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Microstrip-Line to Radial Waveguide Transformer for Rotating Mode Excitation by using a Quasi-Coaxial Structure

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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. A cost-effective 60 GHz MMIC modules with a post-wall planar antenna [1] were developed for high-gain and high-efficiency linearly-polarized wave radiation. A quasi-coaxial structure [2] for cylindrical mode feeding is also proposed for a concentric-array radial line slot antenna (CA-RLSA) [3]. 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.

For this purpose, the authors propose the microstrip-line (MSL) to radial-line transformer for rotating mode excitation by using a quasi-coaxial structure as shown in Fig.1. In the proposed structure, the quasi-coaxial structure is fed by four MSLs with 90-degree phase differences (0 deg, 90deg, 180deg, 270deg). The phase differences for the four MSL ports are realized by planar circuits using three branch-line couplers (90 degree hybrids) and a quarter-wavelength delay line. The quasi-coaxial structure to radial waveguide transformer is designed using FEM-based simulator (HFSS). 90 degree hybrids are designed using MoM-based simulator (Ensemble). The total characteristic is analyzed by connecting scattering matrices of all the components, or the quasi-coaxial structure to radial waveguide transformer, 90 degree hybrids and a quarter-wavelength delay line.

2. Microstrip-Line to Radial Waveguide Transformer for Rotating Mode Feeding

Figure 1 shows the MMIC RF module with a CA-RLSA. The RF output from the MMIC is MSL. A transformer between RF module and CA-RLSA is proposed in this paper by neglecting RF module and slots in a CA-RLSA. The structure of MSL to radial waveguide is shown in Fig.2. The thickness of the radial waveguide is 0.5mm, and the dielectric constant ε_r is 2.2. Quasi-coaxial line, which is made of three stacked substrates, is used to feed the radial waveguide. The thickness of the three substrate is 0.15mm, and the dielectric constants ε_r are 4.22, 3.484, 4.22, respectively. There are

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eight via holes (diameter: 0.3mm), for outer conductor of the quasi-coaxial structure, around the inner conductor of the quasi-coaxial structure, which also suppress leakage into the substrate. The structure is symmetric with respect to the center axis of the MSL. Four MSLs, which are fed by 90 degree phase differences, are connected to the inner conductor of quasi-coaxial line to realize rotating mode (uniform in amplitude and linearly tapered in phase in the ϕ-direction) excitation. The 90 degree phase differences (0 deg, 90deg, 180deg, 270deg) for four ports of the quasi-coaxial structure input are realized by MSL planar circuits, which are made of three branch-line couplers (90 degree hybrids) and quarter-wavelength line as shown in Fig.2(d).

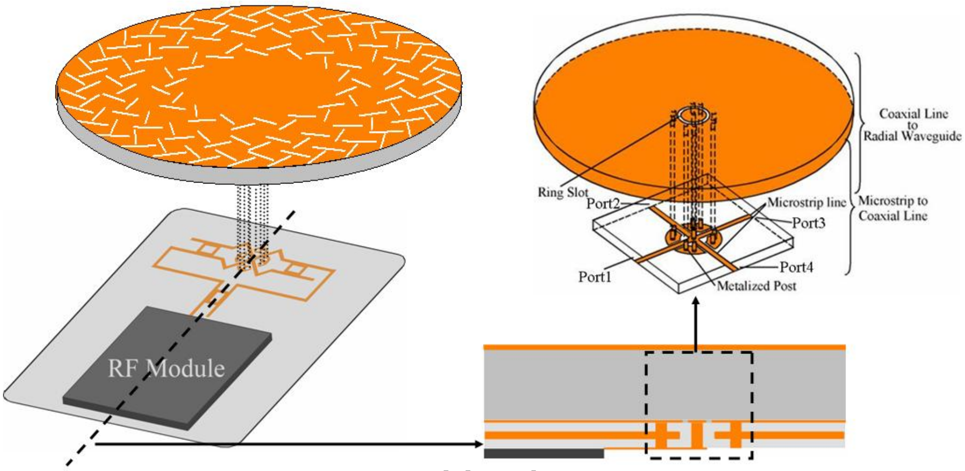
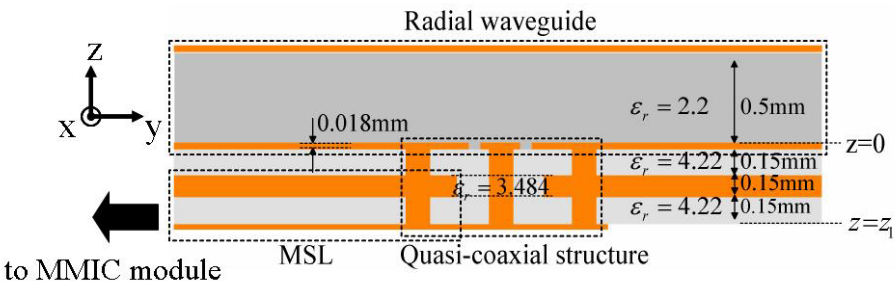
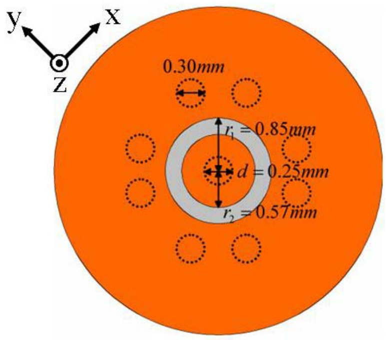


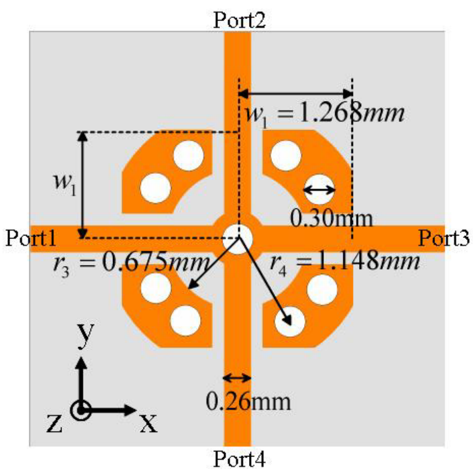
Figure 1: MMIC module with a CA-RLSA

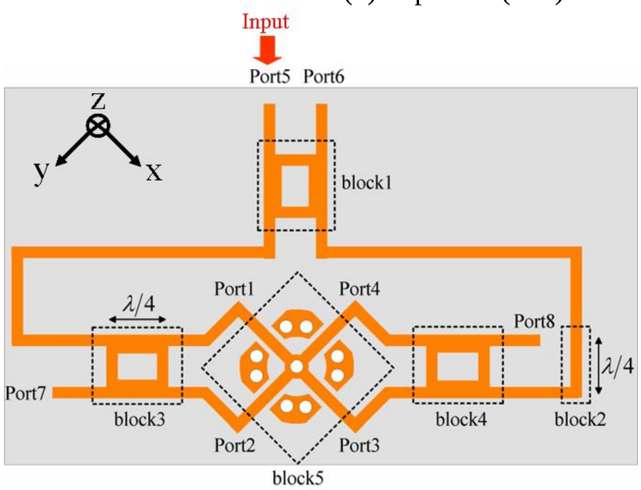




(a) Cross-section

(b) Top view (z=0)





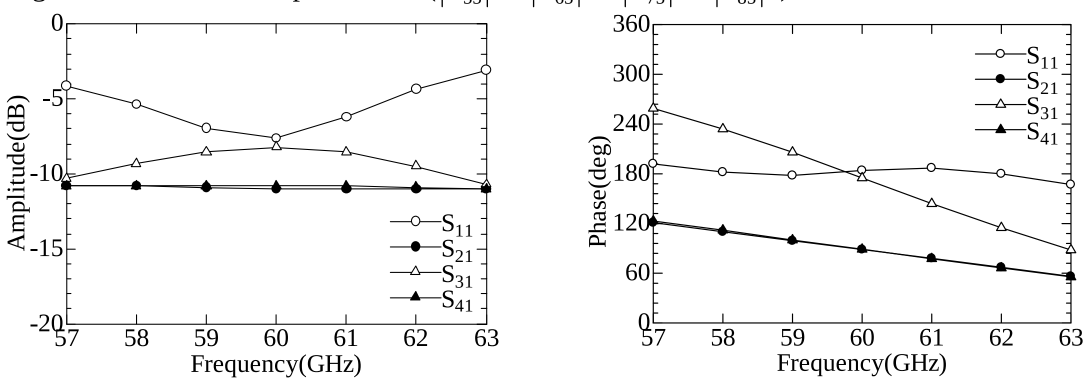
(c) Parameters of quasi-coaxial structure

(d) Bottom view ($z = z_1$)

Figure 2: MSL to radial waveguide transformer for rotating mode excitation

3. Numerical results

As an example, the proposed transformer is designed at 60GHz. Quasi-coaxial structure to radial waveguide transformer (block5 in Fig.2(d)) is designed by FEM-based simulator (HFSS Ver.9) so that the reflection becomes minimum value by adjusting r_1, r_2, r_3, r_4, d and w_1 in Fig.2. Frequency characteristics of scattering matrix of block 5 are shown in Fig. 3 by neglecting blocks 1-4. At 60GHz, S_{11}, S_{21}, S_{31}, and S_{41} are -7.6dB, -11dB, -8.21dB and -10.8 dB, respectively. Deviations of amplitude and phase in the ϕ-direction in the radial waveguide are shown in Fig.4 with the ideal excitation for port 1,2,3 and 4. The simulated amplitude and phase deviation in ϕ-direction is $\pm$0.5dB and $\pm$2.2 degree at 60GHz. 90 degree hybrids (block1,3 and 4 in Fig.2(d)) in the planar rotating mode feed circuit are designed using MoM-based simulator (Ensemble Ver.5). Fig.5 shows frequency characteristics of scattering matrix of a 90-deg hybrid (blocks 1,3, and 4). Total characteristic of MSL to radial waveguide transformer for rotating mode feeding is analyzed by connecting scattering matrices of blocks1-5 in Fig.2(d) by assuming matched termination for ports 5-8. The frequency characteristic of a quarter-wavelength delay line (block2 in Fig.2(d)) is also considered in the analysis. At 60GHz, S_{15}, S_{25}, S_{35} and S_{45} are -6.49dB$\angle$169deg, -6.42 dB$\angle$83.8deg, -6.56 dB$\angle$-6.24deg and -6.53 dB$\angle$-92.9deg, respectively. Frequency characteristic of scattering parameters for the whole structure is shown in Fig.6. At 60 GHz, reflection S_{55} is suppressed to -36dB while the reflection of block5 are quite large as shown in Fig.3. Total power loss due to reflection into ports 5-8 is also shown in the figure. At 60GHz, total power loss ($|S_{55}|^2 + |S_{65}|^2 + |S_{75}|^2 + |S_{85}|^2$) is -15dB.



(a) Amplitude (b) Phase

Figure 3: Frequency characteristics of scattering matrix of block5

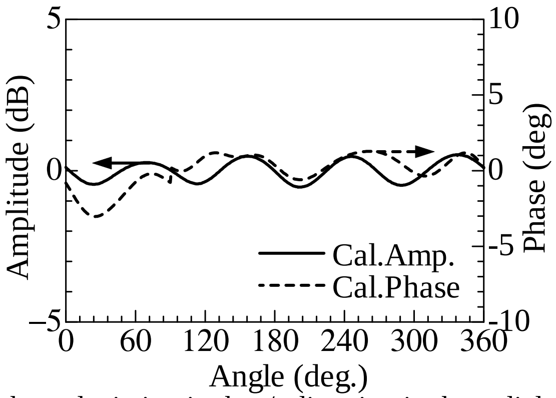
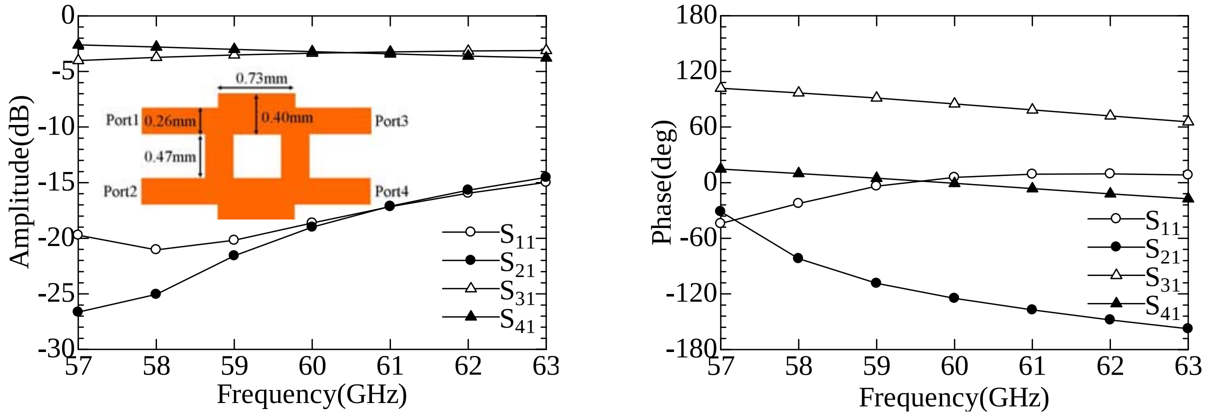
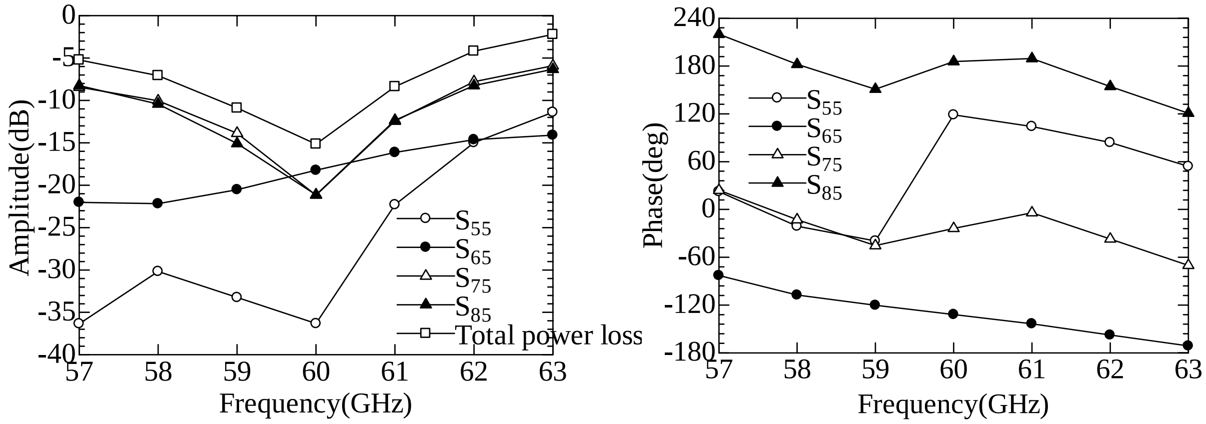


Figure 4: Amplitude and phase deviation in the ϕ-direction in the radial waveguide with the ideal excitation for port 1,2,3 and 4



(a) Amplitude (b) Phase

Figure 5: Frequency characteristics of scattering matrix of a 90-deg hybrid(blocks 1,3 and 4)



(a) Amplitude (b) Phase

Figure 6: Frequency characteristic of scattering parameters for the whole structure

4. Conclusion

MSL to radial waveguide transformer for rotating mode excitation by using a quasi-coaxial structure has been proposed. Calculated amplitude and phase deviation in the circumferential direction in radial waveguide are ±0.5dB and ±2.2 degree when ideal excitation is assumed to four input ports of the quasi-coaxial structure. MSL planar circuit is designed to excite the quasi-coaxial structure. The calculated total reflection and power loss at 60GHz are -36dB and -15.15dB, respectively. Confirmation by the experiment is a future task.

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