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A composite antenna with high-gain at dual-band

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Abstract: A composite high gain antenna whose working frequencies are separated far away from each other is proposed in this paper. It is composed of a dielectric superstrate that is excited by patch antennas. The superstrate works as electromagnetic band gap (EBG) resonator for C band achieving the gain of 16.7 dBi at 4.8 GHz in simulation. While it also works as Fresnel lens for K band, the gain reaches 30.4 dBi at 24 GHz. Compared to a single patch antenna, 7.2 dB and 21.4 dB gain enhancement are obtained in those two frequencies respectively. The impact of the superstrate is also verified by the experiment. It has been confirmed that the superstrate increases gain at two frequency bands.

Keywords: Dual-band superstrate, Fresnel lens, EBG resonator antenna, high gain.

Classification: Antennas and Propagation

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1 Introduction

Synthetic aperture radar is frequently employed in the satellite industry due to the quick development of spaceborne remote sensing satellite communication[1]. Using two or more frequency bands to obtain more information about the imaging region is a wonderful solution to meet the measuring needs in a challenging working environment. Low frequency range has reduced loss and scattering from trees, making it excellent for variational detection with low false alarm rate. High frequency band has high target recognition, trace function, and sensation of resolution. Besides that, millimeter wave is widely used in 5G communication. The high gain antenna with a large frequency ratio provides an idea for combining sub-6 and millimeter waves.

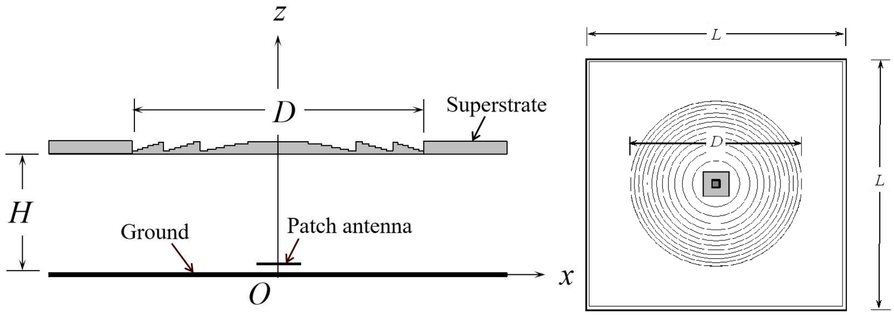
An antenna array is typically used in classic designs to meet the high gain requirement. It not only results in enormous apertures with low efficiency, but also in issues with side lobes, and intricate feeding system. With these factors in mind, a superstrate can be added over a simple feeding antenna to provide high gain and aperture efficiency even better than an antenna array. Numerous studies have been done on dual-band superstructures to improve gain or directivity using EBG or FSS (Frequency Selective Surface)[2-3]. It occurs frequently for two bands to be quite close to one another and for the frequency ratio to be less than 1:1.4. Chen's group has raised the ratio to 1:2 in recent works[3]. Additionally, lenses have been used in high gain antennas. In lens applications, lightness and thinness are extremely required, and the Fresnel lens is better equipped to realize them with a short focal length than a spherical lens.

In this research, a dual-band high gain antenna composed of a dielectric superstrate is proposed. A large working frequency ratio of 1:5 is intended for the dielectric superstructure. The dielectric superstrate, which is used as an EBG for the low frequency band and a Fresnel lens for the high frequency band, increases the gain. It represents an innovative effort to bring together two operating principles. The impact of the superstrate is verified by both simulation and experiment. This design can be summed up as a broad approach to creating dual-band high gain antennas. Due to the various operating theories, the frequency ratio restriction can be overcome.

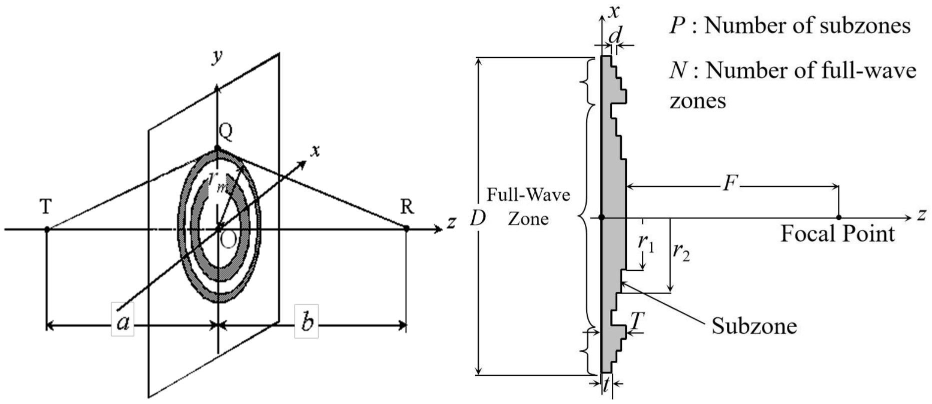
2 Antenna design and methodology

The geometry of the proposed antenna is shown in Fig. 1(a). Simple patch antennas fed by coaxial line are used as feed source in this design. The structure of Fresnel lens is inserted in the center of a dielectric slab to make up a dual-band superstrate, which is set above the feeding patches.

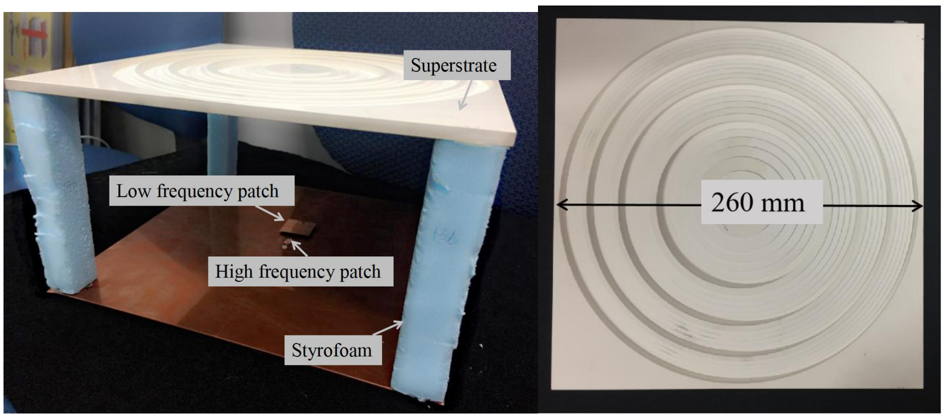
From the previous research[4-6], the size of EBG dielectric slab L is larger than $2\lambda_L$. Here, λ_L is the wavelength of low frequency in free space. The thickness is decided by $T = \lambda_L'/4$, λ_L' is the wavelength of low frequency in dielectric slab. The height between EBG slab and antenna can be decided by $H = m\lambda_L/2$ that m is defined as positive integer.



(a) Side view and top view.



(b) Fresnel zone and cross section of Fresnel lens (P = 6, N = 1)



(c) Processed antenna.

Fig. 1. Geometry of proposed antenna

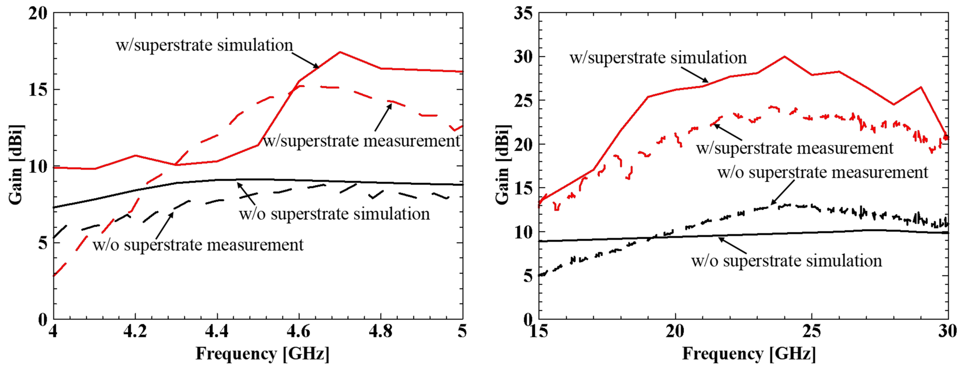
A Structure of Fresnel lens is indicated in Fig. 1(b). The transmission point (T) and receiving point (R) are in the same optical axis. The area is called Fresnel zone whose optical path difference between TOR and TQR is $m\lambda_H/2$ ($m = 1, 2...$). λ_H is the wavelength of high frequency in free space. The annular conductor or absorber used to reflect or block the electromagnetic wave in the Fig.1(b) is called Fresnel zone plate (FZP)[7]. When the minimum optical path difference between the zones equals to λ_H/P, the radius r_n and thickness d of each zone are shown as

$$r_n = \sqrt{\left(\frac{n\lambda_H}{P}\right)^2 + \frac{2nF\lambda_H}{P}}, n = 1, 2, \ldots, NP \tag{1}$$

$$d = \frac{\lambda_H}{P(\sqrt{\varepsilon_r} - 1)} \tag{2}$$

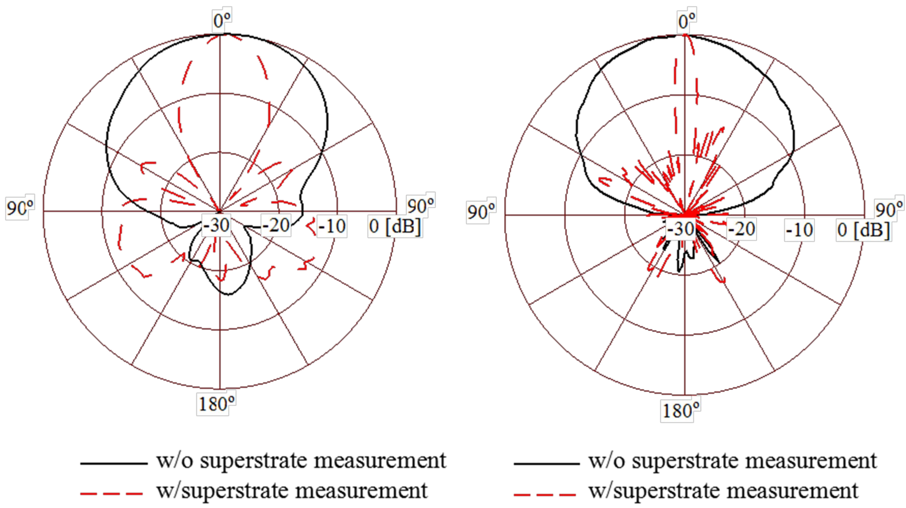
N, the number of full-wave Fresnel zones, presents the number of zones whose phase varies 2π. P presents the number of phase correction zones in the range of 2π phase variation. Fig. 1(b) shows the situation of $N = 1$, $P = 6$. It means in 2π phase shift area, a full-wave zone is subdivided into 6 subzones. The phase changes $2\pi/P$ between neighboring subzones by adjusting the thickness of the dielectric slab. F is the focal length. D is diameter of the outermost full-wave zone. On the basis of (1) and (2), a Fresnel lens can be obtained.

24 GHz was chosen as high frequency in this design. Focal length F is selected to be 136 mm which is close to $2\lambda_L$. D is selected to be $2r_n$ as 260 mm, limited with the size of dielectric slab. Other parameters are relevant to the EBG design.



(a) At C band. (b) At K band.

Fig. 2. Measured and simulated realized gain of the proposed antenna.



(a) At 4.8 GHz (b) At 24 GHz

Fig. 3. Measurement of normalized radiation pattern in E plane.

3 Experiment results

Fig. 1(c) indicates the manufactured superstrate with the parameters of D = 253 mm, L = 260 mm. The superstrate is above the feeding patch antennas which is supported by styrofoam pillars. The antenna was hand-made so that it was very difficult to integrate the two patches in the same vertical axis with coaxial feed. So the high frequency patch was put in the central of the ground and the low frequency was beside it. The measurement was done in anechoic chamber.

Measured and simulated gain performance of the dual-band high gain antenna is shown in Fig. 2. The superstrate performed well on gain enhancement in simulation. About 6 dB increment occurs during 4.6 GHz to 5 GHz. The same is true of high frequency band. 21.4 dB gain enhancement is achieved by adding this superstrate. The experiment also agrees with the effect that the superstrate can achieve the gain enhancement on patch antennas at two separated frequencies, but the measured gain is generally lower than simulation results after loading the superstrate. Firstly, it is due to the error of the hand-made antenna. Secondly, the styrofoam may be slightly deformed when we set the antenna for measuring, unparalleled superstrate can lead to undesirable result.

Fig. 3 shows the measurement of normalized radiation pattern in E plane. By loading the superstrate, the beam width narrows and the directivity becomes strong. The beam becomes a quite concentrated pencil shaped beam especially at high frequency. Because of this, the gain markedly increased comparing with a single patch.

4 Conclusion

In this paper, a new type of dual-band high gain antenna is proposed. By adding a dielectric superstrate above feeding patch antennas, high gain was achieved. The dielectric superstrate was designed as a Fresnel lens. It acted as not only EBG resonator for C band, but also lens for K band. With the feed source of patch antennas, the gain reached 16.7 dBi at 4.8 GHz in simulation. And 30.4 dBi was achieved at 24 GHz. The experiment also proved the superstrate had a good ability of gain enhancement at both of the frequencies.

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