Multiband Antenna Employing Multiple Metamaterial Reflectors

Hideya So, Atsuya Ando, and Takatoshi Sugiyama

Abstract

NTT Access Network Service Systems Laboratories has proposed and developed a multiband sector antenna for mobile wireless communication systems employing multiple metamaterial reflectors and a multiband radiator that is suitable for areas with limited space. We present in this article a design for a triple-frequency-band antenna that radiates at 800-MHz, 2-GHz, and 4-GHz bands as an example of the proposed antenna.

Keywords: multiband antenna, metamaterial, wireless communication

1. Introduction

Mobile wireless communication systems must now offer higher bit rates because of the increasingly widespread use of smartphones and tablet terminals. Mobile wireless communication systems such as cellular networks commonly utilize multiple frequency bands to achieve high system capacity. In addition, cellular systems use a sector configuration to improve frequency efficiency [1].

A conventional sector antenna is shown in **Fig. 1**. It has a radiator and metal reflector for each frequency band used in mobile wireless communication systems. As these systems begin handling more frequency bands, it is expected that the increased number of antennas and the larger space needed for these systems will become a problem.

2. Multiband sector antenna employing multiple metamaterial reflectors

NTT Access Network Service Systems Laboratories is developing a small-volume multiband sector antenna employing multiple metamaterial reflectors. Metamaterial reflectors have a periodic structure and consist of dielectric rods. They also have electromagnetic band gap (EBG) characteristics, meaning that they can reflect/transmit electromagnetic waves according to the frequency band [2]. The EBG characteristics enable the reflectors to act as a band-stop filter or a band-pass filter.

The concept of the proposed N-band sector antenna employing N metamaterial reflectors and a multiband radiator is shown in **Fig. 2(a)**. The center frequency of the desired frequency band is defined as f_n ($f_1 > f_2 > \ldots > f_N$). Metamaterial reflector #n reflects the electromagnetic waves of f_n similarly to the way a metal reflector does. On the other hand, metamaterial reflector #n transmits the electromagnetic waves of

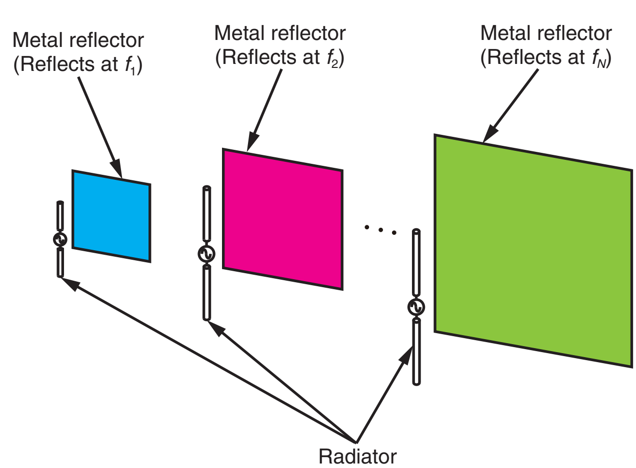
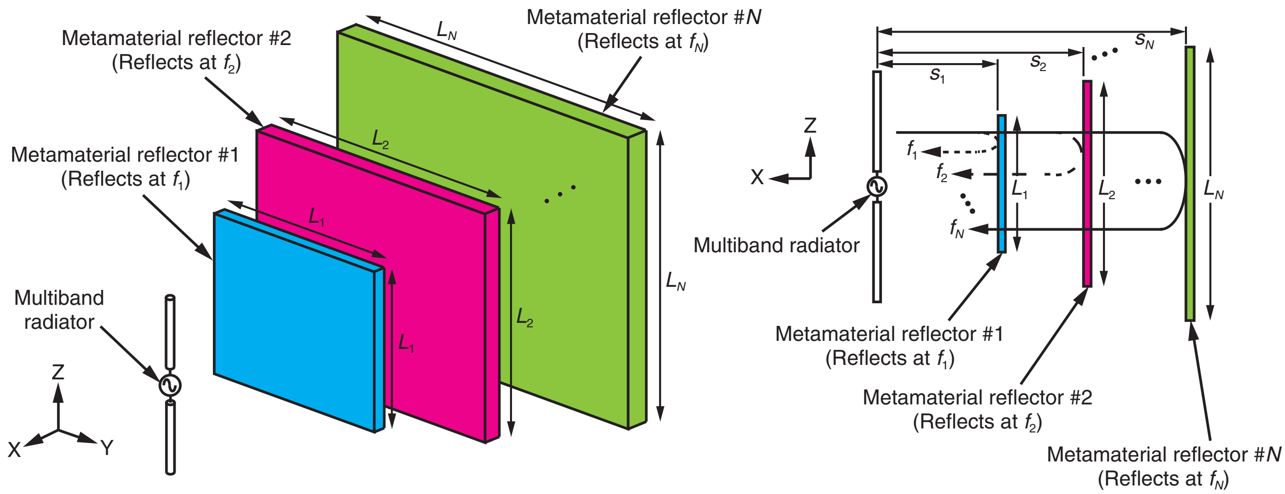


Fig. 1. Conventional sector antenna.



(a) Perspective view

(b) Side view

Fig. 2. Concept of multiband sector antenna employing multiple metamaterial reflectors.

specific frequency bands ($f_{n+1}, f_{n+2}, \ldots, f_N, N > n$) as if the reflector was transparent. Each metamaterial reflector reflects/transmits different frequency bands, so the proposed antenna can radiate multiple frequency bands in an area with a small footprint.

The reflectors are square, and their side lengths are indicated by L_n. The distance between the multiband radiator and the front surface of each metamaterial reflector is s_n, as shown in **Fig. 2(b)**. Metamaterial reflector #N, which is furthest from the multiband radiator, can be implemented as a metal reflector in the proposed antenna.

The proposed concept yields better design prospects than those of other design concepts because when the reflected frequency bands change or the number of frequency bands increases, we only need to change the EBG bands or increase the number of metamaterial reflectors in the proposed antenna to adapt to the situation.

3. Woodpile metamaterial

We applied woodpile metamaterial [3] to the reflectors of the proposed multiband sector antenna. The woodpile metamaterial structure consists of layers of dielectric rods and is illustrated in **Fig. 3**. The rods have a base of $w_{n1} \times w_{n2}$, where w_{n1} is the rod depth along the X-axis, and w_{n2} is the rod width along the Y- and Z-axes. Layer B (D) is at right angles to layer A (C) in space, and the woodpile metamaterial consists of four layers of rods. The spacing between rods in each layer is indicated by a_n. The rods in layer C (D) are set to the spacing of half of a_n from the rods of layer A (B).

4. Triple-frequency-band antenna

We fabricated a triple-frequency-band sector antenna with the same 90° beamwidth that radiates at 800 MHz, 2 GHz, and 4 GHz in order to verify the concept of the proposed antenna [4]. The prototype is shown in **Fig. 4**. The triple-frequency-band sector antenna comprises a multiband radiator, metamaterial reflector #1 (reflects electromagnetic waves at 4 GHz), metamaterial reflector #2 (reflects electromagnetic waves at 2 GHz), and a metal reflector (reflects electromagnetic waves at 800 MHz). The multiband radiator is separated from the reflectors by distance s_n, which is a quarter of the wavelength of each frequency band. That is, s_1 = 18.8 mm, s_2 = 37.5 mm, and s_3 = 93.8 mm. The multiband radiator consists of a biconical antenna and a dual-band sleeve dipole antenna [5].

The metamaterial reflectors consist of ceramic rods with a relative permittivity of 9.6 and a loss tangent of 3.5×10^5. The parameters of both metamaterial reflectors are w_{11} = 4.7 mm, w_{12} = 8.6 mm, a_1 = 37.5 mm, w_{21} = 14.1 mm, w_{22} = 14.6 mm, and a_2 = 75.0 mm. The side lengths of the reflectors are L_1 = 83.6 mm, L_2 = 164.6 mm, and L_3 = 375.0 mm.

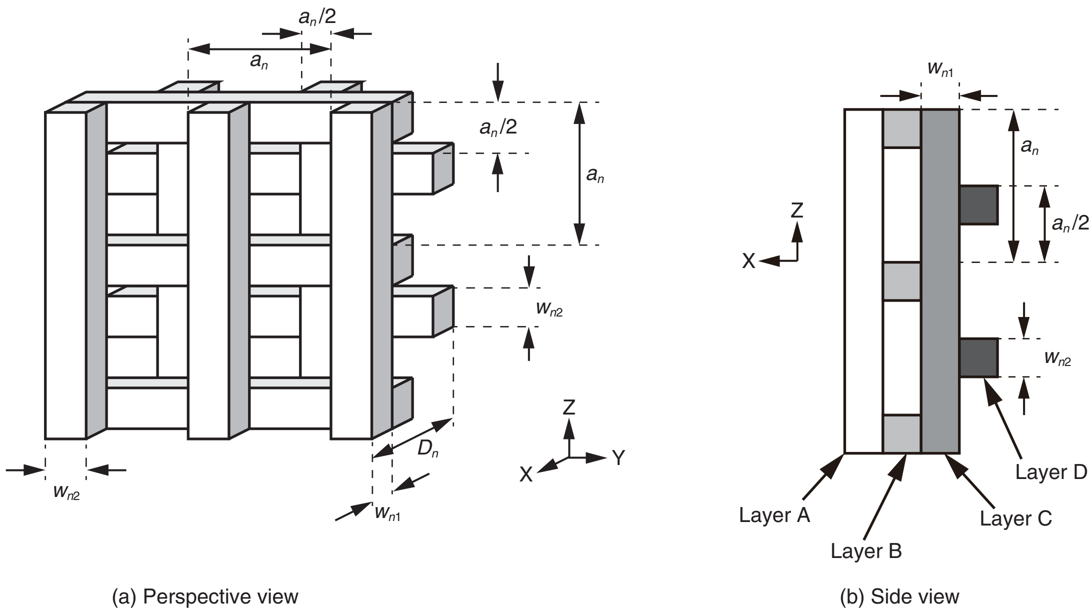


Fig. 3. Woodpile metamaterial structure.

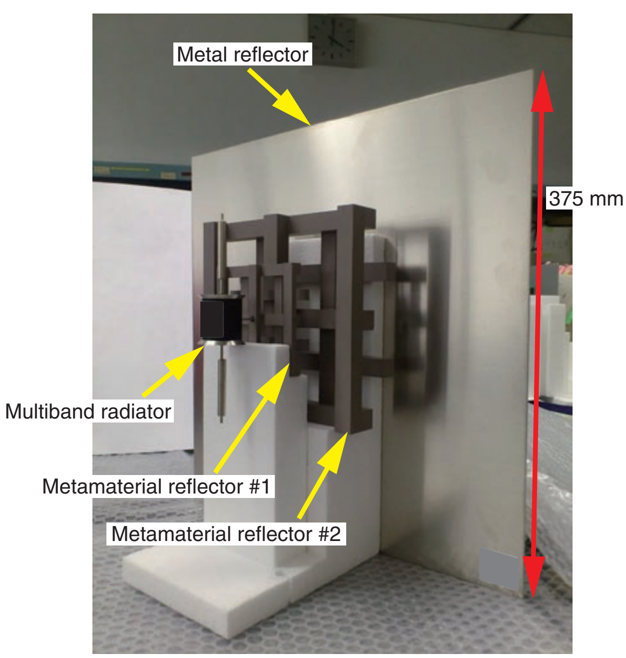


Fig. 4. Prototype antenna.

The EBG characteristics of the metamaterial reflectors are plotted in **Fig. 5**. It should be noted that each EBG characteristic corresponds only to the respective metamaterial reflectors. The center frequencies of the EBG band in the measurements and the electromagnetic field simulations are in good agreement. A finite array was used in the measurements, and consequently, the transmission characteristics degraded in comparison to those in the electromagnetic field simulations in which an infinite array was considered.

The radiation patterns on the horizontal plane for each frequency band are shown in **Fig. 6**. The proposed antenna has excellent directivity in each frequency band, and the measurement results match the electromagnetic field simulation results well. The beamwidth for each frequency band is indicated in **Table 1**. The proposed antenna achieves a beamwidth of approximately 90° at 800 MHz, 2 GHz, and 4 GHz, as designed.

5. Summary

We developed a novel multiband sector antenna employing multiple metamaterial reflectors and a multiband radiator for a sector antenna in mobile wireless communication systems. A triple-frequency-band sector antenna that radiates at 800-MHz, 2-GHz, and 4-GHz bands was designed, and a prototype was fabricated. We clarified the feasibility of the proposed small-footprint antenna in measurements and simulations.

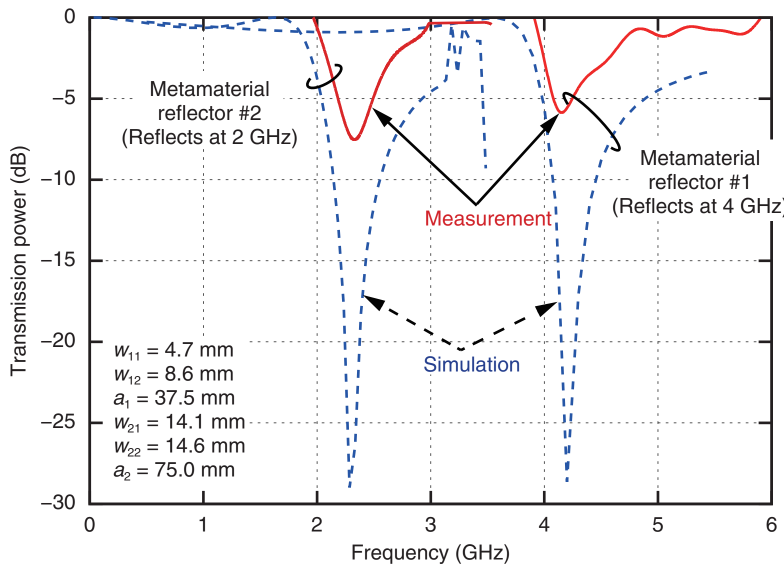


Fig. 5. EBG characteristics of woodpile reflectors.

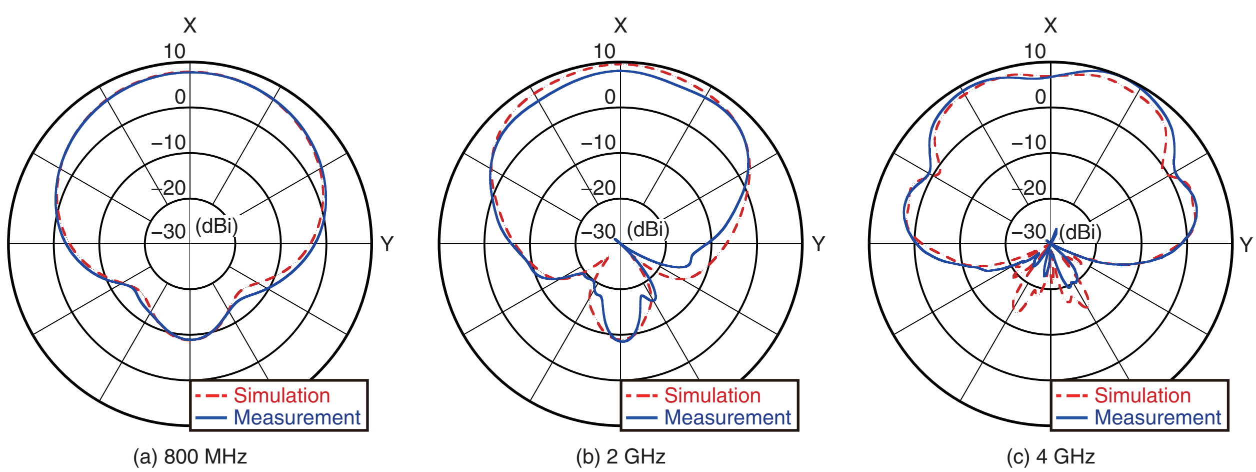


Fig. 6. Radiation patterns of proposed antenna on horizontal plane.

Table 1. Beamwidth for each frequency band in horizontal plane.

	800 MHz	2 GHz	4 GHz
Simulation	94°	90°	90°
Measurement	98°	103°	89°

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