Experiment and Analysis of Reflect Beam Direction Control using a Reflector having Periodic Tapered Mushroom-like Structure

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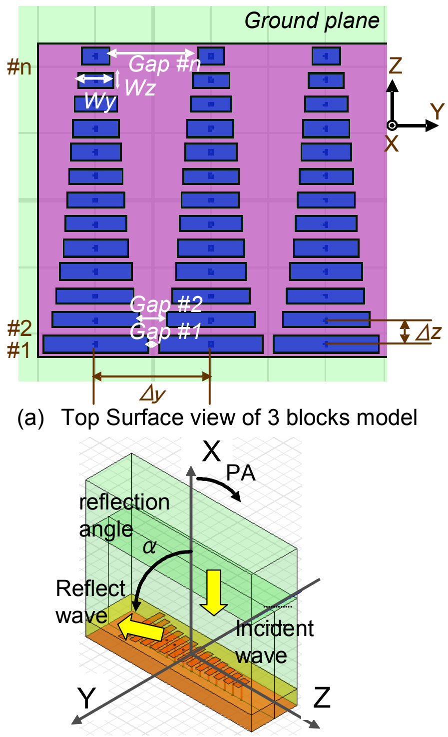
1. Introduction

Recently, study and standardization of very high speed (>2 Gbps) wireless systems such as the 60 GHz WPAN [1] have been progressed. Using high-frequency, we can achieve higher data rates, but the range of access is very short (<10 m). To achieve high frequency (>5 GHz) wireless broadband communication for mobile use, we need to expand accessible area and to eliminate blind zones occurrence at valleys between tall buildings that is more significant problem when we use higher frequency. Generally, in the mobile and wireless communication systems, RF boosters are used to extend cellular coverage area [2]. Since ordinary RF boosters need transceivers, cables, electric power supply, and so on, the installation space for the boosters is limited, and this leads to a lot of cost to cover the blind zones. To solve this issue, [3] has reported the utilization of reflectors to cover the blind zones with reflected beams. However, the reflect beam direction of ordinary metallic reflector is decided by only specular reflection. To reflect incident wave that comes from horizontal direction to blind zones in valley of tall buildings, we need to tilt the reflector leaning over buildings but it is difficult to satisfy quake-resistance standards.



(a) Top Surface view of 3 blocks model

(b) Overhead view of 1 block model

Figure 1: Periodic tapered mushroom-

On the other hand, recently [4] has reported that using mushroom-like structure, high impedance surface (HIS) with non-identical lattices can steer a reflected beam to 20.2 degree. In this paper, we investigate the possibility that the reflectors having mushroom-like structure can be used to cover the blind zones. We design a reflector having tapered mushroom-like structure based on the principle of reflect array for 70 degree steering of reflect beam. We apply periodic structure to the reflector to achieve adequate size of it for working in 8.8GHz band. Experimental results and calculated results are shown comparing mushroom-like structure with metallic plate.

2. Design of Tapered Mushroom Structure

Reflect beam direction of tapered mushroom-like structure is decided using reflection phase of each element like reflect array [5]. Each element of tapered mushroom structure is formed by mushroom-like structure that consists of ground plane, via hole and mushroom-like element. The length of each mushroom-like element is decided by desired reflection phase. The tapered mushroom structure is a set of the elements which lengths are slightly different from each other.

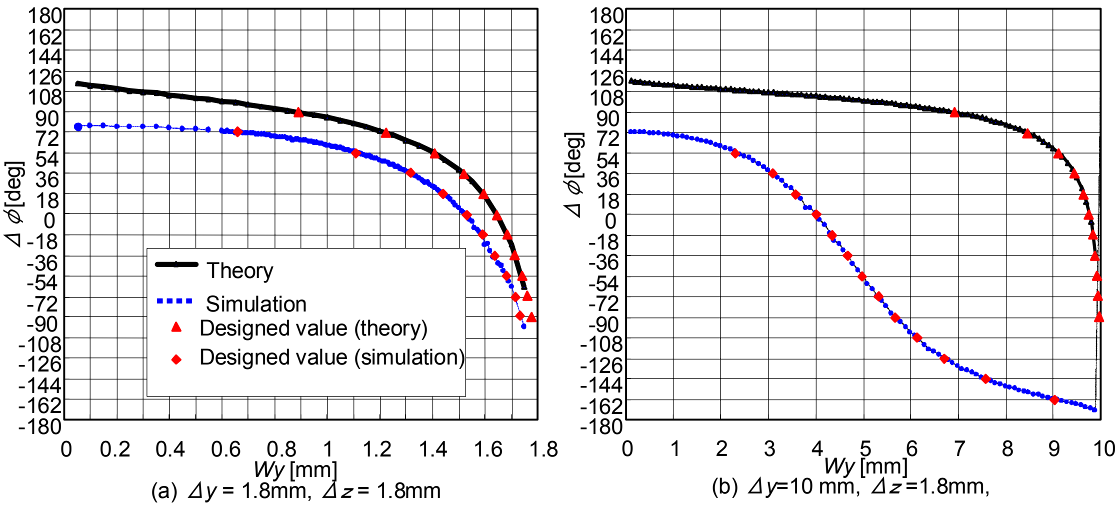


Figure 2 : Reflection Phase of tapered mushroom-like structure

The structure of tapered mushroom is shown in Fig.1. Reflection coefficient of mushroom like structure approximately is obtained using left-hand transmission-line theory as follows [4], [6].

Incident wave coming from *X* axis positive direction is reflected by reflect angle α. The reflect angle α is obtained using pitch of mushrooms Δz shown in Fig.1 and reflection phase $\Delta\phi$ as formula (1).

$$\alpha = \sin^{-1}(\lambda\,\Delta\phi/(2\pi\,\Delta z)) \quad \cdots(1).$$

Reflection coefficient of mushroom like structure is shown as formula (2) using impedance of free space η and surface impedance *Zs*.

$$\Gamma = (Zs - \eta)\,/\,(Zs + \eta) = |\Gamma|\,\exp(j\,\Phi) \quad \cdots(2).$$

Surface impedance Zs of mushroom like structure is shown as (3) using inductance *L* and capacitance *C* [6].

$$Zs = j\omega L\,/\,(1-\omega^2 LC) \ \ldots (3)$$

When we set desired angle to 70 degree, active frequency is 8.8 GHz and phase difference between adjacent mushrooms is π /10, and the pitch of adjacent mushrooms of the z axis direction Δz is obtained as 1.8mm.

The theoretical and simulation results of phase reflection $\Delta\phi$ versus mushroom's patch length *Wy* are shown in Fig.2. In the simulation, we adopt finite element method and calculate one element analysis model with periodic boundary condition shown in Fig.3. When Δy is 1.8mm shown in Fig. 2(a), simulated results well agrees with theoretical ones, because the patch size of mushroom-like structure is enough small compared with wavelength. However, it is hard to manufacture the structure to make phase difference by patch size difference less than 0.1mm. When Δy is 10 mm shown in Fig. 2(b), simulated results does not well agree with theoretical ones, however we can choose adequate patch length *Wy* to get same phase shift from 54 degree (3π/10) to -162 degree (-9π/10). In our experimentation, we choose 10mm for Δy. The design conditions and parameters are shown in Table 1. To make enough size reflector, we sort 13×45 blocks tapered mushroom structure as shown

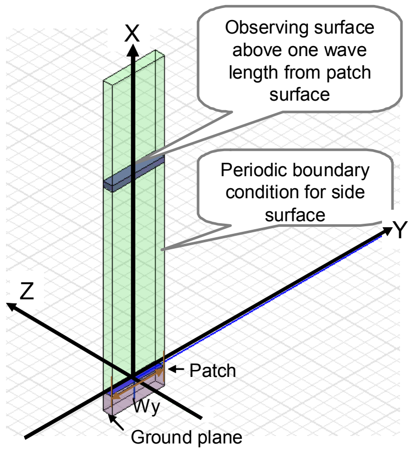


Figure 3: Analysis model of finite element method for reflection phase

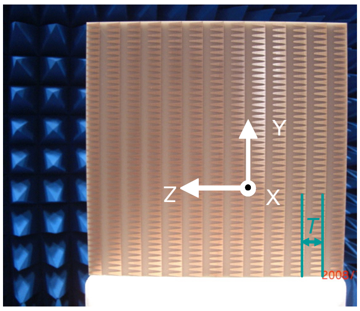


Figure 4 : Photograph of 13 × 45 blocks tapered mushroom reflector

in Fig. 4. The size of reflector is 450mm×456mm. We set the period of blocks T to 'Δz x 20' to get 2π phase shift. This makes constant phase difference in z direction.

3. Experiment and Calculated Result

To show the effect of reflect beam direction control using a reflector having Periodic Tapered Mushroom-like Structure (We call this PTMS), far field pattern is calculated using finite element method. In the simulation, plane incident wave is coming from X axis positive direction. To use limited memory condition, we adopt 1 block model shown in Fig.1(b) and make 13 × 45 blocks analysis model finite periodic structure using periodic boundary structure. With these assumptions, we can calculate forward scattering in the simulation. The simulation results of PTMS and same size metal reflector for comparison are shown in Fig.5(a) and Fig.5(b) respectively. In this paper, we use directivity of the PTMS defined as the ratio of the scattered intensity in a given direction from the PTMS to the average scattered intensity in all directions. While in the one case of metallic reflector, the reflect beam towards specular reflection direction; $\theta = 0^\circ$, in the other case of PTMS, the reflect beam towards $\theta = -70^\circ$. We can get the reflect angle α equal to 70 degree.

Table.1 Design conditions and parameters

Parameter	Value	Parameter	Value
Polarization	horizontal	Wy #3	6.72mm
Steering angle	70 degree	Wy #4	6.15 mm
Frequency	8.8GHz	Wy #5	5.69 mm
Substrate	*3.2 mm t FR4*	Wy #6	5.33 mm
Number of elements	13	Wy #7	4.99 mm
Δ y	10 mm	Wy #8	4.68 mm
Δ z	1.8 mm	Wy #9	4.36 mm
Wz	1.2 mm	Wy #10	4.02 mm
Wy #1	9.04mm	Wy #11	3.58 mm
Wy #2	7.59mm	Wy #12	3.10 mm
		Wy #13	2.32 mm

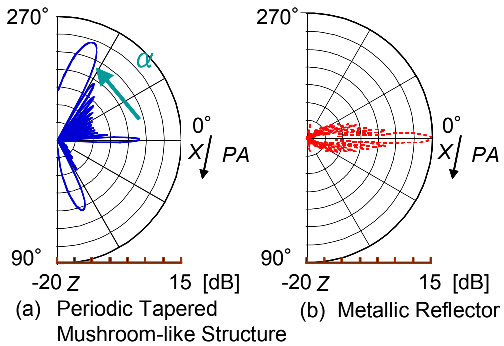
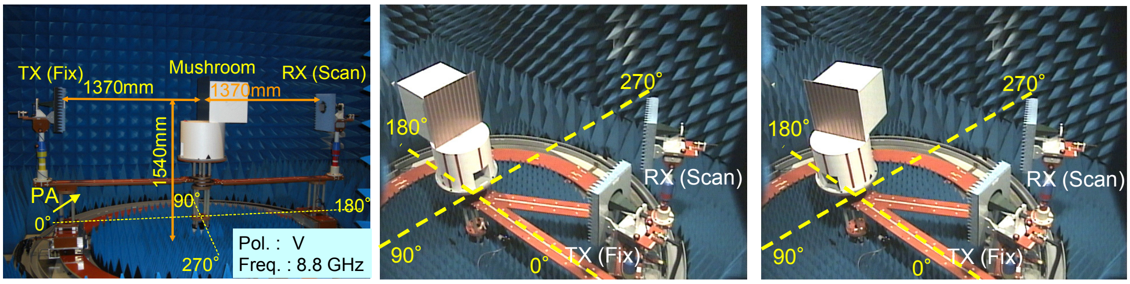


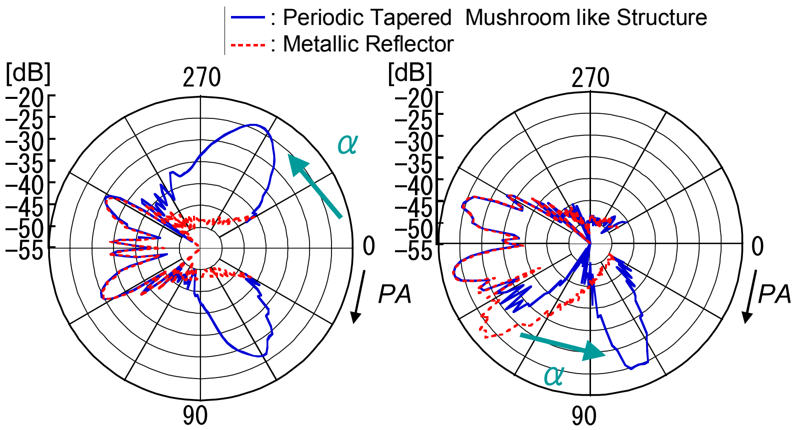
Figure 5: Calculation result of far field pattern using finite element method.

We measured reflect and scattering wave from the PTMS like reflector. The measurement system and arrangement of reflector and antennas are shown in Figure 6. Fig.6(a) shows the total view of measurement system that consists of a table for test reflector set in the center of chamber, fixed transmitting antenna in the place where the scan angle is 0 degree, and receiving antenna for scanning on the circumference of circle. The scanning available angle of receiving antenna is from 30 degree to 300 degree which is restricted by antenna pole space. The distance from surface of test reflector to aperture of both transmission and receiving horn antenna is 1370mm (40 λ at 8.8 GHz). We use standard horn of 18.6 dBi directivity for both transmission and receiving horn antenna. We measure incident angle 0 degree and -70 degree cases. Incident angle is 0 degree when test reflector is set to its normal direction toward scan angle 0 degree as shown in Fig.6 (b). Incident angle is -70 degree when test reflector is set to its normal direction toward 70 degree of scan angle as shown in Fig.6(c). We use proposed PTMS and metallic reflector for the test reflector. In the measurement, we use vertical polarization and control the beam azimuth direction for comparison with analysis result to suit the experiment equipment constraint. The measurement result is shown in Figure 7. In Figure 7, blue solid line shows the result of using PTMS for the reflector and red dotted line shows the result of using metallic reflector. We set 0dB as the value of measured level when both cables are connected directly. Fig.7 (a) shows the result of the case of that the incident angle is 0 degree as shown in Fig.6 (b). We can see the reflect beam toward *PA* = 303 degree where -63 degree rotated from specular reflect direction. As the result, the level of -63 direction is more than 20 dB larger than the case of metallic reflector. Fig. 7 (b) shows the result of the case of that the incident angle is -70 degree as shown in Fig.6 (c). We can see the reflect beam of metallic reflector toward specular reflection direction and reflect angle is 70 degree (*PA* = 140 degree) shown by dotted line. In the case of PTMS, we can see the beam direction steered by -70 degree from specular reflection direction (PA=70 degree). The difference between the peak level of reflect wave of PTMS case and metallic reflector case is less than 2 dB. We can confirm that the -70 degree beam control can be achieved using PTMS for reflector from both calculated and measured results.



(a) Total view of measurement system (b) 0 degree incident angle (c) -70 degree incident angle

Figure 6: The measurement system and arrangement of reflector and antennas.



(a) 0 degree incident angle (b) -70 degree incident angle

Figure 7 : Experimental results of far field pattern

4. Conclusion

This paper presents reflect beam direction control using Periodic Tapered Mushroom like Structure (PTMS) for reflector. We design the reflector based on left-hand theory and decide detail parameter using finite element method simulation. We can confirm the proposed PTMS can control the reflect beam direction 70 degree by analysis and experimental result. To study on the effect of propagation environment improvement, it is necessary to produce novel propagation analysis method, because ordinary ray-tracing system simulation only assumes specular reflection. It is our future work.

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