Application Article

Broadband Multilayered Array Antenna with EBG Reflector

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Most broadband microstrip antennae are implemented in the form of slot structure or laminate structure. The impedance bandwidth is broadened, but meanwhile, the sidelobe of the directivity pattern and backlobe level are enlarged. A broadband stacked slot coupling microstrip antenna array with EBG structure reflector is proposed. Test results indicate that the proposed reflector structure can effectively improve the directivity pattern of stacked antenna and aperture coupled antenna, promote the front-to-back ratio, and reduce the thickness of the antenna. Therefore, it is more suitable to be applied as an airborne antenna.

1. Introduction

As the wideband communication system and high-resolution radar popularization, microstrip antenna claims more demands for bandwidth. In order to expand bandwidth, increasing the number of resonate frequencies is an effective solution. The above purpose can be achieved by clipping patch or using the coupled patch. However, this method will break the completeness of original microstrip antenna, for antenna pattern the sidelobe will increase, the gain and front-to-back ratio will decrease. Meanwhile, the asymmetry of slot and coupling patch makes antenna radiation patterns lack symmetry which will be more inconvenient in use [1, 2].

Electromagnetic band-gap (EBG) structure, which is a periodic structure composed of metal and medium can show band rejection characteristics when propagating electromagnetic wave. Many research results demonstrate that antenna with EBG structure will improve pattern performance effectively [3, 4]. This paper applied metal EBG structure to miniaturize antenna and fractal principle to increase the effective cycle length. The structure adjusts the antenna impedance characteristics, restrains backward radiation, increases the antenna front-to-back ratio, improves the symmetry of antenna patterns, and optimizes the antenna pattern characteristics without increasing the size of antenna.

2. Antenna Design

The period of the metal EBG can be calculated by Bragg reflection condition [5]

$$k_{\text{Bragg}} = 2k = \frac{2\pi}{e}, \quad (1)$$

where k is the wave number of guided wave modes, and a is the period of EBG structure. Consider the following:

$$e = \frac{\lambda_g}{2}. \quad (2)$$

Theory width of the traditional microstrip patch antenna is $\lambda_g/2$. With the miniaturization technology of microstrip antenna developing, the size of the microstrip antenna has been greatly reduced. The EBG antenna with the $\lambda_g/2$ period should greatly increase the size for miniaturization.

The fractal principle can solve the problem well. According to Cantor set, the equivalent length of the fractal structure can tend to infinity in the same area. Therefore, the fractal structure can be greatly reduced cycle length of EBG structure.

The generating elements of Minkowski fractal curve replace each side of the rectangle. The rectangular aperture takes fractal iteration to generate a curved fractal structure, shown in Figure 1. Different structures of the generated

FIGURE 1: Element antenna structure.

elements cause different period lengths of the EBG elements in the direction of x and y , which are $5m + 4n + p$ and $2m + 5n + q$, respectively, where p and q are the element interval of EBG structure on the directions of x and y , respectively. While the period lengths of EBG structure are $a + p$ and $b + p$, where $a = 5m$, $b = 5n$, and p is the space between the EBG structures, m and n are the length and width of the rectangular aperture. Obviously, the EBG structure periods are shorter than the EBG element periods in both x and y directions. In this way, miniaturization is achieved. The EBG period length $5m + 4n + p$ is close to e , which provides a structure characteristic of EBG.

Metal EBG structure is etched on the metal floor to inhibit the motivation of the higher modes. The miniaturization metal EBG structure mentioned in this paper has high impedance surface characteristics in the experiment. In the effective bandwidth, the structure makes vertical incident wave total reflection with the reflection characteristics and enhancement at the same phase in less than spacing $\lambda_g/4$. Using miniaturization metal EBG structure, this paper puts forward an aperture coupling multilayer broadband microstrip array antenna with EBG reflector, which can effectively inhibit backside and side radiation of multilayer gap microstrip antenna, promote front-to-back ratio of the antenna, reduce the mutual coupling effect between element antennas, and improve antenna pattern performance. The element antenna structure is shown in Figure 1.

The antenna uses double patches with multilayer coupling radiation structure, which etches L-shape on the double patches. Patch 1 adhered to dielectric substrate 1 is the radiation patch, and patch 2 adhered to dielectric substrate 2 is the coupling patch. Foam 1 is inserted between two-layer metal patches to improve resonance bandwidth. According to the slot antenna principle, slot can change current path of patch surface to form the resonance frequency points. According to the principle of laminated antenna, it can make multiple layer antenna form many resonance frequency points that have different sizes of radiation and coupling patches and different dielectric constants of the substrates. Adjusting the structure parameters of foam 1 thickness, w , l , h , d , h_1 , h_2 , and so on, can make more resonant frequency points distribution in working band to reduce the reflection coefficient and effectively extend antenna impedance bandwidth.

TABLE 1: The sizes of array antenna (unit: mm).

	w	l	d	h	h_1	h_2
Patch 1	11	19	2	12.5	3.3	3.6
Patch 2	8.5	16	1	6.6	3.4	1

EBG reflector uses metal EBG structure shown in Figure 1. The shadow region is copper clad area. Compared with the traditional reflector, the distance from EBG reflector to radiation source is less than $\lambda_g/4$ and the thickness of foam 2 and the antenna is reduced. At the same time, the maximum level of sidelobe and backlobe radiation pattern of the antenna is also reduced.

In Figure 1, three-layer substrate is FR4 with relative permittivity $\epsilon_1 = \epsilon_3 = 2.2$ and $\epsilon_2 = 2.9$, loss tangent of 0.002, and thickness of 1.6 mm. The material of foam is Rohacell 71 HF with relative permittivity of 2.65; the thickness of foam 1 is 5.3 mm and thickness of foam 2 is 6.4 mm. The diameter of probe interconnected with coupling patch is 0.5 mm.

Equal-amplitude and Phase Multiport Feeding Network is employed. Array configuration is equally spaced arrays, with element spacing $0.75\lambda_0$. According to the array size, EBG periodic expansion can be performed. In design, the array antenna adopts 6×6 element EBG reflector ($m = 2.2$ mm, $n = 2.4$ mm, $p = 1.1$ mm, and $q = 1.3$ mm).

After the simulation optimization, the sizes of array antenna are listed in Table 1, and the designed antenna is shown in Figure 2.

3. Experiment Results and Discussion

In order to avoid the impact of the array factors, this paper simulated the same element antenna with different reflector structure.

It can be seen in Figure 3 that, compared with antennae with common reflector and nonreflector structures, the backlobe level of antenna with EBG reflector is the minimum with a value of only -13.18 dBi. The front-to-back ratio is up to 22.41 dB, 4.15 dB higher than nonreflector structure and 1.07 dB higher than common reflector structure. The maximum side lobe level of E-plane is -10.05 dBi, 7.75 dB lower than nonreflector structure and 3.58 dB lower than

FIGURE 2: The designed array antenna. (a) Whole profile. (b) Each layer show.

FIGURE 3: Element antenna radiation pattern with different reflector structures at 5.35 GHz.

FIGURE 4: The radiation pattern of experimental array antenna at 5.35 GHz.

FIGURE 5: The VSWR of experimental array antenna.

common reflector structure. Common reflector or traditional reflector is constituted by a metal plane.

The proposed antenna is simulated based on the FEM method, using the Ansoft high frequency structure simulator (HFSS). The optimised antenna was also fabricated and tested. The measured curves are shown in Figure 4. Compared with simulation data, the maximum gain of E -plane and H -plane, the first zero degree and back lobe data are consistent with simulation results basically.

Agilent E8362B vector network analyzer is used to measure the antenna impedance characteristics, and the measured results are shown in Figure 5. The impedance bandwidth of $VSWR < 1.5$ is 1.1 GHz (4.9–6 GHz). The relative bandwidth reaches 20.2%. The VSWR coefficient is all less than 1.5. In contrast to four element array antenna, simulation results are close to the measured results. The VSWR curve integrally moves to high frequency direction. The designed center frequency 5.35 GHz excurses to 5.45 GHz, away from 0.1 GHz and relative offset of 1.9%.

4. Conclusion

Above all, microstrip array antenna with aperture coupling stacked structure and EBG reflector has the advantages of small size, wide bandwidth, high gain, suitable front-to-back ratio, symmetrical pattern, and good performance. The processing and assembling of antenna is simple. The stability of structure and electric fitting is high. This array antenna can be used in broadband radar or wireless communication field with better antenna direction and balance of wireless resource allocation.

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