Design of THz Reflect array Antenna using Combination of Different Unit Cell Elements

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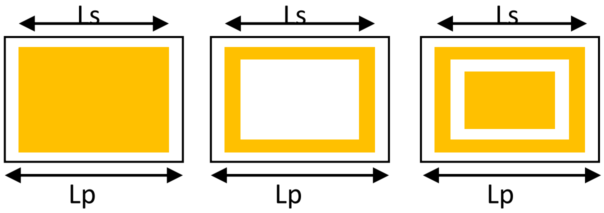
ABSTRACT
A Terahertz (THz) reflectarray is designed using three separate unit cells has been proposed. The reflectarray makes use of gold patches on PDMS substrate in order to obtain a design that covers a phase range of complete 360^O for a frequency of 1 THz. A 255 element array is designed and simulated to show that good directivity and narrowbeam with 8.6^O beamwidth in the ϕ = 0^O plane is obtained using the proposed design.

General Terms
Terahertz, Reflectarray Antenna

Keywords
Terahertz, Reflectarray, Antenna Design, Array Design

1. INTRODUCTION AND BACKGROUND
Terahertz (THz) regime holds a vast number of potential applications in the field of imaging, indoor communication and bio-hazard material detection and a THz antenna is hence a necessity for all these applications [1]. A reflectarray is capable of combining all the advantages of a parabolic reflector with a planar design of a phased array. They consist of cells that essentially provide a phase shift of the incident wave when reflected from the surface. The phase shift depends on the physical dimension of the unit cells. This gives an opportunity to control the direction of reflection and capability to form a collimated far field beam depending on the array phase distribution. Reflectarrays have been used for a long time at microwave and millimeter wave applications. A reflectarray antenna was first proposed in 1963 [2]. It was later intensively studied for various applications in the microwave [3] and millimeter regimes [4] due to its simple design, low fabrication and operation costs. A design of reconfigurable reflectarrays using patch antennas has been explored at microwave frequencies [5]. Reflectarray antennas have been designed for satellite communication providing capabilities of high gain high speed beam steering. The use of a multilayer structure in designing a microwave reflectarray made of three layers with varying sizes of the unit cell patches has been implemented [6].The use of reflectarrays at THz was first demonstrated by Taioming Niu et all [7] where a single unit cell having gold patch on a PDMS substrate. Ideally, it is expected that the phase shift provided by the reflectarray covers the whole 360^O Niu et all are able to achieve a phase shift of around 330^O at 1 THz. A graphene based reflectarray was proposed [7] where the overall phase covered was around 290^O at 1.3 THz and the design is expected to have possibility of making potentially reconfigurable reflectarrays by exploiting the properties of graphene. Recently, a dielectric reflectarray lens antenna has been proposed [8] where columns of dielectrics are formed using 3D printing and is designed to form a high-gain THz lens antenna.

2. UNIT CELL DESIGN
In order to have the reflectarray have a phase that covers complete 360^O we make use of three different unit cell design. These three designs are the square patch, square ring, and the ring loaded patch as shown in figure 1 [9]. Each unit cell has a periodicity of L_p = 140 µmand a variable side length L_s. For the ring unit cell, the width of the ring is fixed at 10 µm. Similarly, for the ring loaded patch, the gap between the patch and the ring is kept fixed at 7.5 µm. The thickness of the substrate is taken as 15 µm and thickness of the metal is 0.04 µm in all designs.



Single Patch Single Ring Ring Loaded Patch

Fig 1: Design of unit cells where L_p = 140 µm is the periodicity, L_s is the side length and material is gold on PDMS substrate and gold ground plane

Each unit cell is designed with conducting material as gold and PDMS substrate which is back coated with gold, where gold acts as the ground plane of the structure. At Terahertz, the metals shows a complex dielectric constant and as such need to be modelled for the simulations. The Drude model is used in order to calculate the plasma frequency ω_p and collision frequency ω_t using the following equations,

$$\epsilon_r = n^2 - k^2 \quad (1)$$

$$\epsilon_i = 2nk \quad (2)$$

$$\epsilon_r = \epsilon_\infty - \frac{\omega_p^2}{\omega^2+\omega_t^2} \quad (3)$$

$$\epsilon_i = \frac{\omega_p \omega_t}{\omega(\omega^2+\omega_t^2)} \quad (4)$$

where ϵ_r is the real part and ϵ_i is the imaginary part of the complex dielectric constant of the metal. Using the values of ϵ from [11], the plasma frequency for gold was calculated to be around 1.1x10^{16} rad/s. The PDMS subsrate is simulated with dielectric constant ϵ = 2.35 and tanδ = 0.03 at 1 THz [7].The unit cell is simulated using CST Microwave Studio Frequency Domain solver , where unit cell boundary condition is used for x and y directions and open (add space) boundary condition is used for z directions which are considered as Floquet ports. Three types of unitcell are shown in figure-1. Phase of reflected wave is calculated on plane of metallic gold structure of the unitcell element. The phase angle vs. dimension for three structures are plotted in figure. 2. The advantage of using three types of unit cell is to cover the whole 360 degree phase angle. As the periodicity of the unitcell is 140 micron for all three cases so different types of unitcell element can easily be fitted in same area.

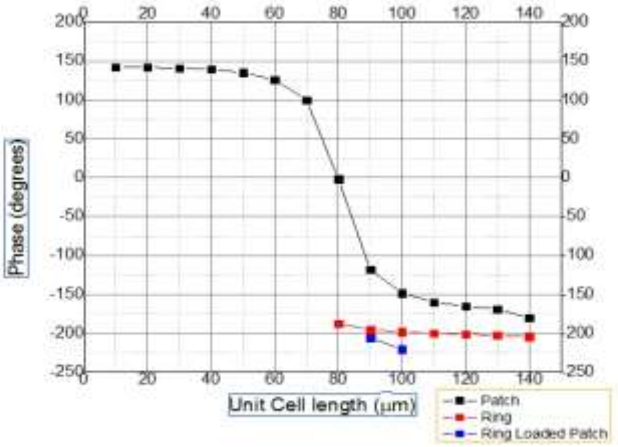


Fig 2: Variation of Phase angle of relfected wave vs. dimension of unit cell

The progressive phase change of unit cell elements is governed by the following equation,
$\phi = K(d - (x\cos\phi_b + y\sin\phi_b)\sin\theta_b$ (5)
where K is propagation constant, d is distance between illuminating horn antenna and corresponding unitcell element which is located on a 2-D plane with coordinate (x,y). ϕ_b and θ_b are angular direction of reflected beam in spherical coordinate system considering the center of planer array coincides with center of the coordinate syatem. simulation ϕ_b and θ_b both are chosen to be zero i.e. the reflected wave will be radiated perpendicular to the structure results broadside radiation.

3. REFLECTARRAY DESIGN

The complete reflectarray is designed using the three types of unit cells discussed in the previous section. The reflectarray is designed for a 15x15 unit cell elements, i.e. 225 elements. The complete design is as shown in figure 3.

The array is designed with onset feeding and normal reflection. The phase at each position of the array is calculated using equation (5). The appropriate type of unitcell as well as the size of unitcell of a particular type is chosen from phase vs dimension graph in figure. 2 according to the calculated phase. Thecomplete array was fed with a horn antenna.

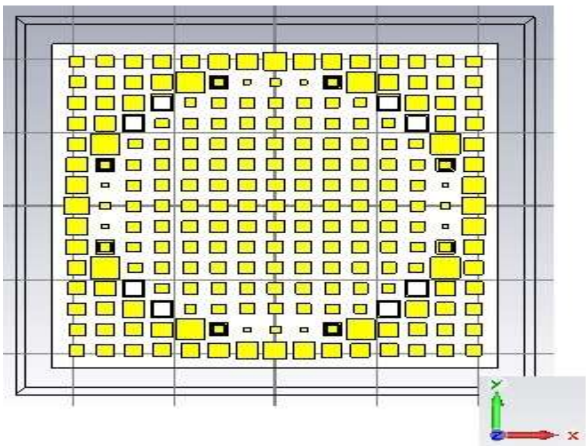


Fig 3: Complete 15x15 reflectarray design

4. SIMULATION AND RESULTS

The full 15 x 15 reflectarray is simulated using Integral Equation solver in CST Microwave Studio.The array is illuminated using a farfield radiation of horn antenna at 1 THz placed normally above the array at a distance where f (focus length)/D(maximum dimension of array) ratio is 0.8. Farfield radiation pattern in Cartesian coordinate of reflected wave is shown in figure-4 which shows a distinct reflected lobe.

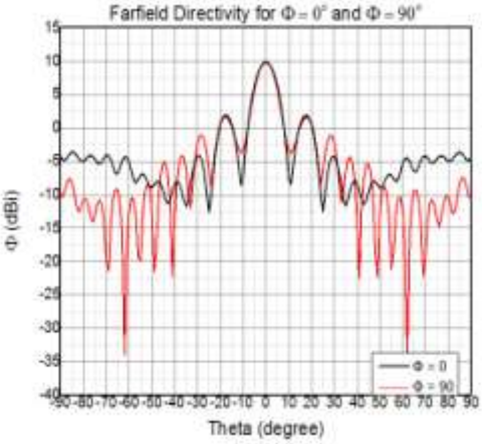


Fig 4: Simulated Results for φ = 0^O and φ = 90^O

From the figure it is evident that maximum power of reflected wave is in broadside direction. 3-db angular beamwidth of reflected wave is 8.6^O and 9.2^O in ϕ_b = 0^O and θ_b = 0^O plane respectively. However, it is observed that the sidelobe level is considerably high. In order to reduce this sidelobe level, a larger size of the reflectarray can be designed as well as f/D can also be optimised. This will lead to a narrower beamwidth alongwith reduction in the sidelobe levels.

5. CONCLUSION

A reflectarray designed to operate at 1 THz has been proposed with the use of three different types of unit cells. The results show that the reflectarray is capable of covering the entire phase variation of 360^O with a 3 dB angular beamwidth of 8.6^O in ϕ_b = 0^O plane and 9.2^O in θ_b = 0^O plane. The directivity can be improved alongwith reduction in sidelobe interference by designing a larger array.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] P. H. Siegel, “Terahertz technology,” IEEE Trans. Microwave Theory Tech., vol. 50, no. 3, pp. 910–928, Mar. 2002.

[2] D. G. Berry, R. G. Malech, and W. A. Kennedy, “The reflectarray antenna,” IEEE Trans. Antennas Propag. 11, 645–651 (1963).

[3] J. Ginn, B. Lail, and G. Boreman, “Sub-millimeter and infrared reflectarray,” U.S. Patent 7623071 B2 (2009).

[4] R. D. Javor, X. D. Wu, and K. Chang, “Design and performance of a microstrip reflectarray antenna,” IEEE Trans. Antennas Propag. 43, 932–939 (1995).

[5] J. P. Gianvittorio and Y. Rahmat-Samii, “Reconfigurable patch antennas for steerable reflectarray applications,” IEEE Trans. Antennas Propag. 54, 1388–1392 (2006).

[6] J. Encinar, M. Arrebola, L. F. de la Fuente, and G. Toso, “A transmit-receive reflectarray antenna for direct broadcast satellite applications,” IEEE Trans. Antennas Propag. 59, 3255–3264 (2011).

[7] T. Niu, W. Withayachumnakul, B. S.-Y. Ung, H. Meneske, M. Bhaskaran, S. Sriram, and C. Fumeaux, "Experimental demonstration of reflectarray antennas at terahertz frequencies," Opt. Express, vol. 21, no. 3, pp. 2875–2889, 2013.

[8] E. Carrasco and J. Perruisseau-Carrier. "Reflectarray antenna at terahertz using grapheme," IEEE Antennas Wireless Propag. Lett., vol. 12, pp. 253 -256, 2013.

[9] Shi-Wei Qu, Huan Yi,Chi Hou Chan, Kung Bo Ng, "Low-Cost Discrete Dielectric Terahertz Lens Antenna Using 3D Printing," IEEE Conference on Antenna Measurements and Applications, 2014.

[10] J. H. Yoon, J. Kim, Y. J. Yoon,W. Lee, and J. So, "Single-layer reflectarray with combination of element types," Electron. Lett., vol. 50, no. 8, pp. 574–576, 2014.

[11] M. A. Ordal, L. L. Long, R. J. Bell, S. E. Bell, R. R. Bell, R. W. Alexander, Jr., and C. A. Ward, Optical properties of the metals Al, Co, Cu, Au, Fe, Pb, Ni, Pd, Pt, Ag, Ti, and W in the infrared and far infrared, APPLIED OPTICS, Vol. 22, No. 7, pp. 10991120, 1983.