A Thin Planar Antenna Based on Gradient Metasurface

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Abstract— Gradient metasurface (GM) can have a pre-defined large wave vector along its surface. It has shining attributes as field enhancement and sub-wavelength transmission. In former works, GMs were excited mostly by plane waves illuminated from high above, and experts concentrated on waveform converting or anomalous reflection. This letter analyses electromagnetic field distribution above GM with some plane waves vertically illuminating. Then it provides a new way to excite GM on one of its edges using parallel plate waveguide, from which we can get an escaping plane wave towards above, and this is the inverse process of plane wave vertical incidence. After a delicate parameter sweep, the simulation shows our design has comparatively high directivity and efficiency within a bandwidth of 0.6 GHz (7.7 GHz to 8.3 GHz). The impact of some important size parameters to the antenna performance is discussed in the letter. On account of the fact that GMs are usually constructed by a mass of unit cells, their shapes are variable and they can cover many facilities, which have great potential in both civil and military use. With the development of metasurfaces, the unit cells will become smaller, and the adjustability of the antennae shapes will rise. To excite GMs with the same unit cells but different shapes, it is possible that we only need to tune their matching structure but not the unit cells. Then a new way to design reconfigurable antennae presents. And with the help of metasurfaces, reconfigurable antennae will be more various and flexible and will have better performance.

1. INTRODUCTION

Surface plasmon polaritons (SPPs) refers to some combinating mode of EM waves and electron density that can hardly escape from a surface [1]. As the research on SPPs goes deeper and many devices have been tested successfully, SPPs shows great potential in optics application. Spoof plasmon polaritons [2], similar to SPPs, have attributes as field enhancement [3, 4] and sub-wavelength transmission [5–8], but in THz or microwave band. Spoof plasmon polaritons act as surface wave in free space, and can be realized by using gratings, prisms [9–11] and gradient metasurfaces (GMs) [2].

However in former works, experts mainly concentrated on how GM can transform incident plane wave into surface wave or realization of anomalous reflection [12–14], which means the sources were always hanging above. In order to extend the range of GMs' application, new ways to excite GMs should be discovered.

This letter analysis field distribution of the surface wave above GM and then gives a new way to excite GM on one of its edges. Our simulation successfully proves GM can radiate energy with comparatively high directivity if it is properly excited. Our simulation was run in HFSS and CST.

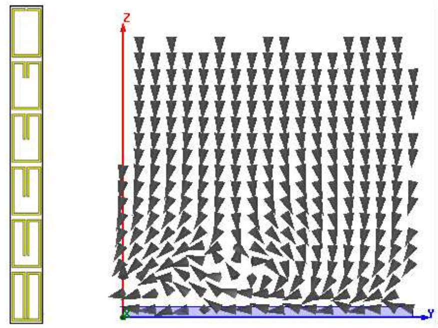
2. PROPERTIES OF GM

GM is usually constructed by several kinds of unit cells. When certain plane wave illuminating onto, neighboring unit cells show gradient reflection index phases, which can provide a large horizontal wave vector. In this way can GM transform the plane wave into a surface wave with high efficiency. Obviously, GM supports surface wave propagating. If we exert an EM-field on one edge of the GM, whose field distribution is similar to that of a surface wave but propagating direction is opposite, we may get an escaping plane wave. It is similar to the reversibility of optical path, making the whole structure as an antenna.

We choose a typical super cell as shown in Figure 1(a) with its size 3.3 mm $\times$ 33 mm. It is constructed by metallic split ring resonators etched on substrate of FR4. There is a metallic sheet on the back of substrate as in Ref. [2]. Its working frequency is 7.87 GHz. Being placed periodically along x and y directions, super cells construct an infinite GM. A y-polarized plane wave vertically incidents onto GM. Power flow at 7.87 GHz is shown in Figure 1(b), in which it shows energy flows along the surface towards $-y$ direction. Magnitude of E-field in x, y and z directions at 7.87 GHz are shown in Figures 2(a) to (c). E-field mainly lies in y and z directions but little in x direction.

3. SIMULATION OF ANTENNA AND PARAMETER DISCUSSION

If we want to excite this GM on one of its edges, we must do it on the side where the former plane wave is propagating to. We need a kind of EM-field whose E-field mainly lies in y and z directions



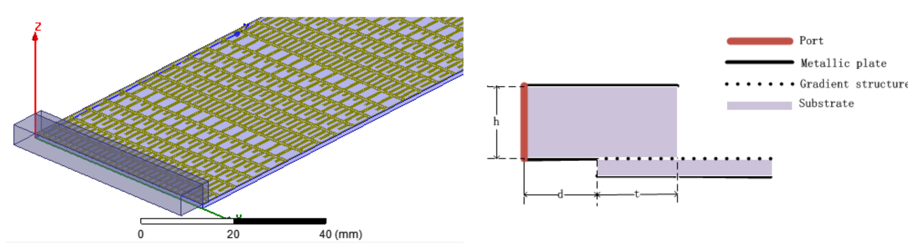
(a) (b)

Figure 1: Design and property of super cell: (a) overall structure of supercell; (b) power flow on yOz plane at 7.87 GHz.

(a) (b) (b)

Figure 2: Snap shot of E-field distribution at 7.87 GHz: (a) E-field in x direction; (b) E-field in y direction; (c) E-field in z direction.

but not x direction, and it should propagate to $+y$ direction. Parallel plate waveguide filled with FR-4 is adopted, because the E-field on its edge is just suit to this situation. We construct our GM by 15×6 super cells. GM and the feed structure is connected as shown in Figure 3(a), and the parameters are set as shown in Figure 3(b). Here Port 1 is set to be lumped port. After a delicate parameter sweep, we fix $d = 7$, $h = 5$ and $t = 2$ Magnitude of S_{11} over frequency is shown in Figure 4. It keeps lower than -10 dB from 7.7 GHz to 8.35 GHz. Total gain in yOz plane (i.e., $\varphi = 90°$) at 7.9 GHz, 8.1 GHz and 8.3 GHz is shown in Figure 5(a). At 8.1 GHz, total gain in yOz plane reaches its peak as 11.7 dB. More anecdotally, as frequency increases from 7.7 GHz to 8.3 GHz, the maximum gain angle changes from $\theta = -6°$ to $\theta = 4°$. Gain distribution in x, y and z directions at 8.1GHz is shown in Figure 5(b). It is clear the radiated E-field mainly lies in y direction, which is similar to the reverse of y-polarized plane wave vertically illuminating. E-field on port 1 at 8.1 GHz is shown in Figure 6. On wave guide's edge, direction of E-field keeps the same, which makes the direction of surface current on unit cell in parallel to be the same, ensuring the whole antenna's high directivity.



(a) (b)

Figure 3: Structure of antenna: (a) overall structure of antenna, (b) parameters setting.

The working frequency of the former infinite GM is 7.87 GHz, while our antenna achieves its maximum gain at 8.1 GHz. This frequency shift is mainly caused by the fact that the environment of the first and second rows of the super cells has changed. The former infinite GM is constructed by super cells being placed periodically. So to each of the super cell, its environment is the same. But in our antenna, it is the parallel plate wave guild that being placed next to it, and what's more, it has a finite size. The attributes of some super cells change, and it leads to the shift.

In the simulation, Port 1 is set to be lumped port with its width of 49.5 mm. At 8.1GHz,

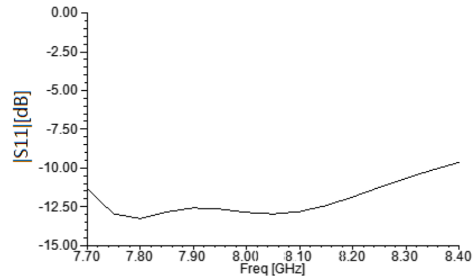
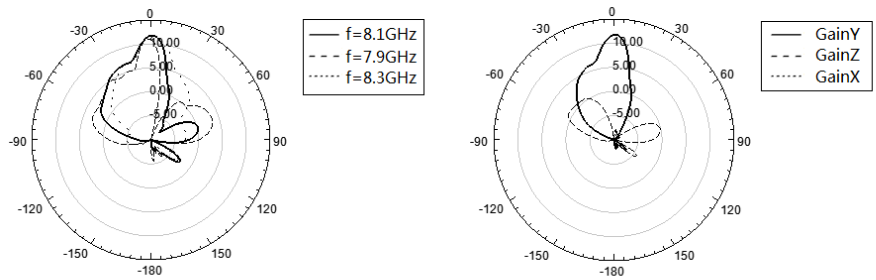


Figure 4: Magnitude of S_{11} over frequency.



(a) (b)

Figure 5: Radiation pattern in dB: (a) Total gain at different frequencies; (b) Total gain distribution in x, y and z directions at 8.1 GHz.

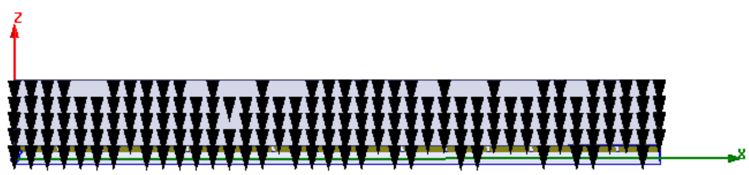


Figure 6: E-field on Port 1 at 8.1 GHz.

wavelength of TEM mode EM-wave propagating in FR-4 is 17.86 mm. The width of Port 1 is 2.77 times as that of the wavelength. However, in practice we usually need to transmit signal from coaxial cable to parallel plate waveguide, while the former can be seen a point source. It is difficult to get a plane wave from a point source within a short distance. This will lead to the inconformity of the phase along the edge of waveguide and the reduction of antenna's gain. To solve this problem, two methods are presented: using narrower super cells or using fewer super cells in parallel. The minimum width of the super cell depends on machining accuracy. More importantly, if the feed structure and GM are cut narrow enough, the result will turn to be destructive. The super cells along the edges of GM can be considered "on the edge", while their attributes have changed a lot as we mentioned. Therefore when designing antenna of this kind, we should take gain, realization method and number of super cells in parallel into consideration.

If we want to change the shape of antenna, we can add or cut some unit cells and tune the parameter of feed structure. Unit cells being made removable, the shape of antenna will be flexible. With the development of GM, unit cells will be smaller, and then the antenna will have higher reconfigurability.

4. CONCLUSION

To sum up, this letter analyses the EM-field above GM when some plane wave vertically illuminates, according to which it gives a new way to excite GM at one of its edges to form an antenna. In the simulation, the antenna shows high directivity and low return loss. The influence of some parameters on antenna is discussed. Due to the fact that GM is usually constructed by small unit cells, this letter provides a new way to design reconfigurable antenna.

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