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Controlling Beamwidth of Slot Antenna by Using Parasitic Elements

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1. Introduction

In recent years, high speed of mobile communication requires frequency of carrier to be higher. So the Base Station antennas with low loss characteristics such as waveguide slot antennas become advantage. Using slots around 0.75 λ length in purpose of being easy to control the excited phase, the H-plane beam widths of these antennas are limited around 70° [1]. In this report the authors proposed a method to design the waveguide slot antennas, those can be controlled the beam width by using parasitic elements.

Method of Moment(MoM) was adopted to analyze [2]. An 8-element-array with uniform distribution in amplitude and phase was designed and measured. The results indicate the beam widths of H-plane can be changed in the range of 60° to 120° by moving the height of parasitic elements. A good agreement between calculated results and measured ones was confirmed in both E and H-planes. In addition, the input impedance, reflection characteristics were also considered when shifting the height of parasitic elements.

2. Antenna structure

Fig.1 shows 8-element-array waveguide slot antenna with loaded parasitic elements. The long slots and short ones are spacing alternately along the vertical direction of antenna to obtain uniform aperture's distribution [1]. We set 3 λ-wide metal plates in left and right sides of waveguide in order to match with the conditions of analytical model. 8 pairs of parasitic elements printed on a dielectric substrate with length l, spacing distance d1, d2 in x direction. The substrate is laid on height h, right above from the surface of slots. This height h of parasitic elements is an important parameter to determine the beam widths of H-plane in radiation patterns.

The structure of antenna is illustrated in Fig.1 and Fig.2.

The designed parameters are shown following.

Frequency 8.45GHz

Size of waveguide a×b=26.63×13.3

Long slots length 23mm、width 0.92mm、4 elements

Short slots length 14mm、width 0.92mm、4 pairs

Parasitic elements length 20mm、width 0.3mm、16 elements

Parasitic elements spacing in x direction d1=9mm、d2=6mm, and they printed on substrate with permittivity ε =3.4

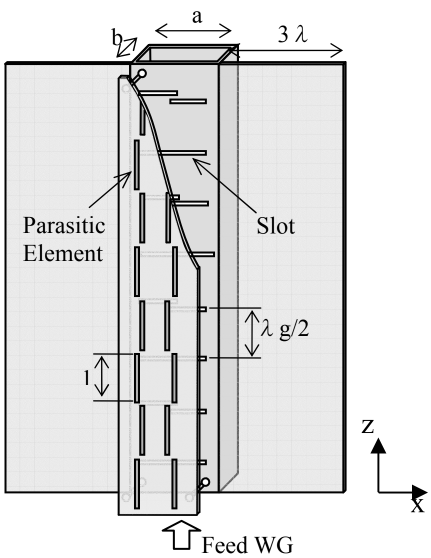

Fig.1 Antenna structure

3. Analysis of basic models

We adopted the Moment method, associating with expansion of eigen modes inside the waveguide [2]. We assume the electric currents on parasitic elements are $\mathbf{j}_p$, $\mathbf{j}_q$ and magnetic currents on slots are $\mathbf{m}_k$. Of course, the magnetic fields on slots are continuous and the transient components of electric fields on

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parasitic elements are null. These two conditions give us a set of simultaneous equations following, those we can derive $\mathbf{j}_p$, $\mathbf{j}_q$, and $\mathbf{m}_k$ from by Moment method.

$\mathbf{H}$ field on slots:

$$\mathbf{H}_{\text{feed}} + \sum_{\text{slots}} \int_{i\text{-th slot}} \mathbf{G}_{ki}^{\text{mm/in}} \mathbf{m}_{ki} ds_i = \sum_{\text{slots}} \int_{i\text{-th slot}} \mathbf{G}_{ki}^{\text{mm/free}} \mathbf{m}_{ki} ds_i + \sum_{\text{p.e.}} \int_{i\text{-th p.e.}} \mathbf{G}_{ki}^{\text{me/free}} \mathbf{j}_{ki} ds_i$$

Transient $\mathbf{E}$ field on parasitic elements:

$$\sum_{\text{slots}} \int_{i\text{-th slot}} \mathbf{G}_{ki}^{\text{em/free}} \mathbf{m}_{ki} ds_i + \sum_{\text{p.e.}} \int_{i\text{-th p.e.}} \mathbf{G}_{pi,qi}^{\text{ee/free}} \mathbf{j}_{pi,qi} ds_i = 0$$

Here, $\mathbf{G}$ is the Green's function and subscripts "m", "e" indicate that the source or observed points are magnetic or electric currents, respectively. In addition, subscripts "p.e.", "in", "free" mean the area of integrations are parasitic elements, inside of waveguide or half free space, respectively.

There are 2 points to consider. First one is to design slot array which generates uniform illumination on the aperture of the antenna. We can obtain it by using long and short slots alternatively like Fig.1. The numerical analysis for this phenomenon was considered and discussed in some other papers [1]. Long slot is around 0.75 λ, longer than resonant slot length, can invert the excited phase itself to be co-phase with short one spaced 0.5 λ g away from it along propagation direction. So it quite sufficient for us to analyze only 2 basic models of long and short slots, those are shown in Fig.2. In these cases, we bring the focus into second point, to consider the changing of excited currents and H-plane of radiation patterns when shifting the height h of parasitic elements.

Fig.3～Fig.6 show the calculated results of these basic models without considering the coupling factor between slots. Like we can see in Fig.3 and Fig.4, the excited coefficients on slots almost have no relation to the height h of electric elements. Amplitudes and phases are only changed slightly around 20%, and 10° respectively. On the other hand, the currents excited on parasitic elements show significant changing when we move their height. For this case, the values change greatly about 40% in term of amplitudes, and especially more than 130° in term of phases. So height h of parasitic elements and their currents have some close relation that gives us a hint to control the radiation pattern effectively. The relation between the height h and H-plane radiation patterns is shown in Fig.5, Fig.6 confirmed our conclusion. It shows that the beam width can be controlled in range of 60° to 120° by varying the height h from 5mm to 18mm.

4. Slot array design and measurement

At discussed, we need to take the parameters of parasitic elements into account when design the slot array. Fig.7～Fig.10 show the calculated and measured results.

Fig.7 shows antenna E-plane and H-plane radiation pattern without parasitic elements. The half power beam width of H-plane is around 70° in measurement, obtains good agreement with calculated one. E-plane side lobe level is about -8dB, gets little bit high. The reason of this phenomenon is the partly incompleteness in uniform illumination design of slot array. But the correctness of analysis is proved clearly and we can improve the characteristics better in next study. Fig.8～10 illustrate the principle planes of radiation patterns when we vary the height h of parasitic elements to 5mm, 14mm, 20mm. In these graphs, the H-plane beam widths are 60°, 90° and 140°, respectively. Fig.11～13 show the measured impedance and reflection characteristics as we changing the height h. When h has low values from 5mm～10mm, beam widths is little narrow, about 60° ～80°. Reflection characteristics are poor in this case. Band width of reflection characteristics is being broader as the height of parasitic elements enlarges. It gets maximum value about 5% when height h reaches to 20mm.

5. Conclusion

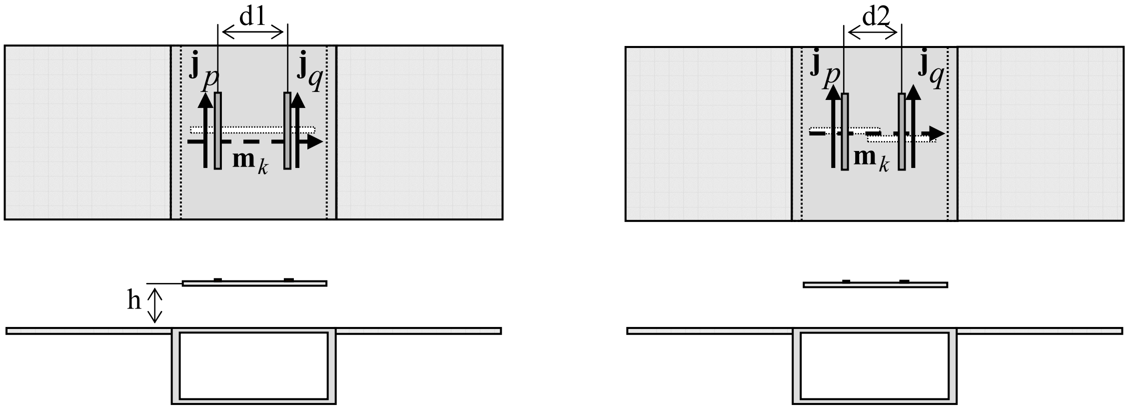
This paper presented a method to control the H-plane beam width in range of 60° ～120° by using parasitic elements. We designed the uniform illumination array in vertical direction with taking the coupling of parasitic elements into account. The calculated results have good agreement with measured data.

Optimizing the parameters of parasitic elements in order to control the beam width and obtain wider band width of antenna is remained for next study.

References

[1] HARON Syamsul Amri, ISHIGAMI Osamu, GOTO Naohisa, PROCEEDINGS OF THE 2002 IEICE GENERAL CONFERENCE, B-1-79, 2002/3.

[2] Jiro HIROKAWA、Workshop of Analysis and Design Methods in Antennas and Propagation(20th), "Analysis of Waveguide Slot Antennas by Using Moment Method", IEICE, pp.66-98, 2000/4



(a) Model1

(b) Model2

Fig.2 Basic models

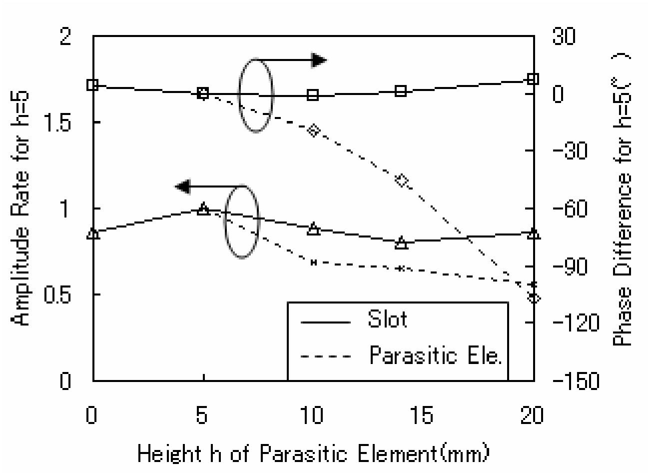


Fig.3 Characteristic of current in parasitic element (Model 1)

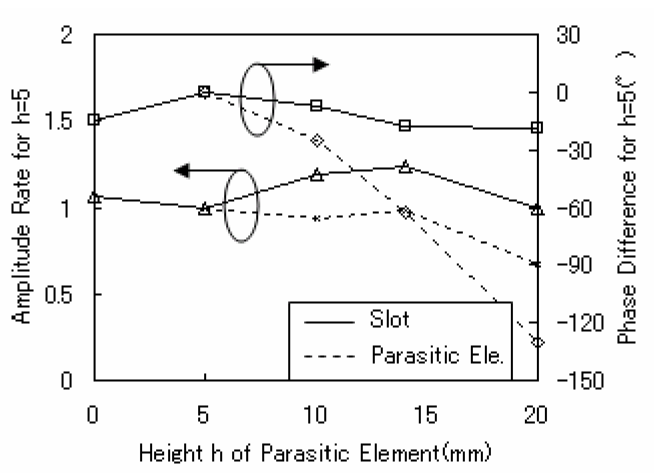


Fig.4 Characteristic of current in parasitic element (Model 2)

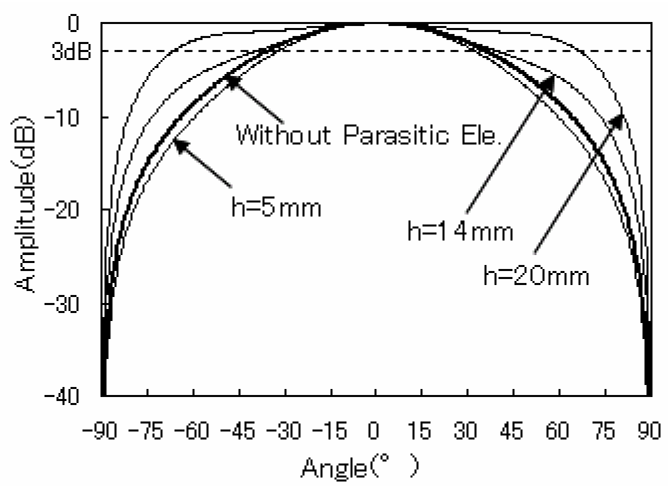


Fig.5 H-plane radiation pattern (Model 1)

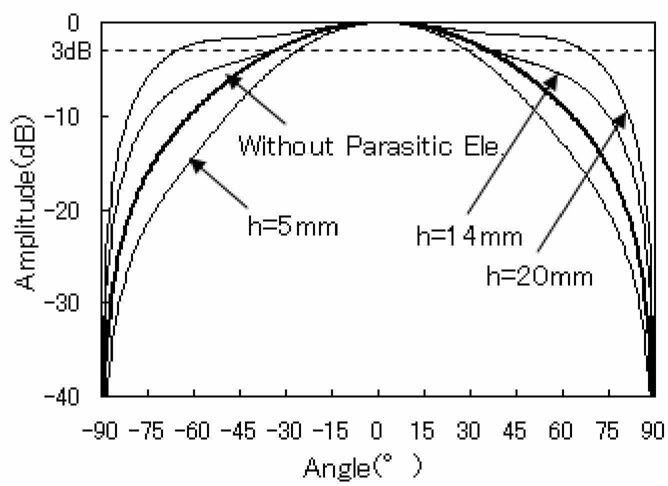


Fig.6 H-plane radiation pattern (Model 2)

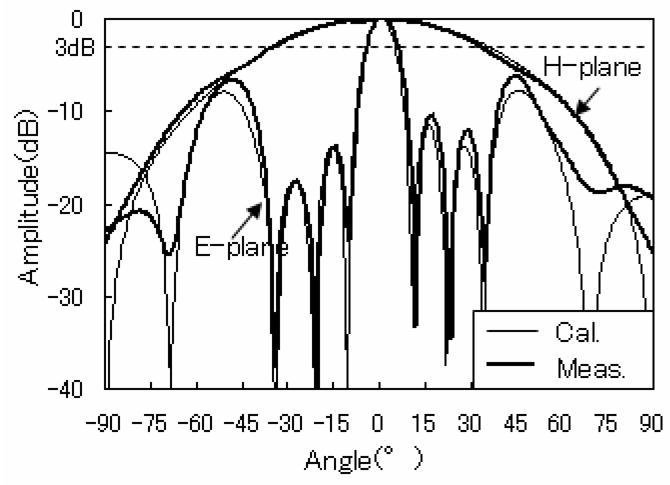


Fig.7 Principle planes of radiation pattern (Without parasitic elements)

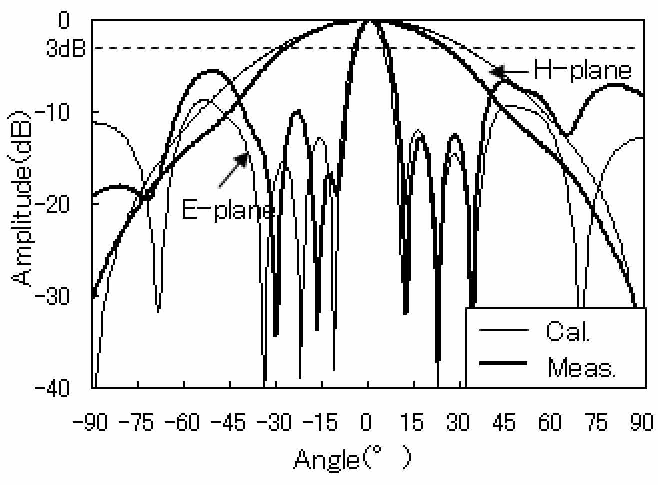


Fig.8 Principle planes of radiation pattern (Height h of parasitic elements =5mm)

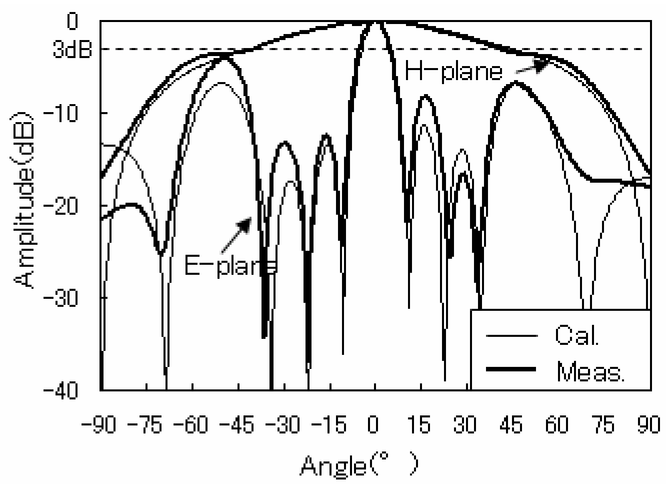


Fig.9 Principle planes of radiation pattern (Height h of parasitic elements =14mm)

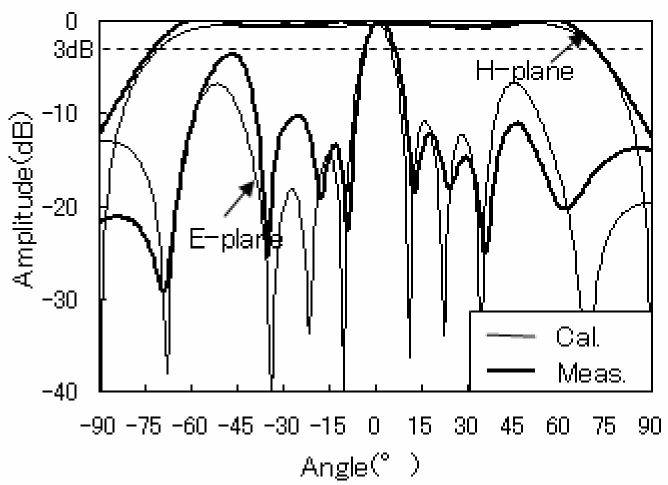


Fig.10 Principle planes of radiation pattern (Height h of parasitic elements =20mm)

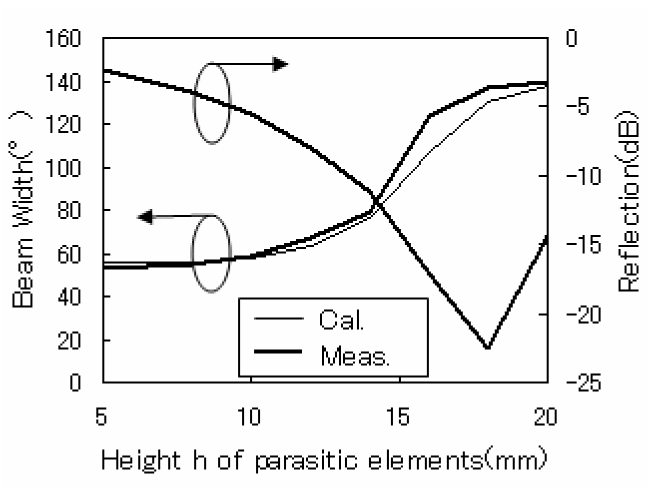


Fig.11 Characteristics of reflection and beam width to height h of parasitic elements

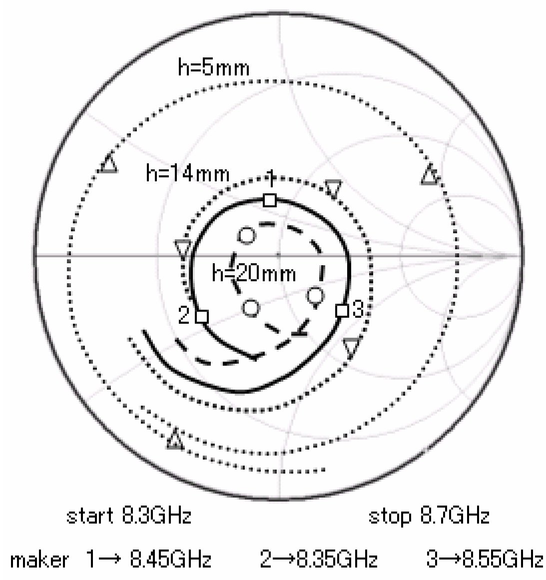


Fig.12 Smith chart