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THz Range Perforated Metasurface-integrated Multiband Fabry-Perot Microstrip Patch Antenna

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Abstract

We have proposed a THz range, multi-band, metasurface-integrated Fabry- Perot cavity antenna. The perforated single layer metasurface provides 40% wide stop bandwidth and it is used as superstrate. The metasurface integrated antenna resonates at the frequencies of 180.0 GHz, 189.46 GHz, 199.02 GHz and 208.82 GHz. The maximum peak gain of 13 dBi is at 189.46 GHz among the four bands. Nearly 5% of gain enhancement is achieved in all four bands after loading the metasurface on the antenna.

1. Introduction

The high demand for fast data transmission rates, low latency, high reliability and interference-free operation has heralded the use of millimetre-wave and terahertz- wave regimes [1]. In addition, multiband operation is also essential as most of the modern handheld wireless devices operate in multiple bands of frequency to provide multiple utilities with a single antenna. One of the main limitations of the THz regime arising from a high attenuation and atmospheric path loss of the signal can be overcome with bulky and expensive high-gain antennas. Therefore, in recent years, Fabry-Perot cavity (FPC) antennas are gaining in popularity as they are simpler in construction, economical and attain high gain and directivity at microwave, millimeter-wave, terahertz frequencies, and even at optical frequencies [2]. The FPC antenna can be designed using periodic structures such as frequency selective surfaces (FSS) and metasurfaces (MS) in different arrangements to increase the gain and directivity by placing it as superstrate [3,4].

Most low-profile FPC antennas consist of a multilayer cavity and/or multilayer configuration. Such designs increase the volume and make it more difficult to realize high-frequency integrated systems [2,4]. Recently, silicon and GaAs based microstrip patch antennas (MPA) are also fabricated to meet the monolithic integration requirements, but these are expensive, complex and high maintenance in profile [1,4]. To overcome some of these drawbacks, we present a simple, cost-effective, robust and mass-producible FSS based metasurface (MS-FSS) integrated with a multi-band MPA for THz range application. Our design of MS-FSS has 20x20 array of periodic holes in a square lattice arrangement on a dielectric substrate. It has 40% wide stop bandwidth ranging from nearly 175 GHz to 272 GHz. It is then used as a partially reflecting surface (PRS) by placing it above the antenna (as a superstrate) to make the FSS integrated MPA work as a FPC antenna. It helps to enhance the gain of the stand-alone MPA due to multiple reflections between the highly reflective FSS and the antenna ground plane, as in a Fabry–Perot (FP) resonator. Our design results in multiple resonances at 180.0 GHz, 189.46 GHz, 199.02 GHz and 208.82 GHz. Nearly 5% of peak gain enhancement is achieved in all the four bands after loading MS-FSS on MPA. An improvement of 2-3 dB is also seen in the reflection coefficient of FP-MPA.

2. Multi-band MPA and MS-integrated MPA

2.1. Stand-alone Multi-band MPA

Figure 1 (a) shows the schematic of THz-range multi-band MPA. The MPA is of conventional design and is made up with dielectric substrate backed by the metallic ground plane and the metallic patch is printed on the top of the substrate. We have used Rogers RT Duroid 5880 as the substrate (relative permittivity of 2.2, thickness 0.79 mm). The substrate has the length (Lg), width (Wg) and thickness of 12.00 mm, 12.00 mm and 0.79 mm respectively. The ground plane is of copper with comparable length and width, and a thickness of 0.35 mm. The rectangular patch is of length and width of W x L = 0.6mm x 1 mm. The rectangular patch has four slots in it as shown in Fig.1 (a). The length and width of slot 1 and 2 is a x b = 0.2 mm x 0.2 mm, whereas the length and width of slot 3 and 4 is c x d = 0.2 mm x 0.4 mm. The slots are inserted in the patch to achieve multiple resonances in the MPA. Four slots have been cut in the patch to provide additional resonance frequencies other than the natural resonance of the patch which is 180 GHz. The photograph of the prototype antenna is shown in Fig. 1(b).

2.2. THz Range FSS based Metasurface

The metasurface uses the same substrate with similar dimensions as in section 2.1 and is shown in Figs. 1 (c, d). The holes are of radius (*r*) 0.2 mm and hole-to-hole spacing (*a*) is 0.4 mm, arranged in square lattice arrangement. The FSS structure consists of 20 x 20 array. The perforation is of through holes of 0.79 mm thickness. The MS-FSS shown in Fig. 1(d) is fabricated using CNC drilling technique, which is easy, fast and simple to use. CST MW Studio^{TM} software is used for the design and analysis in time domain solver.

2.3. Metasurface-integrated Multi-band MPA

The MS-FSS is used as PRS for the multi-band MPA after loading it on the MPA at a distance of 1mm (0.5 λ_0), where λ_0 is the resonant wavelength (considered 180 GHz). The inset-fed multi band MPA (Fig. 1(a)) is selected as the primary source for the FPC antenna.

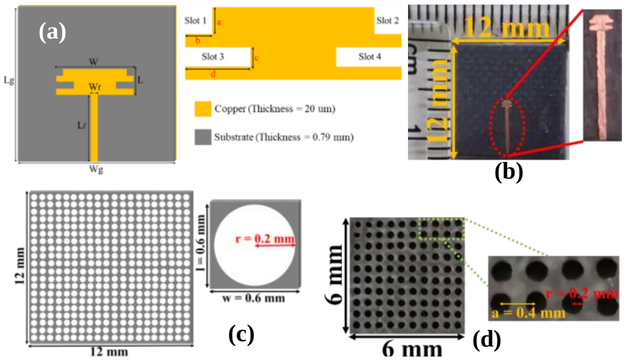

Figure 1. (a) Schematic of multi-band MPA, (b) photograph of multi-band MPA, (c) schematic of FSS-MS with its unit cell dimension in zoomed view and (d) photograph of a smaller-size FSS-MS with 10x10 array.

3. Results and Discussion

S-Parameters and Gain of Multi-band MPA, MS-FSS and integrated system

Figure 2 (a) is the simulated reflection coefficient of the stand-alone MPA. It shows four prominent resonance peaks indicated with star shapes. The MPA resonates at 180 GHz, 189.46 GHz, 199.02 GHz and 208.82 GHz, with reflection coefficients of -28.86 dB, -39.04 dB, -29.13 dB and -20.13 dB respectively. Figure 2(b) depicts the calculated reflection (S_{11}) and transmission (S_{21}) coefficients of MS-FSS in the frequency range of 100-300 GHz. The unit cell shows high reflection and low transmission coefficient in the frequency range of 174.70 GHz to 251.75 GHz as shown in with blue shaded region, which works as stop band, with a width of 39.8%. At 166.40 GHz and at 257.56 GHz, the structure has low reflection coefficient and high transmission coefficient, working as narrow pass bands.

Figure 2 (c) shows the reflection coefficient of MPA and superstrate loaded FP-MPA, and these are found to match exceedingly well. The reflection coefficients attained by FP-MPA are -33.57 dB at 180.0 GHz, -41.33 dB at 189.46 GHz, -32.00 dB at 199.02 GHz and -20.43 dB at 208.82 GHz, shown with black solid line in Fig. 2(c). The reflection coefficient improves by nearly 2-3 dB after loading the superstrate on MPA.

Figure 2(d) depicts the simulated peak gain for the MPA (in black solid line) in the direction of $\theta = 0^0$ (bore-sight). The stand- alone MPA attains peak gains of 7.45 dBi at 180 GHz, 7.93 dBi at 189.46 GHz, 7.13 dBi at 199.02 GHz and 6.53 dBi at 208.82 GHz. The maximum peak gain of nearly 8 dBi is obtained by the multiband stand- alone MPA at 189.46 GHz at bore sight. FP-MPA (shown with blue solid line) has peak gains of 12.22 dBi at 180.0 GHz, 13.02 dBi at 189.46 GHz, 12.24 dBi at 199.02 GHz and 11.19 dBi at 208.82 GHz. At all the four resonance frequencies, the FP- MPA has achieved a significant gain exceeding 11 dBi. On comparing the peak gains before and after loading the superstrate (FP-MPA), we note an increment in gain of nearly 4.7% at 180 GHz, 5.1% at 189.46 GHz, 4.9% 199.02 GHz and 4.7% at 208.82 GHz as shown by the arrows in Fig. 2(d).

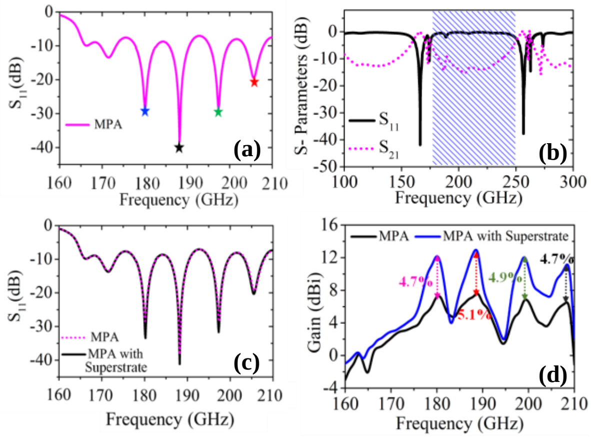

Figure 2. Simulated (a) reflection coefficient of stand-alone MPA, (b) S-parameters of the FSS, (c) reflection coefficient of MPA and MS-FSS superstrate loaded MPA and (d) peak gain as a function of frequency of the MPA and MS-FSS superstrate loaded MPA (the arrows represent the increment of peak gain).

4. Conclusion

A simple, cost-effective, robust and mass-producible FSS-MS integrated multi-band MPA for THz band is presented. The stand-alone MPA shows multiple resonances from 180 GHz to 209 GHz. The MS-FSS attains a wide stop bandwidth of 40% from 175 GHz to 272 GHz. This wide stop band is utilized by keeping the MS-FSS on the MPA as superstrate at a suitable height and making it work as a PRS for the MPA. This MS-FSS integration with MPA works as the FPC antenna and allows to enhance the gain of the stand-alone MPA. The antenna with MS-FSS structure has shown a significant peak gain improvement of nearly 5% in all the four resonating frequencies. Moreover, 2-3dB improvement in reflection coefficient is also attained for all the resonance frequencies of MS-FSS integrated FP-MPA. Our design for the prototype is novel, and is the first proposal for using perforated single layer metasurface as a superstrate in the THz regime. It is suitable for wireless communication, material characterization, and security applications in defense.

Acknowledgments

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