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60 GHz mmWave Metasurface Superstrate for Gain and Bandwidth Improvement

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Abstract

A multi-layer structure designed for the 60 GHz mm-wave frequency band is presented. The design consists of an antenna element on the substrate and a split ring resonator (SRR) metasurface on the superstrate. With the addition of the metasurface superstrate layer, an improved performance of the antenna in terms of gain and bandwidth is achieved. These enhancements are based on the negative index metamaterial (NIM) properties of the designed metasurface sheet. In this proposed design the bandwidth is improved from 3 GHz to 4.5 GHz, while the gain of the antenna is increased from 7.87 dBi to 13.87 dBi at 60 GHz.

1. Introduction

The mm-wave frequency band of 57 – 64 GHz offers significant bandwidth for high-resolution video broadcasting and for short distance high speed wireless communications [1]. A major consideration in this band is the atmospheric loss, which can be mitigated by designing higher gain antennas. This has been addressed by using LTCC structures [2], antenna array systems [3], the use of parasitic elements on the antenna to enhance the gain [4], and the addition of spherical lenses to the antenna too [5]. However, these techniques are either costly, complicated to fabricate, bulky or have a narrow bandwidth. More recently, linear antenna arrays loaded with metamaterial resonators and SRRs to enhance the gain for the linear array have paved the way for the use of metamaterials for such applications [6][7]. Thus, we propose a cost effective, compact, and simple solution to achieve high gain and broader bandwidth for mmWave band antennas.

In this work, the performance of a patch antenna has been improved by using a metasurface superstrate layer at mm-wave frequencies centered at 60 GHz. The superstrate layer is added to the existing design of the patch antenna at a separation of a wavelength and a half, thus forming a multi-layer structure. One layer consists of the antenna and the second is the metasurface layer, where the split-ring unit cells are printed on both sides of the superstrate to enhance the gain and bandwidth of the antenna. In this design, the improvement in the gain and bandwidth is achieved without changing the characteristics of the antenna element. To achieve the improved performance, the superstrate layer was optimized in terms of the unit cell length, width, thickness, gap size of the splits, period and their arrangement. The distance between the two layers is also optimized to provide maximum gain. With an increase of 6 dBi in gain and 1.5 GHz improvement in bandwidth, this design has the potential to be used in the 60 GHz band for high gain and wideband applications.

2. Antenna and Metasurface Superstrate

A patch antenna has been designed and optimized to radiate at 60 GHz using a full wave EM simulator (CST Studio Suite). The patch is fed by 50-Ω line with an inset feed as shown in Fig. 1. The radiated beam from the patch is than coupled to the metasurface sheet which improves the gain and the bandwidth of the patch antenna. Negative values for the permittivity ε_r, and permeability μ_r pave the way for these enhancements and are extracted using the mathematical calculation presented in [8].

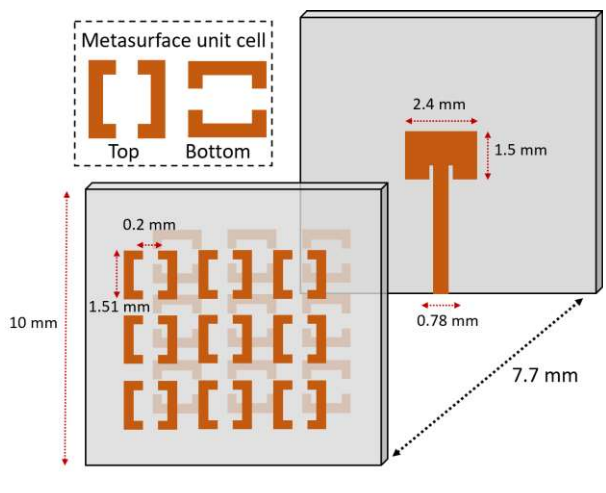

Fig.1. Perspective view of the complete design. The two layers are separated by 7.7 mm which is the optimized distance to provide maximum output.

The complete multi-layer structure along with its parameters are shown in Fig. 1. The dielectric substrate used to design this dual layer structure was Rogers RT5880 (with a dielectric constant of 2.2, a loss tangent tan δ of 0.0009, and thickness of 0.254 mm). The distance between the two layers has been optimized to provide maximum output and corresponds to the length of a wavelength and a half, i.e. 7.7 mm. Tuning this distance helps to improve the gain of the overall structure. The figures of merit for this structure are the bandwidth (which is extracted from the reflection coefficient), and the gain (which is calculated using the far-field radiation).

The superstrate layer consists of a 3 x 3 periodic configuration of the metasurface unit cells. Each unit cell has a square ring on top and bottom side with two splits of 0.2 mm, which are translated on the bottom side with a 90° shift as shown in the inset to Fig.1. Rotation of the split rings resulted in negative values for ε_r, and μ_r. The size of the square ring is 1.51 mm, leading to it resonating at a similar frequency to that of the patch antenna. By increasing or decreasing the size of the unit cell we can tune the metasurface to lower or higher frequencies. The period between two consecutive cells corresponds to one wavelength. Optimization of the period aids in achieving good matching between the two layers along with a directive beam radiating outwards from the superstrate layer.

3. Gain and Bandwidth Improvement

The bandwidth and gain of the patch antenna have been improved by adding a superstrate layer to the existing patch antenna design, making it a multi-layer structure.

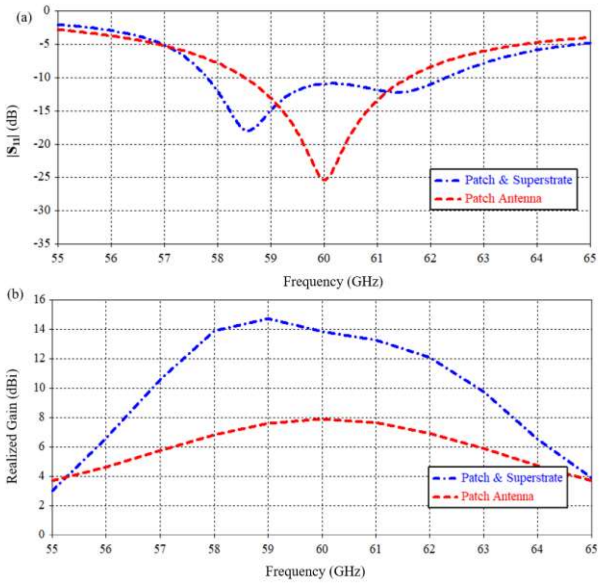

Fig.2. Results that shows a comparison for bandwidth and gain for both the states, Patch antenna only and when incorporated with the metasurface superstrate layer. (a) Bandwidth. (b) Gain.

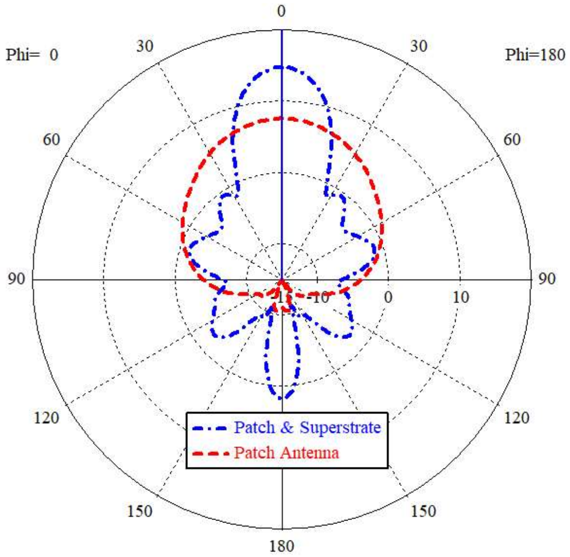

Fig.3. 2D radiation plot for the patch antenna with and without the metasurface superstrate layer.

The antenna and the metasurface layer have been optimized to radiate at 60 GHz. Combining the two layers resulted in two resonances (one from the antenna element and the second from the superstrate layer). These resonances were tuned by changing different parameters of the superstrate layer which resulted in an increased bandwidth. The gain was improved by optimizing the distance between the two layers. The results for the patch antenna with and without the metasurface superstrate layer are shown in Fig. 2. The magnitude of the reflection coefficient for the patch antenna (Fig. 2(a)) indicates an operational 10 dB bandwidth of 3 GHz centered at 60 GHz. When the metasurface superstrate layer is incorporated with the patch antenna, an increase in bandwidth is observed as shown in Fig. 2(b). The total bandwidth of the patch antenna was increased from 3 GHz to 4.5 GHz with a minor deterioration in return loss (although this still remains greater than 10 dB throughout the bandwidth). A notable increase of 6 dBi in the gain of the patch antenna was also achieved as shown in Fig. 2(b). The resultant gain of the multi-layer design is 13.87 dBi at 60 GHz and 14.73 at 59 GHz. The increase in the gain is almost twice that of the patch antenna alone. We also observe a back lobe with the addition of this superstrate layer, but this is approximately 15 dB down from the peak main lobe. The enhancement of the gain for the patch antenna with and without the metasurface layer can also be verified by the 2D radiation pattern shown in Fig. 3. The direction of the main lobe for both the cases is at 0° which shows that the beam is radiated perpendicular to the substrate.

4. Conclusion

The performance of a 60 GHz patch antenna has been improved in terms of gain and bandwidth by adding a metasurface superstrate layer based on an SRR unit cell. These performance enhancements enable the proposed antenna to meet the large bandwidth and higher gain requirement for the 60 GHz band. Adding the metasurface layer to the existing design of the patch antenna with a distance that corresponds to 1.5 wavelengths resulted in an improved gain from 7.87 dBi to 13.87 dBi at 60 GHz, while the bandwidth has been increased from 3 GHz to 4.5 GHz. This design shows the potential of metasurfaces to boost the antenna performance. Thus, enabling the design to be used for high gain and wideband applications in the unlicensed 57 – 64 GHz band.

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