A Novel Design of Parallel Plate Antenna Using One Dimensional Reflectarray

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Abstract—**A new type of reflectarray structure is proposed. It uses one-dimension reflectarray elements and a parallel plate guiding structure. The proposed antenna has high gain, low loss and good radiation pattern. In this paper, we suggest simple and easy design process of proposed antenna and demonstrate measured performance results.**

Index Terms—**antenna, parallel plate reflectarray**

I. Introduction

A reflectarray follows basic principle of reflector antenna that small phase-shifting elements are used to obtain desired phase distribution [1]. Many researchers have investigated reflectarrays for the last decade due to their good properties such as high gain, low-loss and conformal nature [2]. They are also useful in modern communication systems like satellite antenna.

Several works also showed the variety of designing reflectarray itself or phase shifting elements in reflectarray – folded reflectarray, reflectarray of using simple dipole or rectangular patch, patch with delay stub line, patch of various rotational angles, ridged patch and multi-layered element type [3]-[6].

In this paper, we suggest the new type of reflectarray which one-dimensional phase-shifting elements are placed inside the parallel plate guiding structure. As the guiding structure prevents loss, it eliminates the spillover loss significantly. And radiation pattern constructs narrow beam of H-plane and wide beam of E-plane due to aperture shape. We also used multi-layered reflectarray element to ensure robustness to manufacture tolerance [7], [8]. Besides, artificial magnetic conductor is located in two sidewalls of parallel plate and they exhibited side lobe suppression [9]-[11]. We will show the basic steps for designing parallel plate reflectarray and measurement of the proposed antenna.

II. Basic Features

A simple model of the proposed parallel plate reflectarray is shown in Fig. 1. It consists of a metallic parallel plate with a hollow top hole that can guide input power. Phase-shifting elements are on one end of parallel plate and a particular patterned substrate is attached to both sidewalls. It is designed of that center frequency is 40GHz with operation bandwidth 1.5GHz. A waveguide (WR-22) feed point is placed upon top hole of parallel plate, hence the input wave experiences 90-degree bent and travels toward the end wall where the reflectarray elements lie. The incident wave on each reflectarray element has different phase distribution because the geometric distance from feed point to reflectarray surface is not identical. So the proper phase is added to each point for phase uniformity of reflected wave. As a result, the in-phase reflected wave is emitted out of the parallel plate reflectarray.

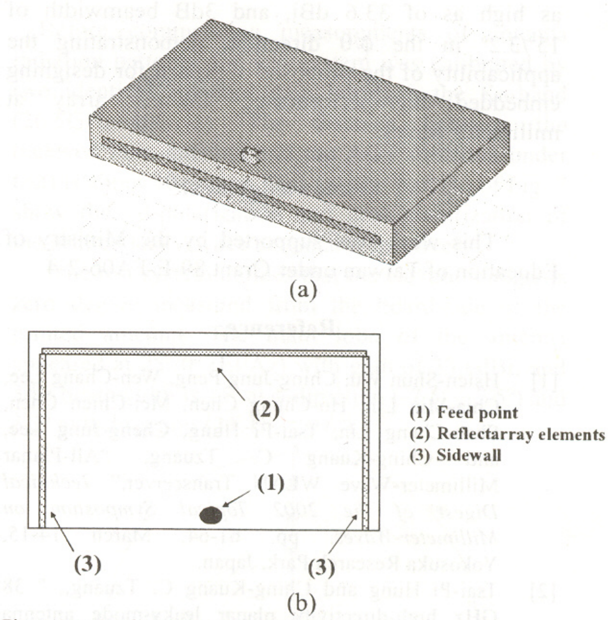


Fig. 1. Proposed parallel plate reflectarray.
(a) Three-dimensional model (b) Horizontally cross-sectional view

The proposed parallel plate reflectarray has the aperture of 150mm by 3.75mm (width × height), and the reflectarray element is located at the end wall that is 75mm far from the feed point. The far field pattern is narrow in H-plane because reflectarray elements can be equivalently regarded as a thin line source of antenna. Such a narrow beam width can be used for a certain high directive antenna application. Moreover, if some beam shaping methods are used, we expect a parallel plate reflectarray to achieve the appropriate beam pattern that is suitable to a specific purpose.

On the other hand, the far field pattern in E-plane shows broad beam because the parallel plate is very thin. Broad beam width can be utilized as sectored beam antenna application such as the base station of mobile communication for subscriber cells.

In a single layered reflectarray, the phase response versus reflectarray element size (or delay line length, rotational angle, dipole length, and so on) reveals rapid variation in the vicinity of resonance point [12]-[14]. So, only a little error in reflectarray element may cause malfunction. Several papers have shown that a multi-layered reflectarray element indicates better phase response than that of a single layered reflectarray. The wide range of phase and mild curve can highly raise the robustness to fabrication error. In addition, artificial magnetic conductor surface is added to both sidewalls in the parallel plate. It is observed that the parallel plate reflectarray with sidewalls of artificial magnetic conductor has better side lobe suppression and slightly higher gain, as compared with normal PEC sidewalls.

III. Design Procedure

A. Transition from Waveguide to Parallel Plate

The first part that input wave meet is transition part (90 degree bent) from WR-22 waveguide to the parallel plate. It is important that the input wave can transport into the parallel plate without large loss.

As depicted Fig. 2, the incident wave goes through transition part so it goes to reflectarray elements and reflected with properly added phase.

We used the field simulator MWS (MicroWave Studio) to evaluate the insertion loss. With a minor tuning, final dimension of transition part has been obtained easily. In the simulation, S-parameter shows low level of reflection over wide frequency range.

B. Reflectarray Element Design

A similar way of designing conventional reflectarray elements was used in this work. Like the other reflectarray, basic rule for assigning required phase of each element is demonstrated in Fig. 3. Although the parallel plate reflectarray is not completely the same as ordinary spatial feed in other two dimensional reflectarrays, it is good approximation that the phase delay of an incident wave is due to the difference of geometric distance solely, not the complete consideration of reflected wave by sidewalls.

We can easily calculate the required phase ϕ_i by using simple relationship (1),

$$-k \cdot R_i + \phi_i = 2\pi N + \Phi \tag{1}$$

where k is wave number, R_i is the distance between the feed point and the individual reflectarray element, N is integer and Φ is arbitrary constant.

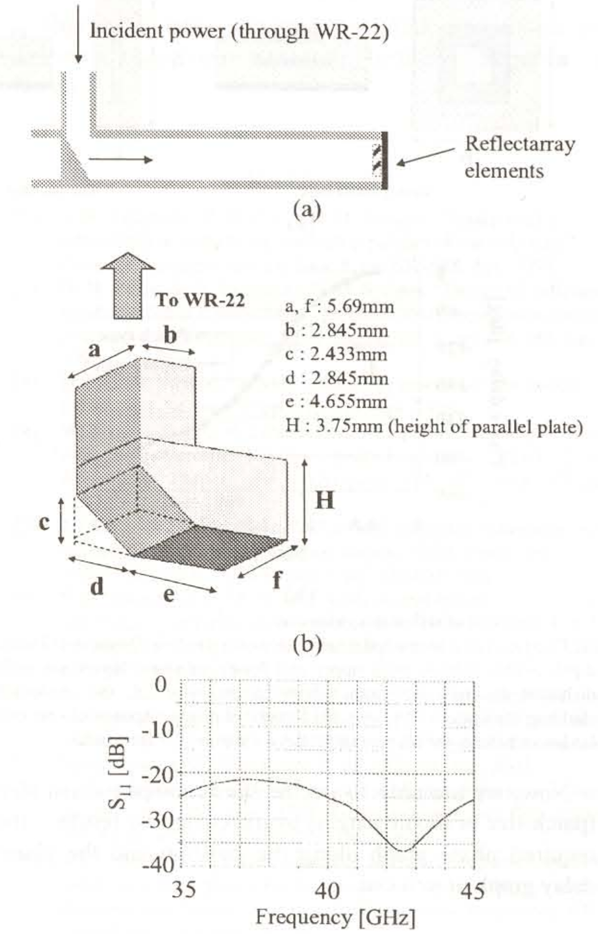


Fig. 2. Waveguide to parallel plate transition model.
(a) Vertical slice model of antenna. (b) Transition model. (c) Simulated reflection versus frequency in (b); transition part only.

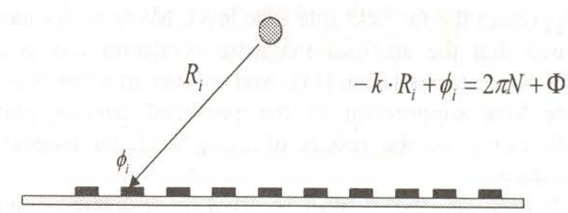


Fig. 3. Basic diagram of designing reflectarray elements.

After the required phase compensation of reflectarray element was obtained, we selected the two types of element described in Fig. 4 and simulated them in WGA method [7].

As shown in Fig. 4(a), the unit cell model of parallel plate reflectarray is very simple. Basically, it consists of two layers; one is the grounded lower layer of larger pattern (patch or dipole), another is the groundless upper layer with smaller pattern of specific size ratio to lower pattern. Typical phase response versus dipole length and patch size is simulated and plotted in Fig. 4(b).

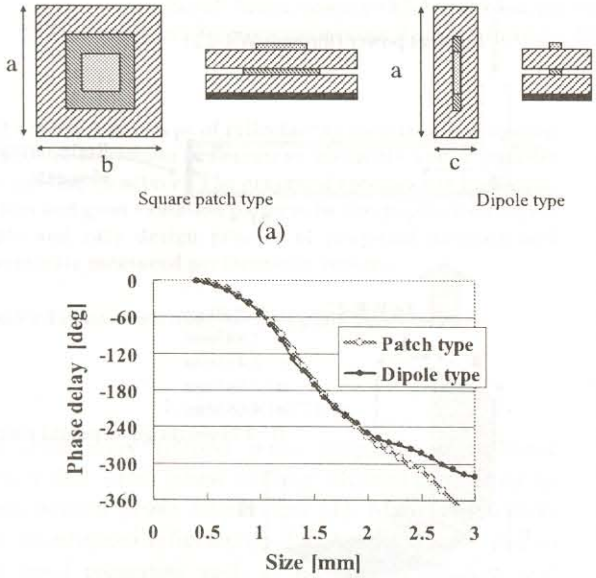


Fig. 4. Unit cell of reflectarray element.
(a) Two types of selected reflectarray elements. (a=b=3.75mm, c=0.75mm, dipole width 0.2mm; both upper and lower substrate layers are with dielectric thickness 0.504mm, relative permittivity 2.6, and conductor cladding thickness 0.018mm.). (b) Simulated phase response of unit cell (as lower pattern varied, size ratio=0.4 for dipole, 0.5 for patch)

Now, we are able to decide the required pattern size (patch size or dipole length) by matching two results – the required phase graph along the position and the phase delay graph of unit cell.

C. *Sidewall design*

Despite the minor part of design, it is interesting that the sidewall treatment with the artificial magnetic conductor suppresses the far field side lobe level. Many works have stated that the artificial magnetic conductor has good merits in antenna design [11]. And we also infer that such a side lobe suppression in the proposed parallel plate reflectarray be the results of using artificial magnetic conductor.

In designing the sidewall, we used single layered simple dipole in Fig. 5(a) to find proper size that crosses zero degree reflection angles. After a few simulations, the required dipole size for sidewalls was obtained. Fig. 5(b) shows the phase response of Fig. 5(a). The final model of parallel plate reflectarray is shown Fig. 6.

IV. Measurement

The proposed structure was fabricated and measured in anechoic chamber. Fig. 7 and Fig. 8 show measurement results of parallel plate reflectarray.

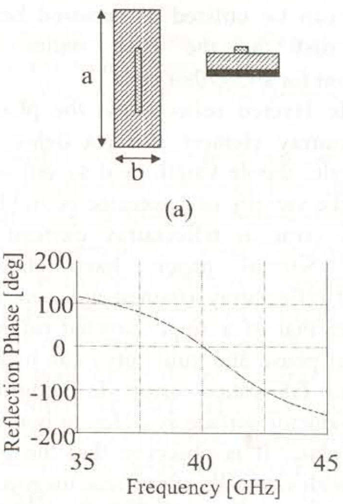


Fig. 5. Unit cell of sidewall pattern array.
(a) Simple model (a=3.75mm, b=0.75mm; dipole width 0.2mm, dipole length 1.838mm). (b) Simulated phase response of (a).

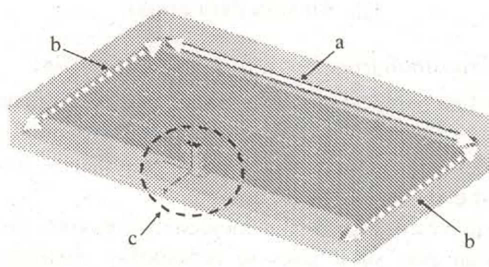
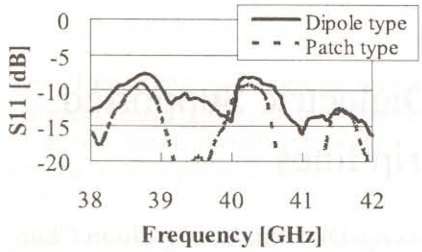


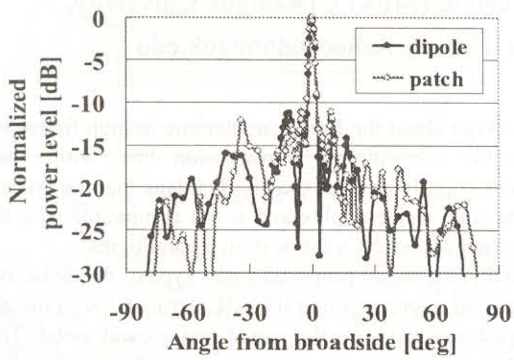
Fig. 6. Final model of parallel plate reflectarray (a=one dimensional reflectarray elements, b=side wall pattern array, c=WR-22 to parallel plate transition part)

The proposed antenna exhibits low insertion loss but slightly higher than the result shown in Fig. 2(c). It might be caused by the flowing backward wave that passes the center position of feed point. Further work is needed to keep feed point from blocking outward wave.

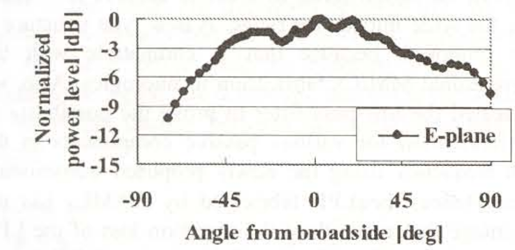
Measured gain is 17.3 dBi to patch type and 16.8 dBi to dipole type. Radiation pattern formed sharp beam in H-plane (about 2.5 degree of 3dB beam width) and wide beam in E-plane (about 90 degree of 3dB beam width), as expected. The suppressed side lobe level by using artificial magnetic conductor at the sidewalls is shown in Fig. 8. It is interesting result that the side lobe level is lowered as much as 3dB when the artificial magnetic conductor is applied to sidewalls.



(a)



(b)



(c)

Fig. 7. Measured results of patch type and dipole type reflectarray elements.
(a) Matching property (b) H-plane pattern of the proposed parallel plate reflectarray (both cases are normalized by their own maximum values)
(c) E-plane pattern when patch element is used

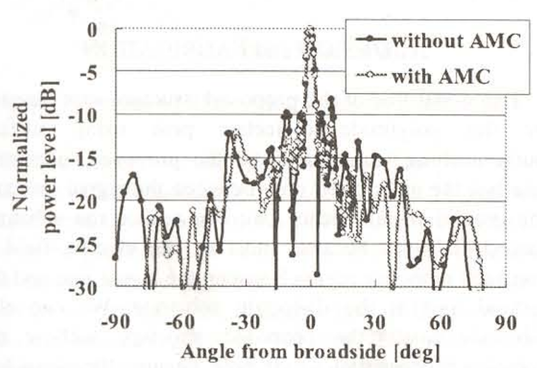


Fig. 8. Effect of artificial magnetic conductor at sidewalls.

V. CONCLUSION

A new type of reflectarray has been proposed and measured. It is shown that the proposed antenna has high gain, low loss and good radiation pattern. We think that such an antenna can be utilized in modern communication area. Further work for enhancing parallel plate reflectarray is to be expected.

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