Rotating-Mode Feed Transitions from a Coaxial Line to a Three-Layered Radial Waveguide

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1. Introduction

Recently, millimeter wave has received substantial attention because of its high-speed data transmission capability and generation of new frequency resource. Radial line slot antenna (RLSA) [1] is a candidate for high-gain and high-efficiency antenna in the millimetre wave band. In the medium gain RLSA, with a few turns of elements, concentric-array RLSA (CA-RLSA) [2] is preferable because the truncation effect at the end of the array is not negligible with spirally-arranged RLSA. Conical beam is produced by a cylindrical mode feeding in a CA-RLSA. A rotating mode feeding, in which the amplitude is uniform and phase is linearly tapered in the circumferential direction in the radial waveguide, is required to get a pencil-beam at the boresight in a CA-RLSA.

Two types of radial waveguide structures have been proposed for the CA-RLSA in the 60GHz band. One structure uses foam material (ε_r=1.08) as a spacer between the bottom and top plate. 50% of efficiency and 33.0dBi of gain at 60 GHz were obtained by the measurement of the RLSA with diameter of 100mm [3]. In this structure, fine alignment of bottom and top plate is difficult, and it causes degradation of the gain. Another structure uses a PTFE (ε_r=2.20) substrate, in which slots are etched on the one side of copper sheet. 55% of efficiency and 33.4dBi of gain at 60 GHz were obtained by the measurement of the RLSA with diameter of 100 mm [3]. Though fine alignment of the bottom and top plate is accomplished in this structure, the efficiency becomes low because of the increase of dielectric loss. In addition, the bandwidth becomes narrow because of the long line effect due to high permittivity of the material.

In this paper, three-layered radial waveguide [4], which is composed of two dielectric layers and one air layer in the middle as shown in Fig.1, is introduced to reduce the dielectric loss. The existence of the air layer can reduce the dielectric loss. The alignment between the bottom and upper plate, which are dielectric substrate with copper plate on one side, is adjusted by a penetrating conducting pin at the center of the radial waveguide in order to reduce the positioning error. Two types of rotating-mode feed transitions from the coaxial line to the three-layered radial waveguide are proposed in the paper; dielectric resonator and circular patch model. Degeneracy-separation method with perturbation element is used to obtain rotating mode by exciting two degenerate modes with 90deg phase difference. According to the principle of degeneracy-separation method, the dielectric resonator is designed so that only TM_{11} mode, which will radiate EM field with sinusoidal pattern in the radial waveguide, is excited. For the transition of the patch model, the perturbation element, which is notches on the patch [5], is designed.

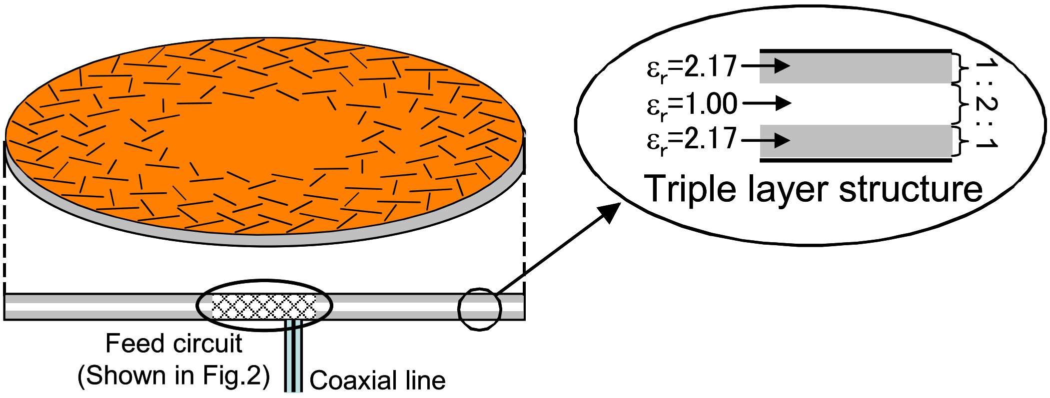


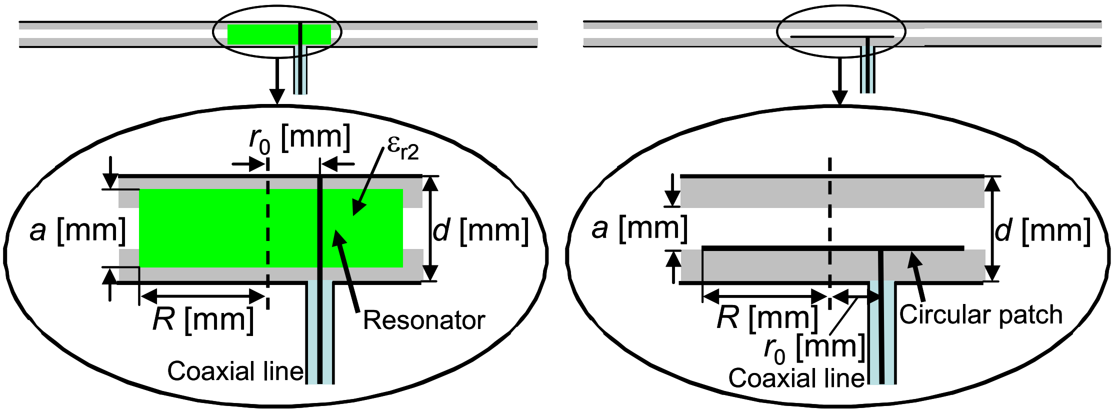
Fig.1 Three-Layered Radial Line Slot Antenna with Air Layer

2. Structure of Feed Circuits

Transitions are investigated and designed in 22GHz band in order to reduce fabrication error in the future work. The structure of three-layered radial waveguide [4], which is composed of two dielectric (ε_r=2.17) layers and one air layer in the middle, is shown in Fig.1. The ratio of the dielectric layer and the air layer is fixed to be 1:2 as shown in Fig.1. The equivalent relative permittivity becomes 1.37 for this case, which is advantageous both in realizing slow wave effect for gain enhancement and reducing long line effect for bandwidth enhancement.

Two types of feed circuits, as shown in Fig.2, are investigated. In the Model 1 of Fig.2 (a), the feeding part of the middle layer is filled with dielectric material with high permittivity for spacer and high-Q resonance. From the view point of fabrication, $a = d/2$ is preferable because milling of dielectric layers is not needed. But it might be not enough to obtain high-Q resonance because the thickness of the dielectric is not large enough. The dielectric resonator is fed by the penetrating inner conductor of a coaxial line. Degeneracy-separation method using a conducting pin will be used to obtain rotating mode.

In the Model 2 of Fig.2 (b), a circular patch is printed on the surface of the lower dielectric layer. This structure needs spacer between the lower and upper substrate, and positioning error will be concerned. A penetrating pin at the center of the circular patch will be considered for the solution of the problem. Degeneracy-separation method using notches on the periphery of the patch will be used to obtain rotating mode.



(a) Model 1 (b) Model 2

Fig.2 Two Types of Feed Circuits

3. Design Example

3.1 Design to Excite TM_{11} Mode

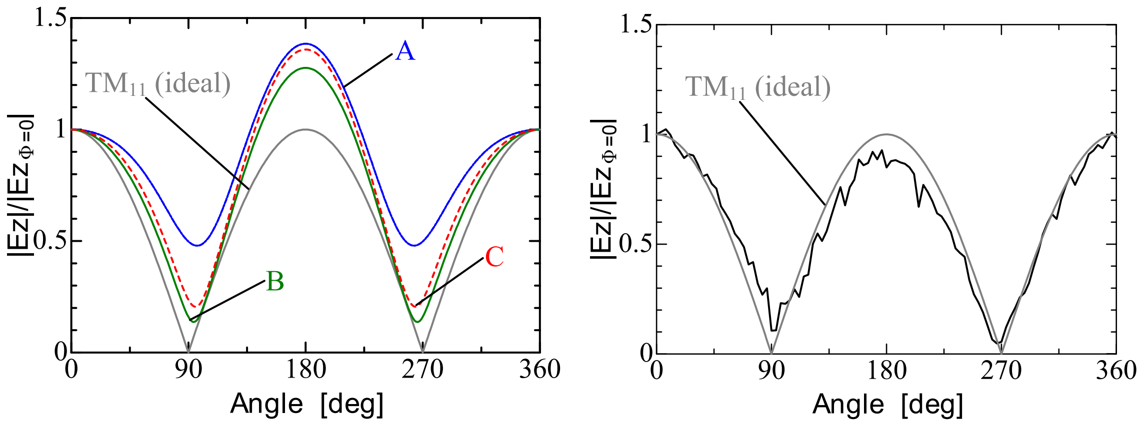
The mode matching method was used in the design of Model 1, while FEM-based EM Simulator, Ansoft HFSS was used in the design of Model 2.

In consideration of Model 1 analyzed by the mode matching method, the quantity H defined by $H=\left\{\sum_{i=0,2,3\cdots}\left|a_{\mathrm{TM}_{i1}}\right|\right\}/\left|a_{\mathrm{TM}_{11}}\right|$ ($a_{\mathrm{TM}_{i1}}$: excitation coefficient of TM_{i1} mode) is introduced, which expresses the purity of TM_{11} mode; the smaller, the better. The waveguide height (d) is designed as large as possible under the condition that unwanted LSE modes in the radial waveguide are cutoff. Resonator height (a), resonator radius (R) and feeding point radius (r0) are designed so that unnecessary modes of the resonator are suppressed, or H becomes small, and excitation of TM_{11} mode is dominant. When H is small, sinusoidal amplitude pattern in the circumferential direction is realized. As an example, designed parameters for Model1 are listed in Table1. In the parameters B and C, the waveguide height is as large as possible to suppress unwanted LSM mode. Fig.3 shows the amplitude variation in the circumferential direction. As a reference, sinusoidal curve is plotted. From the curve for Model1-A in Fig.3 (a), it is seen that unnecessary higher modes are not suppressed enough. The thick resonator is useful to suppress unnecessary mode by comparing Model1-A and Model1-B. Fig.3 (a) It is observed that unwanted TM_{01} mode is more suppressed in Model1-B than Model1-A. H of Model1-C is 0.214 when ε_{r2}=7. After the numerical investigation, it is found that small H can be realized when the waveguide height d is small.

Fig.3 (b) shows the amplitude distribution in the circumferential direction for Model 2. As an example, designed parameters are d=3.20mm, R=2.50mm, and r0=1.00mm. This structure does not require a dielectric with high permittivity. The distribution similar to sinusoidal curve can be obtained, from which good rotating mode will be expected.

Table 1 Designed parameters for Model 1 without Perturbation

	ε_{r2}	d [mm]	a [mm]	R [mm]	r0 [mm]	H
Model1-A	9.8	2.0	1.0	2.58	1.7	0.432
Model1-B	9.8	2.0	1.9	1.69	1.5	0.149
Model1-C	7.0	2.4	2.3	1.93	1.7	0.214



(a) Model 1 (b) Model 2

Fig.3 Circumferential Field Distribution without Perturbation Element

3.2 Design to Obtain Rotating Mode for Model2

Perturbation element, to obtain rotating mode, is designed for Model2. Notches on the patch, which work as perturbation elements to separate two degenerate modes and excite them with the same amplitude and 90deg phase difference [5], are shown in Fig.4. R, r0, w1 and w2 are varied so that the field distribution becomes rotating mode. As an example, designed parameters are d=3.20mm, R=2.44mm, and r0=0.60mm, w1=0.64mm, w2=0.44mm. Circumferential electric field distribution is plotted in Fig.5. Field distribution has deviation of $\max_{\varphi}|E(\varphi)|-\min_{\varphi}|E(\varphi)|$=4.5dB in amplitude and $\max_{\varphi}\left|\angle E(\varphi)+\varphi\right|-\min_{\varphi}\left|\angle E(\varphi)+\varphi\right|$=39 degrees in phase from the ideal values of rotating mode.

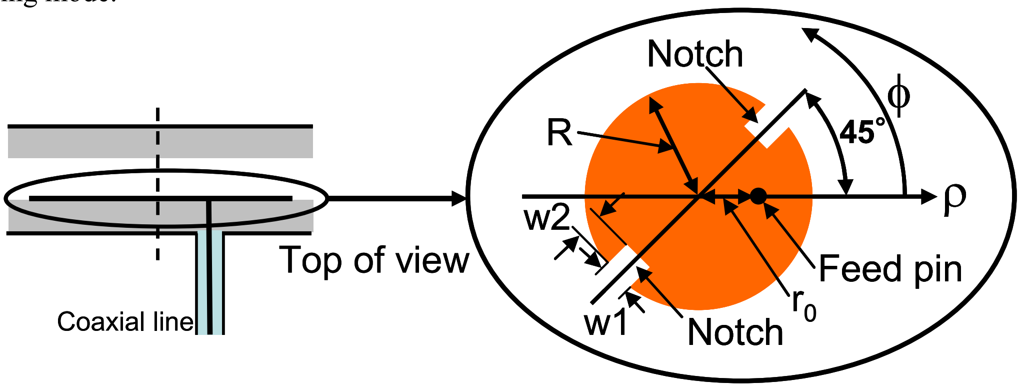
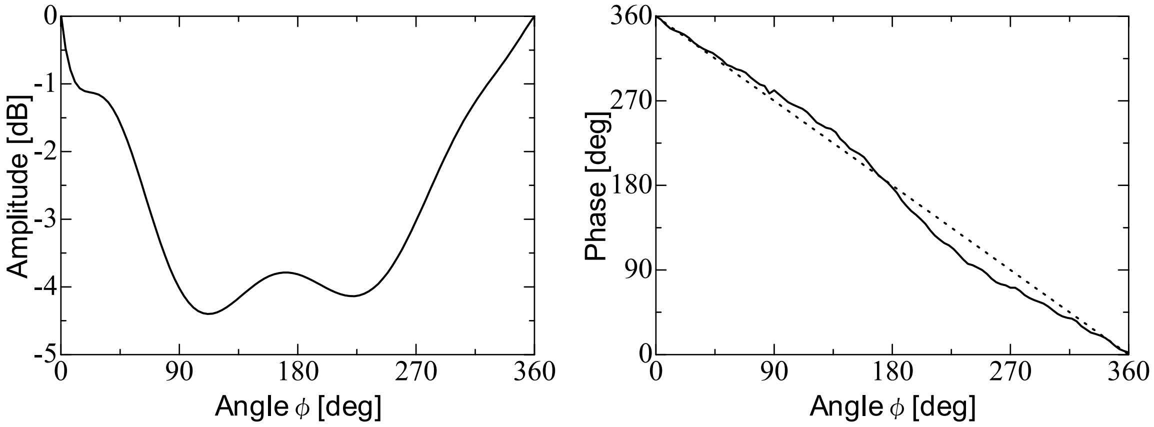


Fig.4 Patch Resonator with Notchs



(a) Amplitude (b) Phase

Fig.5 Circumferential Field Distribution of Model2 with Perturbation Element

4. Conclusion

Rotating-mode feed transitions from the coaxial line to the three-layered radial waveguide are proposed. The rotating mode with amplitude deviation of 4.5 dB and phase deviation of 39deg is realized by the transition with a circular patch model with notched for perturbation. Confirmation by measurements and design of slots on the radial waveguide are future tasks.

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