Terahertz Reflectarray Antennas: An overview of the State-of-the-art Technology

Ruyuan Deng1, Fan Yang1, Shenheng Xu1, Paola Pirinoli2
1. Electronic Engineering Dept., Tsinghua University, China
2. Dipartimento di Elettronica e Telecomunicazioni, Politecnico di Torino, Italy

Abstract: Reflectarray antenna has emerged as a new generation of high-gain antennas. Recently, the reflectarray research has been expanded from microwave to THz and optical frequencies. In this presentation, several design methodologies on THz reflectarray antennas are reviewed, such as planar patch reflectarrays, 3D structure reflectarrays, and reconfigurable reflectarrays. Some practical applications of reflectarrays have also been discussed. It is expected that this overview will stimulate creative THz reflectarray research in the community.

Keywords: Antenna, Reflectarray, Terahertz.
Outline

• Introduction

• Representative THz reflectarray designs
  ➢ Planar patch reflectarrays
  ➢ 3D structure reflectarrays
  ➢ Reconfigurable reflectarrays

• Practical application of reflectarray

• Summary
Reflectarray Antennas

Parabolic Reflector
- Simple, well developed
- Bulky, limited beam scan

Microstrip Array
- Low profile, flexible beams
- Power loss in the feed network

New high-gain antennas
- Low profile
- Low mass
- Easy to fabricate
- Easy for circuitry integration
- Element phase: individual control

Reflectarray
- Beam-scanning reflectarrays
- Amplifying reflectarrays
- Multi-beam reflectarrays
- Contour-beam reflectarrays

Images are from www.deepspace.jpl.nasa.gov and www.activefrance.com/Antennas
THz Frequency Band

- Terahertz frequency (THz) band

THz radiation exhibits the following properties:
- Penetration, High resolution imaging, Spectroscopy, and so on.
- Application: System Image, Remote Sensing, Radar

The goal of this talk is to review the technology advancement of THz reflectarray.
Progress on THz Reflectarrays

- **Planar reflectarray**
  - Reflection property analysis of patch element
  - Prototype design, fabrication, and measurement

- **3D structure reflectarray**
  - Dielectric reflectarray
  - TiO$_2$ dielectric resonator reflectarray
  - Perforated reflectarray
  - Dielectric spherical reflectarray

- **Reconfigurable reflectarray**
  - Graphene-based THz reflectarray
  - Liquid crystal-based THz reflectarray

- **Practical application of reflectarray**
  - Holography using patch-dipole nanoantenna reflectarrays
First use of reflectarray in the THz range [1].
Demonstrated the feasibility of using a traditional square patch as the reflectarray phasing element at 28.3THz.
The modeled and measured phase response results were compared.

Major concern for THz reflectarray antenna design: losses associated with reflectarray elements.

Example: A square patch element for 28.3 THz [2]

Unit-cell: $5.54 \times 5.54 \text{ µm}$
Patch: $3 \times 3 \text{ µm}$ square patch, 100 nm thick
Dielectric substrate: $\varepsilon_r = 2.2$, lossless, 450 nm thick
Ground plane: perfect electric conductor

A material threshold is noticed for total power loss and phase range reduction.

1 THz Reflectarray: Design

![Diagram of Gold and Platinum layers with dimensions](image)

\[ \varepsilon_r = 2.35, \tan\delta = 0.03 \]
\[ a = 140\mu m, h = 15\mu m \]
\[ Z_{SR,Au} = 0.287 + j0.335, Z_{SR,Pt} = 0.628 + j0.667 \]

1 THz Reflectarray: Experiment

fabricated using microfabrication and polymer processing techniques on 3” silicon substrates

Change slab height to adjust reflection phase

\[ \varepsilon_r = 2.78, \tan \delta_e = 0.039 \]
Periodicity=1.5mm, Aperture size=30mm

3D-Printed Dielectric RA: Experiment

#1: Minimum phase wrap

#2: Minimum loss

#3: Fresnel zone plate

### TABLE I

**SUMMARY OF D-RA RADIATION PERFORMANCE AT 100 GHz**

<table>
<thead>
<tr>
<th>Design</th>
<th>Directivity</th>
<th>Gain</th>
<th>SLL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26.48 dB</td>
<td>24.69 dB</td>
<td>-20.7 dB</td>
</tr>
<tr>
<td>2</td>
<td>26.34 dB</td>
<td>24.96 dB</td>
<td>-18.2 dB</td>
</tr>
<tr>
<td>3</td>
<td>23.80 dB</td>
<td>23.09 dB</td>
<td>-11.8 dB</td>
</tr>
</tbody>
</table>
3D Reflectarray: Spherical Element

- Concentric sphere element
  - Core made of ordinary dielectric
  - Shell made of plasmonic materials
- Phase change by varying the dielectric constant of the core

3D Reflectarray : TiO$_2$ Dielectric Resonator

- Dielectric resonator as the element
- Phase change by changing the diameter of TiO$_2$

3D Reflectarray : Perforated Holes

- element consists of perforated holes
- Phase change by changing radius of hole

Graphene-based THz Reflectarray (I)

A liquid crystal layer is placed under the dipole element. The reflection phase is reconfigured by varying the dielectric constant of the liquid crystal through a bias voltage.

Wide-angle, broadband, efficient reflection holography by utilizing coupled dipole-patch nanoantenna cells

IR Imaging System Using RA: Element

(a) Unit cell geometry: top view of the patch and dipole nanoantennas unit cells and the phase response they create (left to right 0–300°).

(b) phase response (top) and amplitude response (bottom) of the different antenna elements obtained from numerical simulations for individual elements in an array of identical neighbors.
IR Imaging System Using RA: Experiment
Summary

- Progress on THz reflectarray is reviewed.
  - Planar patch reflectarrays
  - 3D structure reflectarrays
  - Reconfigurable reflectarrays
  - Infrared imaging system using reflectarray

- Challenges for THz reflectarray:
  - Material properties and fabrication facility
  - Antenna measurement, including the feed system
  - Important applications
Thanks!

Questions?