Dual Frequency Selective Reflectarray for Propagation Improvement

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ABSTRACT: This paper proposes a novel dual frequency selective reflectarray that can control reflected beams independently at dual frequencies using two different polarizations. The reflectarray improves propagation by controlling the scattered beams to achieve high speed in broadband wireless mobile communication systems at a high frequency. The reflectarray comprises cross-dipole arrays and double square loops. Measurement and analysis results show the effectiveness of the reflectarray.

INTRODUCTION

Recently, the study and standardization of very high-speed (beyond 2 Gbps) wireless communication systems [1] have progressed. By using a high frequency, we can allocate a sufficient bandwidth to achieve high data rates in the systems. However, the coverage area becomes smaller when using a high frequency because the propagation loss increases due to the greater loss from a diffracted field, and this leads to difficulty in using high frequencies in mobile communications. In order to address this issue, we proposed the use of reflectarrays placed on the top of buildings to eliminate blind zones in the valleys between the buildings by controlling the direction of the scattered waves using the reflectarrays [2-5]. We investigated two types of beam control reflectarrays. One is a metamaterial reflectarray [3] that uses very small elements compared to the wavelength. The other is a frequency selective reflectarray using crossed-dipole elements with square loops [2], [4]. We focus on the latter reflectarray, which has three features. The first feature is that the reflectarray can scatter both vertical and horizontal polarizations in the same direction by using a crossed-dipole array. Even when polarization rotation occurs in outdoor propagation environments, this reflectarray can deal with both vertical and horizontal polarizations, and can direct scattered electromagnetic waves in the desired direction. The second feature is that this reflectarray scatters only the desired frequency but is transparent to the electromagnetic waves at other frequencies because frequency selective loop elements are placed on the back side of the reflectarray. Therefore, this reflectarray can control the beam of the desired frequency, and does not affect other systems. The third feature is that the design of this reflectarray incorporates independent horizontal and vertical dipole arrays in a cross dipole array, which enables it to control independently the direction of both horizontally and vertically polarized scattered beams. This third function yields several application possibilities, e.g., the ability to control the scattered beam direction in multi-polarization MIMO systems or polarization diversity systems.

In this paper, we propose a novel dual frequency selective reflectarray that independently scatters low frequency radio beams using horizontal elements and high frequency radio waves using vertical elements in different

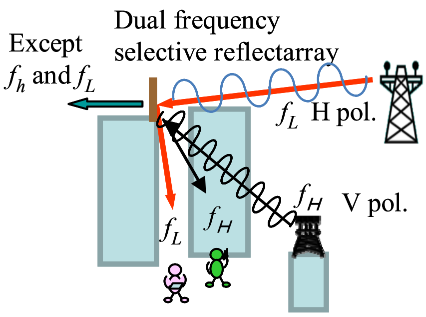

Fig. 1 Propagation improvement using dual frequency selective reflectarray.

Tab. 1 Design parameters of reflectarray

Incident Angle	$\theta_i = 0°$, $\phi_i = 0°$	$\theta_i = 0°$, $\phi_i = 90°$
Polarization	x-pol.	y-pol.
Reflection Angle	$\theta_s = 30°$, $\phi_s = 0°$	$\theta_s = 30°$, $\phi_s = 90°$
Frequency	8.75 GHz	17.5 GHz

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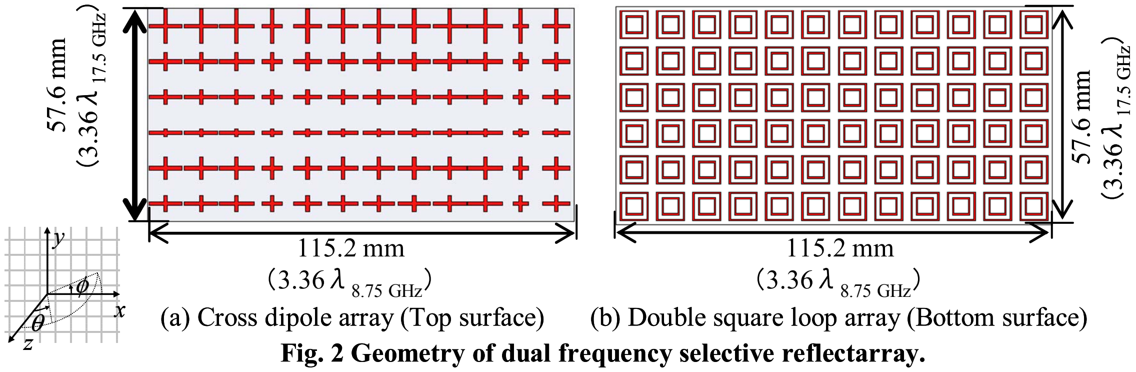


(a) Cross dipole array (Top surface) (b) Double square loop array (Bottom surface)

Fig. 2 Geometry of dual frequency selective reflectarray.

desired directions. This reflectarray consists of cross dipole elements on the top side of a dielectric substrate and double square loops on the back side to configure a dual frequency selective surface. Although the length of dipole elements and the array spacing of ordinary reflectarrays is about half a wavelength, a shorter length and narrower array spacing are adopted to construct the dual frequency selective reflectarray operated at dual frequencies with a ratio of 1:2.

DESIGN OF DUAL FREQUENCY SELECTIVE REFLECTARRAY

The concept for improving the propagation characteristics using the dual frequency selective reflectarray is illustrated in Fig. 1. A low frequency horizontally polarized wave, f_L, and a high frequency vertically polarized electromagnetic wave, f_H, are incident from different directions, and they are scattered in different desired beam directions to eliminate blind zones. At the same time, the reflectarray is transparent to other frequencies. The geometry of the dual frequency selective reflectarray is shown in Fig. 2 where Fig. 2(a) is the top surface composed of 12 X 6 cross dipole elements for dual frequency beam control. The horizontal dipole element array deals with horizontally polarized incident waves at the low frequency of 8.75 GHz and the vertical dipole elements array deals with vertically polarized incident waves at the high frequency of 17.5 GHz. The size of the reflectarray is 115.2 mm X 57.6 mm and these lengths are 3.36 wavelengths at f_L and f_H. Fig. 2(b) shows the bottom surface of the reflectarray where the frequency selective surface consists of double square loops [6]. The perimeters of the outer and inner square loops are 29.8 mm and 18.2 mm, respectively. In Fig. 2, we set the inter-element spacing to 9.6 mm (0.28 wavelengths at 8.75 GHz and 0.56 wavelengths at 17.5 GHz). The array spacings of the cross dipole array and the double square loop array are both 9.6 mm, which corresponds to 0.28 wavelengths at f_L and 0.56 wavelengths at f_H. Fig. 3 shows the reflection and transmission coefficients of the double square loop array without the cross dipole array calculated using the finite element method. It is confirmed that the reflection coefficient is at maximum and the transmission coefficient is at minimum at both the target frequencies, i.e., f_L and f_H, which means that the double square loop array scatters only the beam at the desired two frequencies, but is transparent to other frequencies. Fig. 4 shows the reflection phase of the reflectarray composed of the cross dipole array with the double square loop array at f_L and f_H as a function of the length of the cross dipole elements. By using the relationship between the reflection phase and element length shown in Fig. 4, we can design the reflectarray to obtain the desired beam directions at f_L and f_H in the same manner [2].

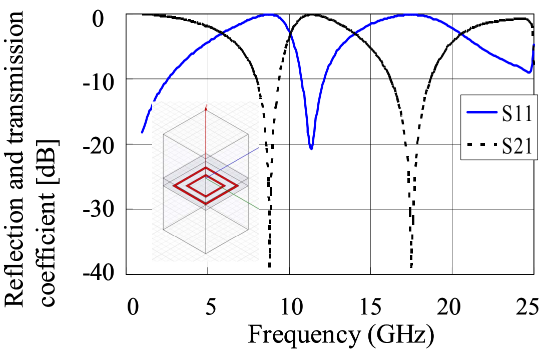


Fig. 3 Reflection and transmission coefficients of double square loop array vs. frequency.

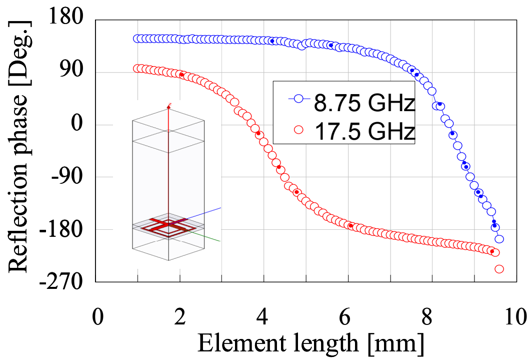
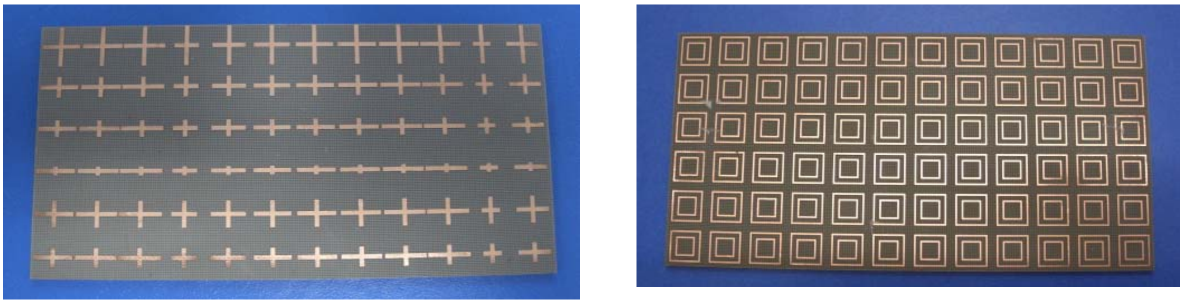


Fig 4 Reflection phase of reflectarray vs. length of cross dipole elements.



(a) Cross dipole array (Top surface) (b) Double square loop array (Bottom surface)

Fig. 5 Photographs of fabricated reflect array.

Tab. 1 gives the design parameters of an example reflectarray. We define the coordinate axes as shown in Fig. 2. At the low frequency of f_L = 8.75 GHz, an x-polarized wave with the incident direction of $\theta_i = 0, \phi_i = 0$ and the desired scattering direction of $\theta_s = 30^\circ, \phi_s = 0$ are assumed. At the high frequency of f_H = 17.5 GHz, a y-polarized wave with the incident direction of $\theta_i = 0, \phi_i = 90^\circ$ and the desired scattering direction of $\theta_s = 30^\circ, \phi_s = 90^\circ$ are assumed. Photographs of the designed and fabricated reflectarray are shown in Fig. 5.

EXPERIMENT AND ANALYSIS RESULTS OF DUAL FREQUENCY SELECTIVE REFLECTARRAY

Fig. 6 shows the experimental configuration that comprises transmitting and receiving horn antennas that set both side of reflectarray where two types of horn antennas are used, one for low frequency and one for high frequency to measure the near-zone transmission coefficient, $|S_{21}|$. From Fig. 7, we note here that the dual frequency selectivity of the double square loop array is preserved even when we combine it with the cross dipole array.

Measurement of the far field scattering pattern of the dual frequency selective reflectarray is also performed. The measurement system, arrangement of the reflectarray, and the transmitting and receiving antennas are shown in Fig. 8. Fig. 9 shows the measured and calculated results. The measured data are in good agreement with the calculation results. We note here that the x-polarized scattered wave at f_L = 8.75 GHz has maximum scattering toward the direction of $\theta_s = 30^\circ$ shown in Fig. 9 (a) and the y-polarized scattered wave at f_H = 17.5 GHz has maximum scattering toward the direction of $\theta_s = 30^\circ, \phi_s = 90^\circ$ shown in Fig. 9 (b).

CONCLUSION

This paper proposed a novel dual frequency selective reflectarray for beam control of scattered waves to eliminate propagation blind spots. The requirements for the design of the reflectarray are that the directions of the scattered waves at dual frequencies must be controlled independently using two different polarizations, and that incident waves at other

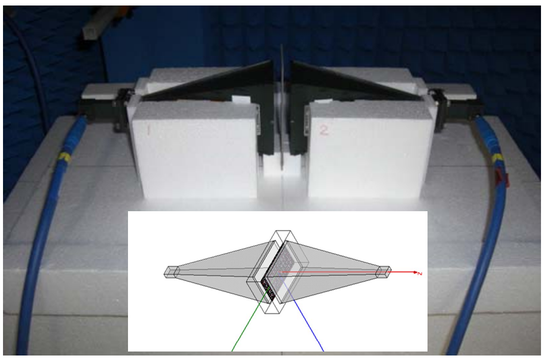


Fig. 6 Experimental configuration for measurement of near-zone transmission coefficient.

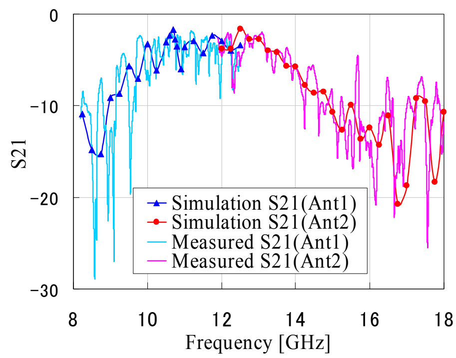


Fig. 7 Near-zone transmission coefficient of reflectarray.

frequency must pass straight through the reflectarray. To meet these requirements, a reflectarray is proposed that comprises cross dipole arrays on the top surface and double square loops on the bottom surface as a dual frequency selective surface. A reflectarray operated at 8.75 GHz and 17.5 GHz was designed in order to control scattered waves in a 30 degree beam direction. Measurement and finite element analysis were performed to confirm the capabilities of dual frequency selection and the control of the directions of scattered beams depending on wave polarizations.

ACKNOWLEDGEMENT

The authors thank Dr. Long Li of Xidian University and Prof. Uebayashi of Chukyo University School of Information Science and Technology for their useful advices and supports.
This work was supported by "The research and development project for expansion of radio spectrum resources" of The Ministry of Internal Affairs and Communications, Japan.

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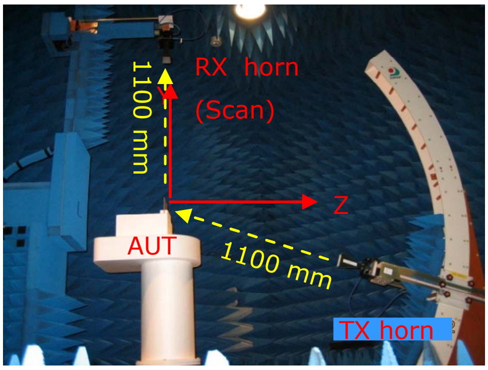
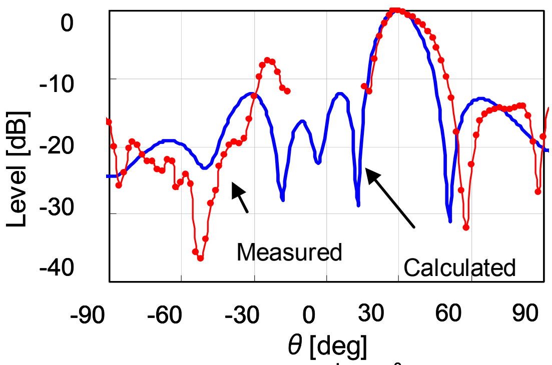
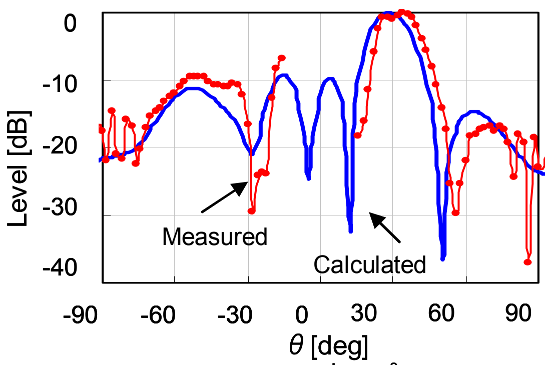


Fig. 8 Experimental configuration for measurement of scattering pattern.



(a) 8.75 GHz (Φ = 0° plane)



(b) 17.5 GHz (Φ=90° plane)

Fig. 9 Measured and calculated far-zone scattering pattern of reflectarray.