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Inverted-L Reflectarray Element With Interdigital Gap Loading Structure

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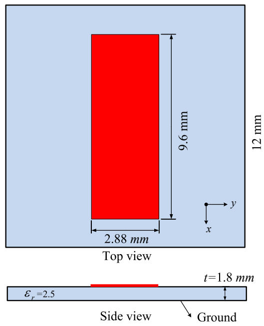
1. Introduction

In mobile communication system, it is a serious problem that radio wave signal from base stations is blocked by the high and dense buildings in a downtown, high-building district, especially in narrow streets, which will result in a weak signal level and poor communication qualities, and this kind of areas are typically called blind spots. Many efforts were made in order to eliminate blind spots which dramatically degrade the efficiency of data transmission. The general way is to add RF boosters on the top of high-building but with high installing expenses (activity components and RF generator are required) and bulkiness power supply system. Moreover, installation of the heavy boosters is also a critical issue because quake-resistance regulations should be taken into account in areas with frequent earthquakes, especially in Japan. Therefore, from the economic and technological points of view, a passive device is generally desired.

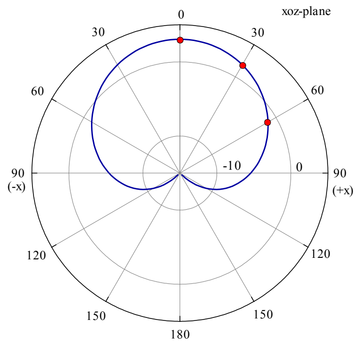
A reflectarray which can reflect an incident wave to a specified direction is an effective tool to solve the problem of blind spots. The reflectarray is a passive device and has other advantages, such as surface mountable with low mass and volume, easily deployable, low manufacturing cost, scannable beam, and integratable with a solar array, etc. [1–7]. It is considered to embed the reflectarray into the vertical building walls or to integrate them into firmly settled advertisement boards on the top of buildings. By properly design the required phase for each element of reflectarray, the incidence wave signal form the wireless communication base station can be scattered with a broad angle for covering different areas, especially blind spots. Most research literatures about reflectarray focus on the phase techniques to generate the required phase to scan the incidence wave to a desired direction, such as varying the element size, adding stud line, rotating element, and so on. However, to eliminate the blind spots in wireless communication system, a broad scattering angle is usually required to cover the narrow street, especially in the high-building district. Theoretically, it is very difficult to design a reflectarray with a very large scattering angle if the reflectarray has a traditional planar structure. That is because the equivalent aperture becomes very small for a large scattering resulting in a greatly degraded efficiency.

In this research, inverted-L reflectarray element (ILRE) is first designed to enhance the gain at the desired scattering angle. For a typically reflectarray phase technique, the size of each element should be varied to obtain a proper compensation reflection phase for the desired scattering angle. However, the main beam direction of each element with different size will be influenced to deviate from the desired scattering angle, which make it impossible to design a reflectarray for blind elimination. To tackle this problem, interdigital gap loading structure is combined with the ILRE. By using the combined structure, a wide refection phase and stable scattering angles are obtained simultaneously.

Detailed inverted-L reflectarray element (ILRE) with intergigital gap loading structure design is discussed in Sections II. Section III describes the design of an 11×1-element reflectarray.



(a)



(b)

Figure 1: Traditional planar microstrip reflectarray element (a) Configuration. (b) Scattering pattern.

2. Inverted-L Element With Interdigital Gap Loading Structure

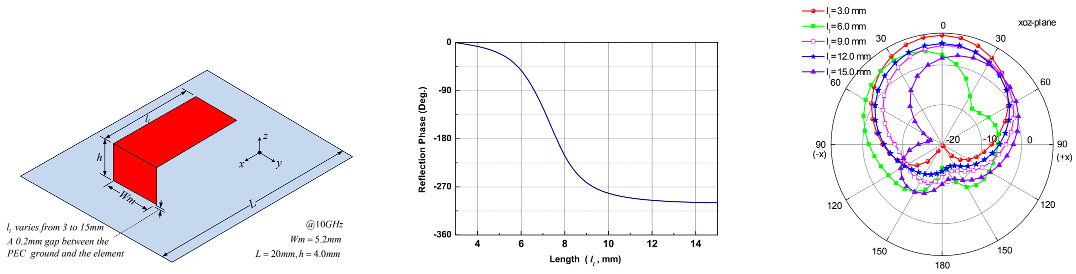
2. 1 Inverted-L Reflectarray Element

For a traditional reflectarray element, taking planar dipole element for example (as shown in Figure 1.(a)), the main scattering beam directs to the normal direction for a normal incidence wave. And the gain will become smaller and smaller with the elevation angle increasing. As can be found in Figure 1.(b), the maximum directivity at 30-degree is 1.2 dB less than that at 0-degree. And for 60-degree, more than 4.3 dB decrease can be observed. Thus, for a typically planar dipole reflectarray with a large scattering angle, the efficiency will become very low.

Inverted-L antenna has a compact size and a tilting radiation pattern [8]. To enhance the gain at the desired direction, the inverted-L structure can be used for reflectarray element design as shown in Figure 2.(a). The ground size of the unit cell is 20 mm × 20 mm ($0.66\lambda \times 0.66\lambda$ at 10 GHz). The inverted-L element is mounted on the top of the ground with a 0.2 mm gap. The ILRE has a height of 4 mm and a width of 5.2 mm. The other detailed dimensions are also given in Figure 2.(a). The permittivity of the substrate is selected as 2.5. As expected, the main beam direction can be shifted to a degree from the normal direction and the directivity can also be enhanced for the direction. On the other hand, to obtain a proper compensation reflection phase for the desired scattering angle, the size of each element should be varied. For a typically phase technique in reflectarray, by changing the horizontal length of the elememt l_l from 3 mm to 15 mm, a reflection phase range about 300 degrees can be obtained as shown in Figure 2. 1.(b). However, a serious problem appears while changing the element length, that is the main beam of the IFRE varies simultaneously, as can be observed in Figure 2. 1.(c). The problem of variable main beam direction makes it impossible to design a reflectarray in a specified direction.

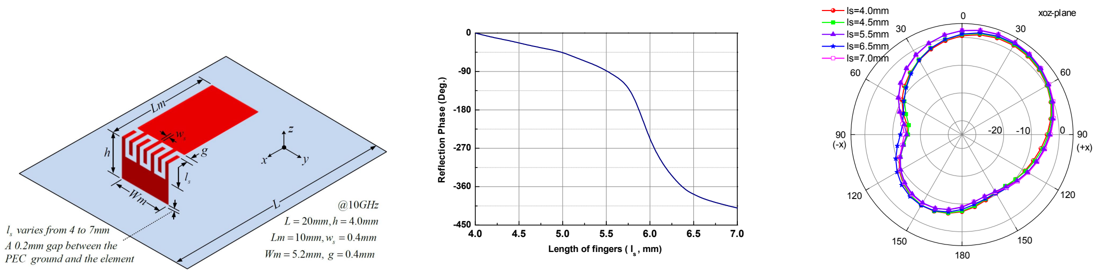
2. 2 Inverted-L Reflectarray Element With Interdigital Gap Loading Structure

As discussed in the last part, to obtain a sufficient reflection phase range, the ILRE should vary the size, which results in a serious problem of main beam changing. To tackle this problem, another phase technique is selected. As shown in our previous work [6], reflectarray using interdigital gap loading structure can obtain an excellent reflection phase range. Combined with this phase technique, a new reflectarray element structure is designed. The interdigital gap structure is intergrated at the corner of the inverted-L element, to obtain stable scattering angle and sufficient phase range. The proposed structure is depicted in Figure 3.(a). The unit cell is still kept the size of 20 mm × 20 mm ($0.66\lambda \times 0.66\lambda$ at 10 GHz). The element is also not connected with the ground plane with a gap of 0.2 mm. But the horizontal length of the elememt is kept as l_m =12 mm, and the reflection phase variation is obtained by controlling the finger length l_s. As expected, a large reflection phase range more than 400 degrees is obtained by



(a) (b) (c)

Figure 2: Inverted-L reflectarray element (a) Configuration. (b) Reflection of phase versus various element legth l_l at 10 GHz. (c) Scattering pattern of ILRE versus various element length l_l at 10 GHz.



(a) (b) (c)

Figure 3: ILRE with interdigital gap loading structure (a) Configuration. (b) Reflection of phase versus various element legth l_s. (c) Scattering pattern of ILRE versus various element legth l_s .

controlling the finger length of the interdigital structure. As shown in Figure 3.(b), the phase range are obtained within a small size variation range (4 mm to 7 mm). It is quite useful for the limited height of the ILRE (for the finger length connot be large than the element height h). It is also should be noted, as shown in Figure 3.(c), that stable scattering patterns are obtained for different elements. By changing the finger length l_s from 4 mm to 7 mm, the main beams are kept almost in the same direction (30-degree in this research), while a broad phase range more than 400 degrees is obtained. These advantages makes it a good candidate for large scattering angle reflectarray design.

3. Design of 11× 1-element reflectarray

For a reflectarray design, the required phase shift calculation depends on the primary source position and the reradiation direction [4]. To scatter the wireless wave signal from the base station to the blind spots, normal incidence and 30-degree desired scattering angle are considerd. According to the reflection phase response with the finger length depicted in Figure 3.(b), an 11×1-element reflectarray (along x) is designed to validate the performance.

The scattering pattern of the proposed reflectarray at 10 GHz is depicted in Figure 4. The direction of the maximum directivity points at 30-degree in xoz-plane when the plane wave normally incident to the proposed reflectarray, which agree well with the design angle. The maximum directivity is 13.4 dBi. The directivity of the reflectarray is defined as the ratio of the scattered intensity in the main beam direction from the reflectarray to the scattered intensity averaged over all directions.

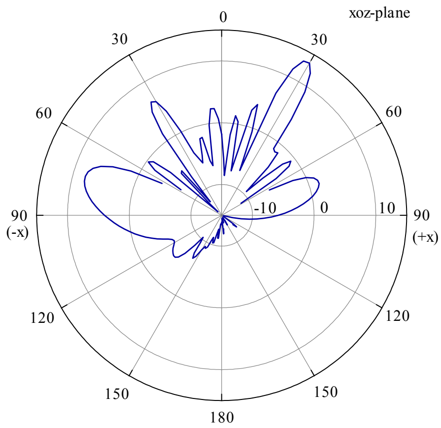


Figure 4: Scattering pattern of 11×1-element reflectarray at 10 GHz.

4. Conclusion

A novel inverted-L reflectarray element (ILRE) with interdigital gap loading structure is proposed for reflectarray design to improve the propagation channel quality for wireless communications in a non-line-of-sight (NLOS) environment. By using the inverted-L structure structure, the directivity at the desired direction can be enhanced. Combined with the interdigital gap loading structure, both broad reflection phase range and stable scattering angle are obtained. The proposed reflectarray technique can be used to eliminate the blind spots of base station antennas in a downtown, high-building district and other applications.

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