Study of A designed and experimental multi-beam antennas based on Spoof Surface Plasmon Polaritons structure

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Abstract. The new type of artificial electromagnetic two-dimensional surface consists of an array of subwavelength unit structures arranged according to the periodicity of the dispersion curve. It has a significant role in regulating electromagnetic waves, and it has become one of the hot topics in the field of information. In this paper, the Spoof Surface Plasmon Polaritons (SSPPs) are regulated and applied to the wireless millimeter-wave base station communication. It has the characteristics of low profile, low cost, high isolation, broadband, and high gain. As a proof of concept, the antenna array is designed, simulated, processed and measured. The dual-beam adaptive antenna based on SSPPs at 10 GHz. The experimental results are in good agreement with numerical simulations. The proposed antenna has promising applications on planar wireless communication devices, such as multi-beam antennas, beam-scanning antennas, and wave controllers.

Keywords: Spoof Surface Plasmon Polaritons (SSPPs), antenna array, dual-beam, eigenmode analysis.

1. Introduction
Surface Plasmon Polaritons (SPPs) refer to a collective resonance effect produced by the coupling between electromagnetic waves and free electrons on the metal surface at the interface between metal and medium.[1] It is a metamaterial that binds electromagnetic energy to the surface and decays exponentially in the vertical and interface.[2] The SSPPs in the electromagnetic band can be transmitted on structured metal surfaces (such as slotted, perforated, periodic array structures, etc.) It has advantages such as sub-wavelength effects and field localization and enhancement phenomena, miniaturizing and reducing signals in microwave devices. There are important application scenarios for mutual interference and restraint of electromagnetic energy. In 2004, the 3D metal plasmon was designed by the Pendry team through manual drilling. At this time, the frequency of the Spoof SPP has been greatly reduced from the original optical band to the microwave band, and the theory and characteristics are both Very similar. In 2005, a group represented by Professor Hibbins first discovered the appearance of the artificial surface plasmon in the laboratory. In 2006, Maier et al. adopted the method of periodic circumferential grooves on the surface of metal pillars to realize the transmission and energy accumulation of terahertz artificial surface plasmons. Subsequently, a variety of metal structured surfaces such as spiral grooves, wedge grooves, and inclined grooves have been proposed and proved to support SPPSs. In 2008, the Natata team at the University of Utah conducted experimental research on one-dimensional hole arrays structure. In the same year, Williams and others verified the
transmission performance by processing two-dimensional periodic vias on metal surfaces and applying them in the THz frequency band experiment.

Currently, there are theoretical studies on SSPPs, and the use of their physical characteristics in practical devices is still scarce. In the field of microwave science, only Southeast University has researched more and made some simple filter devices. In the following, people's main research hotspots in this field have expanded from pure theory to practical engineering needs. At present, a large number of devices have been designed, such as filters, circulators, couplers, power dividers, etc. However, effective antennas are still rarely studied. Due to the particularity of the antenna unit, it has been difficult to research the high efficiency of surface waves into radiated space waves. Therefore, in this paper, we propose and design a type of dual beam antennas array based on SPPSs.

2. Design and Simulation

We design an antenna array based on SPPSs. The dispersion curve can be changed with the unit cell of SPPSs. The definition of dispersion is the change of its phase through a unit cell structure, as shown in Figure 1. In order to better verify our theoretical analysis, we perform unit cell modeling in CST. Through a series of Boolean operations, we can draw the model of the H-shaped structure we analyzed. The specific parameters of the model are that the unit cell period P is 5 mm, the metal groove depth h is 4 mm, and the metal groove width a is 2 mm. The ordinate represents the frequency of the simulation in 8GHz; the abscissa represents the phase change along the periodic structure of the unit. It can be seen from the figure that the change of the tangent slope is smaller than the vacuum electromagnetic wave k0, which indicates that the electromagnetic wave propagates through the x direction and decays exponentially in the z direction. Through the curve, we can get the frequency range of the metal periodic PEC structure. Note that the eigenmode solution here is the characteristic solution of the Maxwell equations. There is only one layer of metal structure, which is SSPPs.

Based on the theoretical analysis of the SSPPs transmission line designed in the previous section, the circular patches were placed on both sides of the transmission line to couple the surface waves of the transmission line to the effective radiation free space. From Figure 2, we can clearly see that at 8GHz, the surface current and magnetic field on the transmission line are perfectly coupled to the circular patch antenna.
3. Measurement and Results Discussion

For further verifying the performance of the dual-beam antenna array based on SSPPs, we fabricate and process a sample and conduct the measurements. The photograph of the fabricated sample is shown in Fig. 3. From the fabricated sample we can see that the circular patches are neatly arranged on both sides of SPPSs. By coupling the energy on the SPPSs to these circular patches, and they radiate into space as antennas.

Figure 4(a) presents the simulation result of the 2D far-field beam pattern of the antenna array based on SPPSs. It is clear that the original beam splits evenly into dual-beam centered on the z-axis, and the simulation results verify that the antenna array based on SPPSs can be used to control EM waves. Hence, the good agreement between numerical simulated 4(a) and experimental measured results 4(b) are observed and the antenna array based on SPPSs has been verified.
4. Conclusion

In this paper, we proposed and realized a dual-beam antenna array based on SSPPs. Through theoretical design and further experimental implementation, the proposed antenna is verified having great potential in dynamic adjustable applications, such as radio detection and ranging, low orbit satellite communication equipment, polarization converter devices, and so on.

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These authors are contributed equally to this work.

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