Design of A Novel Dual Band High Gain Antenna Based on the Enhancement of Wave Propagation

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Abstract. A novel planar high gain antenna is presented based on enhanced microwave transmission to meet the needs of antenna gain in communications systems. The antenna consists of two intersecting sub- wavelength holes, add in the surrounding annular groove used to improve transmission enhancement effect. The results show that the gain of the antenna at the operating frequency 11.9GHz is 11.4dB, and the gain of 16.2GHz at the operating frequency point is 12.4dB, which has a high application value in the field of wireless communication.

1. Introduction

When the light is irradiated in the metal subwavelength periodic hole array structure, extraordinary optical transmission occurs [1]. In 2004, M Beruete et al. Found the enhancement of wave propagation when the electromagnetic wave is irradiated in the metal subwavelength hole array structure [2]. Since transmission enhancement has great potential in optical filters and new light sources, biosensors and other fields [3-5], transmission enhancement has attracted wide attention from scholars at home and abroad, and the discussion of the mechanism that triggers the phenomenon has become Research hotspot. A groove structure is added around the metal subwavelength hole, and when the depth $h$ of the groove satisfies [6].

$$\eta = (2\nu+1) \lambda / 2$$

Electromagnetic waves resonate in the grooves, as the secondary radiation source radiate outwards again, so that surface plasmas continue to spread on the metal surface, such structures are often used in the antenna design. Baida et al. Tried to add a metal cylinder to the metal sub-wavelength hole [7], which became a sub-wavelength annular hole, and the periodic annular groove was added around the annular hole. It brought transmission efficiency up to 80%.

In the microwave band, the wavelength of the electromagnetic wave is much larger than the wavelength corresponding to the plasma oscillation frequency of the metal surface. Therefore, there is no electron oscillation on the metal surface, so that the surface plasmon does not excite, but the same structure (periodic subwavelength hole and groove Fold structure) in the microwave band after the equivalent media handling will have the same characteristics with surface plasmas [8].

In this paper, a new dual-band high-gain antenna is proposed by applying the transmission enhancement phenomenon to the antenna design. By etching the subwavelength hole and the annular groove on the metal plate to control the excitation, coupling and propagation of the surface plasmon. The antenna can meet the needs of wireless communication and have a high application value.
2. Dual band pass filter design

Ebbesen and Genet argue that surface plasmas are the key to the phenomenon of transmission enhancement. The surface plasmas are electromagnetic waves formed by the continuous oscillation of charged particles on the surface of the metal. It can not propagate continuously on the smooth surface. However, the periodic subwavelength array of the metal surface affects the excitation, coupling and propagation of the surface plasmas. It can make the surface of the plasma surface in the metal continued to spread and results transmission enhancement phenomenon.

Surface plasmas can be divided into propagating surface plasmon (PSP) and localized surface plasmon (LSP) [9]. PSP is excited by the free electron continuous oscillation of metal surface, it can propagate on the metal surface, This paper opens a subwavelength round hole in the center of the metal plate, by adding a cylindrical groove above the hole, used to change the propagation distance of the PSP. Add a circular groove around the cylindrical groove, so that the PSP excited again and continued propagation on the antenna surface, the structure shown in Figure 1.

![Figure 1 Antenna I structure](image)
(a) Top view (b) Profile

Use the Ansoft HFSS simulation software to simulate the antenna, the antenna return loss S11 as shown in Figure 2.

![Figure 2. Return loss S11 of antenna 1](image)

It can be seen S11 gets a peak at 15.1GHz and return loss to -13.5dB, which is caused by the PSP. The localized surface plasmas are generated by the continuous oscillation of free electrons on the metal particles, they are confined to metal particles around. For the case of two or more metal particles, there is a coupling between the particles, with near-field coupling and far-field coupling [10]. In order to stimulate the local surface plasmas and to study this coupling effect, we improved the antenna 1, improved antenna structure shown in Figure 3, on the basis of a structure of the antenna we added another metal hole, and let two metal round hole intersection, add metal cylinder in each metal hole, respectively, there is a spacing between the cylinder, so there will be coupling effect between the two metal cylinder.
The parameters of the optimized antenna are shown in Table 1, where $h_1$ is the depth of the outer groove, $h_2$ is the depth of the central groove, $m$ is the width of the outer groove, $R$ is the diameter of the cylinder, $w$ is the spacing of the cylinders, $s$ is the spacing between the cylinder and the hole.

| Parameter | $m$ | $g$ | $L$ | $s$ |
|-----------|-----|-----|-----|-----|
| Size      | 3   | 4.5 | 4.6 | 1.2 |
| Parameter | $w$ | $h_1$ | $h_2$ | $R$ |
| Size      | 0.2 | 4.5 | 4   | 5.6 |

Perform the material on the antenna and Antenna physical map as shown in Figure 4, Antenna simulation and testing $S_{11}$ as shown in Figure 5, $S_{11}$ appears two frequency peak, 11.9GHz and 16.2GHz, respectively, and both less than -10dB. When the parameter is optimized, the range of $R$ is 3.0mm to 7.0mm. We find that the second peak is less than -5dB in the process of $R$ changing from 3.0mm to 4.0mm. When $R$ from 4.0mm to 7mm, the second peak quickly reduced, the lowest reached -19.5dB. Thus we believe that the second peak is generated by the localized surface plasmas because the localized surface plasmas are sensitive to the size of the metal particles and when the size of the metal particles is too small ($R<0.2\lambda$), The effect of localized surface plasmas will be small.

The far-field pattern of the antenna at 11.9GHz and 16.2GHz is simulated and analyzed. The radiation pattern is shown in Fig. 6 and Fig. 7. It can be seen from the figure 11.9GHz and 16.2GHz gain of 11.4dB and 12.4dB, respectively, Compared to the traditional flat antenna, 5.0dB and 5.8dB upgrade respectively.
Figure 6. far-field pattern of the antenna at 11.9GHz and 16.2GHz (a) 11.9GHz (b) 16.2GHz

3. Conclusion
In this paper, a dual-band high gain antenna is designed based on the excitation and characteristics of the propagating surface plasmas and the local surface plasmas from the surface plasmon theory. The simulation and experimental results show that the antenna has good radiation characteristics. The process has a high reference value for the design of multi-frequency antenna and the application of surface plasmas.

Reference
[1] Ebbesen T W, Lezec H J, Ghaemi H F, et al. Extraordinary optical transmission through sub-wavelength hole arrays [J]. Nature, 1998, 391(6):1114-7.
[2] Beruete M, Campillo I, Dolado J S, et al. Enhanced microwave transmission and beaming using a subwavelength slot in corrugated plate [J]. Antennas & Wireless Propagation Letters IEEE, 2005, 3(1):328-331.
[3] Yi Chenlin. Enhanced Optical Transmission through the Periodic Arrays of Fish-Shaped Metallic Nano Structure[J]. Laser & Optoelectronics Progress, 2013, 50(5):053101.
[4] Tsai M W, Chuang T H, Meng C Y, et al. High performance midinfrared narrow-band plasmonic thermal emitter [J]. Applied Physics Letters, 2006, 89(17):173116-173116-3.
[5] Dahlin A, Zäeh M, Rindzevicius T, et al. Localized surface plasmon resonance sensing of lipid-membrane-mediated biorecognition events [J]. Journal of the American Chemical Society, 2005, 127(14):5043-8.
[6] MartãN-Moreno L, García-Vidal F J, Lezec H J, et al. Theory of highly directional emission from a single subwavelength aperture surrounded by surface corrugations [J]. Physical Review Letters, 2003, 90(16):167401.
[7] Baida F I, Labeke D V. Light transmission by subwavelength annular aperture arrays in metallic films [J]. Optics Communications, 2002, 209(1-3):17-22.
[8] Cao Q, Lalanne P. Negative role of surface plasmons in the transmission of metallic gratings with very narrow slits [J]. Physical Review Letters, 2002, 88(5):057403.
[9] Alkaraki S, Gao Y, Parini C. Dual Layer Corrugated Plate Antenna [J]. IEEE Antennas & Wireless Propagation Letters, 2017, PP(99):11-27.
[10] Hayashi S, Okamoto T. Plasmonics: visit the past to know the future [J]. Journal of Physics D Applied Physics, 2012, 45(43):433001.
[11] Lamprecht B, Schider G, Lechner R T, et al. Metal nanoparticle gratings: influence of dipolar particle interaction on the plasmon resonance [J]. Physical Review Letters, 2000, 84(20):4721.