Middle-Feed Post-Wall Waveguide Antenna with Cosecant Radiation Pattern for Base Station Antennas

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1. Introduction

The authors have discussed a post-wall waveguide slot array for a base station antenna in millimeter-wave communication systems [1]. Since the space propagation loss of a millimeter-wave is generally larger than that of a microwave, a base station antenna should be required a higher gain in millimeter-wave bands. A planar antenna with low-loss transmission line and low-cost is good for this purpose. A post-wall waveguide is easily manufactured at low cost for mass production by making densely arrayed via-holes and metal-plating the surfaces [2]. The measured transmission loss of the post-wall waveguide at 25.6 GHz is small around 0.038 dB/cm. The authors proposed a post-wall waveguide slot array with end-feed for the base station antenna as shows in Fig.1(a). The 3dB beam width is 84 degrees in the horizontal plane. A cosecant beam pattern with null filling in the vertical plane is synthesized in order to get uniform illumination over a coverage area. The slot array is series-fed so that the beam direction is squinted by frequency change [2]. The beam squint causes serious gain reduction at the front of the array. The feed position should be moved around the center of the slot array to avoid this beam squint. A method is proposed in Ref.[3], where another slot array with a Taylor pattern is placed on the left of the antenna in Fig.1(a) to cancel the beam squint of the two antennas. This paper proposes another method as shown in Fig.1(b), where the feed position is moved around the center without additional slots using a H-plane power divider. The design method of the end-feed array is shown in Sec.2. The determination of the feed position is discussed in Sec.3. The structure of the middle-feed antenna is presented in Sec.4. The radiation patterns of this antenna are shown in Sec.5. The conclusions are summarized in Sec.6.

2. Design of the end-feed antenna

Figure 1(a) shows the structure of the end-feed antenna. The excitation coefficients of 16 elements are determined by a technique for shaped beam pattern synthesis [4]. Figure 2 shows the excitation coefficients. Each radiating element consists of two parallel slots. The slot spacing in a pair is determined to suppress the reflection for traveling wave excitation [5], so that the excitation phase of the elements can be adjusted by the element spacing. The excitation amplitude is controlled by the slot length. The coupling of each element can be determined simply according to the power conservation in a traveling-wave excited array. The mutual coupling among the slot pairs should be included in the modification of the array design because all the slots are parallel to each other. Figure 5(a) shows the frequency dependence of the radiation pattern in the end-feed antenna on the E-plane. A cosecant beam with null filling is observed at 25.6 GHz. The average element spacing is $0.707\lambda_0\ (=0.799\lambda_g)$. The beam squint between 25.2 GHz and 26.0 GHz is 3.4 degrees.

ISBN: 89-86522-78-0 94460©KEES

3. Feed position in mid-feed antenna

The feed position is determined in terms of the frequency dependence of the beam direction and the directivity of a 16-element array factor, which is approximately calculated by using the equal element spacing in average even though the actual spacing is unequal depending on the coupling. The frequency dependence of the excitation coefficient of each element is assumed to be unchanged in amplitude but it is varied in phase according to the change of the guide wavelength. Figure 3(a) and (b) show the beam direction and directivity for various feed position. #n means that the feed position is placed between Elements #n and #n+1. In the directivity, the solid lines show the peak in the beam direction the dotted lines show the value in 2-degree direction. The physical center of the array is located at #8. The equal power division for the taper amplitude distribution shown in Fig.2 is obtained at #6. The feed position is determined at #7 to minimize the beam squint to 0.4 degree over a 2 GHz bandwidth. On the other hand, the beam squint is 8.6 degree for the end-feed at #0 over the equal bandwidth. The 1 dB down bandwidth of the peak directivity is 1.4 GHz for the middle feed at #7 while it is 0.6 GHz for the end feed at #0.

The spacing between Elements #7 and #8 should be increased to $1.50\lambda_g\ (=1.33\lambda_0)$ to place the H-plane divider as shows in Fig.1(b). The excitation phases of Elements #7 and #8 are modified by trial and error process to avoid degradation of the radiation pattern as possible due to the increase of the element spacing, while the amplitude of these elements is unchanged. Figure 2 shows the modified excitation coefficients. The H-plane divider separates the slot array into two sub-arrays. The divider and the two sub-arrays are independently designed. The divider for #7 should have the amplitude ratio of 1.63 dB and the phase difference of −83.1 degrees to the two sub-arrays.

4. Middle-feed antenna

Figure 1(b) shows the designed H-plane middle-feed antenna. The number of slot pairs is 16. The design frequency is 25.6 GHz. The post-wall waveguides have a dielectric constant of ε_r = 2.17 and a thickness of 3.2 mm. The radius of the posts is 0.6 mm and the typical post spacing is 2.4 mm. Figure 4(a) shows the structure of the H-plane divider and its design parameters. The divider is analyzed by the Method of Moments. In the analysis, the post-wall waveguides are replaced by metal-wall waveguides with equal guide wavelength. The width of the radiating waveguide is 6.2 mm and that of the feed waveguide is 5.5 mm. The divider is designed so that the reflection is suppressed and the power dividing ratio $|S_{21}|^2/|S_{31}|^2$ is 1.63 dB derived in Sec.3. The position of the reflection-canceling post p =2.10 mm and q =0.45 mm are obtained. Figure 4(b) shows the dividing characteristics. At the design frequency, the reflection is −15.1 dB, the power dividing ratio is 1.63 dB and the phase difference is −24.5 deg. The reflection keeps less than −15 dB over the bandwidth. The power diving ratio and the phase difference are almost unchanged. The two sub-arrays are designed similarly to Sec.2. The phase difference between Elements #7 and #8 is obtained by that of the H-plane divider and a proper shift of the positions of these elements.

5. Analysis results

Figure 5(b) shows the calculated directivity of the middle-feed antenna. The beam direction and the peak directivity in the both types of the antenna are summarized in Table 1. The variation of

the beam direction of the middle-feed antenna over a 0.8 GHz band is 0.1 deg compared with 3.4 deg using the end-feed antenna. In Fig.5(b), there is a null in the cosecant-pattern region at 26.0 GHz, which will be removed. The sidelobe level in the Taylor pattern region increases up to –8.8 dB at 25.6 GHz.

6. Conclusion

The middle-feeding post-wall waveguide antenna for base station antennas has been proposed. In the analysis, the beam direction is almost unchanged by a frequency change in comparison to the end-feed. In future, we will experiment this model.

References

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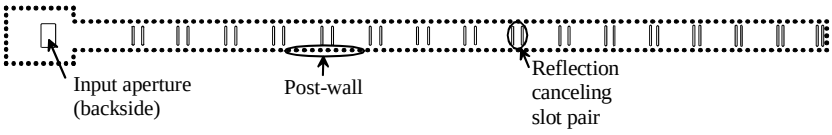
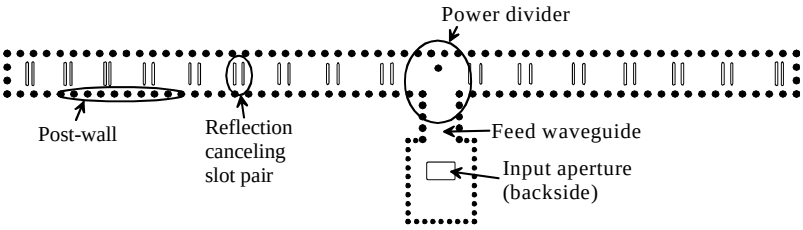


(a) End-feed antenna



(b) Middle-feed antenna

Figure 1: Antenna structure

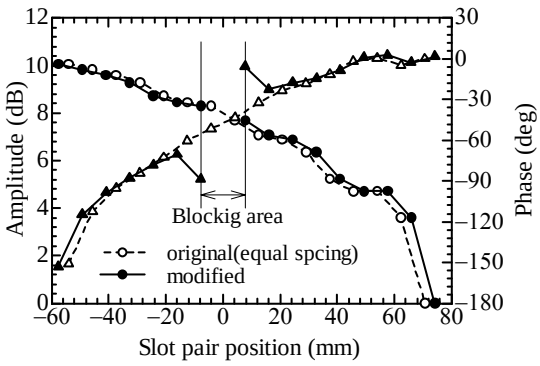
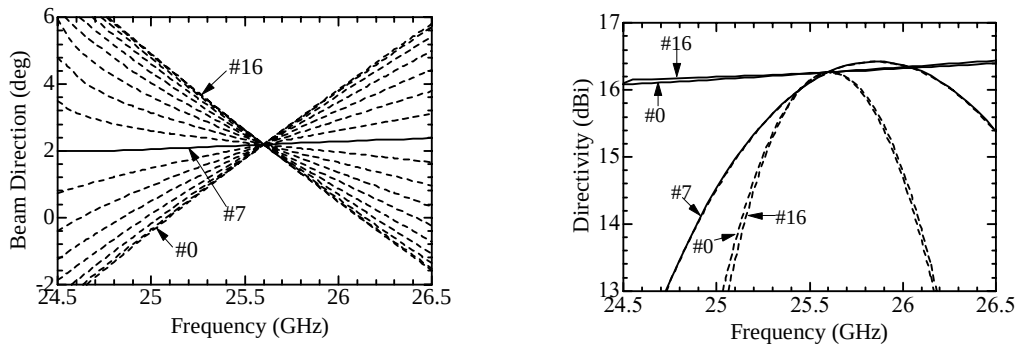


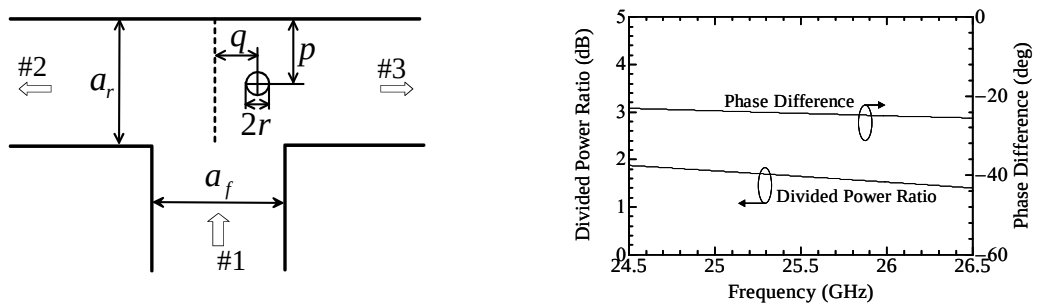
Figure 2: Excitation coefficients



(a) Main beam direction

(b) Directivity

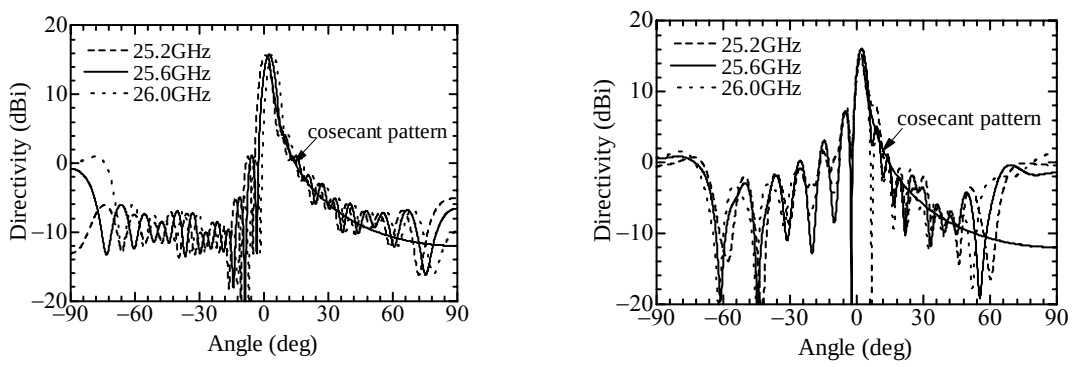
Figure 3: Frequency characteristics for various feed position



(a) Structure

(b) Frequency characteristics

Figure 4: H-plane divider (T-junction)



(a) end-feed

(b) middle-feed

Figure 5: Calculated frequency dependence of radiation patterns including slot coupling

Table 1: Comparison between the end-feed and the middle-feed antenna

	The end-feed antenna		The middle-feed antenna	
Frequency	Direction	Directivity	Direction	Directivity
25.2 GHz	0.7 deg	15.7 dBi	2.3 deg	15.1 dBi
25.6 GHz	2.3 deg	15.8 dBi	2.2 deg	16.0 dBi
26.0 GHz	4.1 deg	15.9 dBi	2.2 deg	16.2 dBi