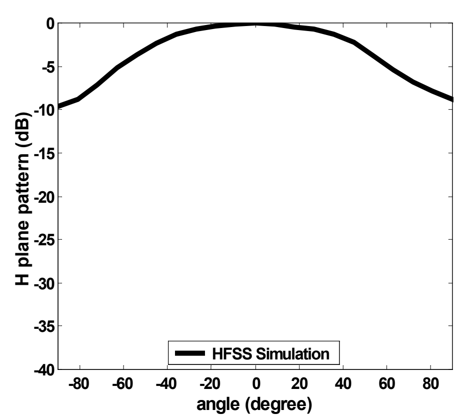

Fig. 10 Simulated H plane pattern of three-pole gap-coupled UDR