



A Sub-THz FMCW Radar Imager using a Phased-Array-Fed Shaped-Reflector Antenna

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Objective

The objective of this project is to design a sub-THz radar imager. The system uses an FMCW phased-array in combination with a custom reflector surface to steer and control the beam. This combination is fast, mechanically simple, and cheap.

Key Parameters:

Operating Frequency: 200 - 257 GHz

Target Distance: 3 m

Scannable Area: 1 m²

Reflector Area: 20 cm²

Sub-THz Radar Imaging

In comparison to traditional imaging techniques, sub-THz radar imaging offers several major advantages:

- **High resolution:** With wavelengths in the range of millimeters, very fine details can be resolved
 - **Material penetration:** Waves can penetrate many materials and reveal details behind them
 - **Spatial efficiency:** Higher frequency allows for the use of smaller antennas
- These techniques are used in many applications:
- **Security Screening:** Hidden weapon detection and identification
 - **Non-destructive Testing:** Inspection of material defects under paint and other layers
 - **First Response Tools:** Visibility through smoke and fog
 - **Industrial Processes:** Through-wall imaging and ground-penetrating radar

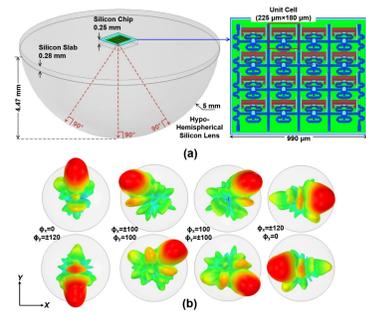
FMCW Phased-Array

The phased-array allows the beam to be electronically steered. A hypo-hemispherical silicon lens is used to maintain normal wave incident at the silicon-air interface.

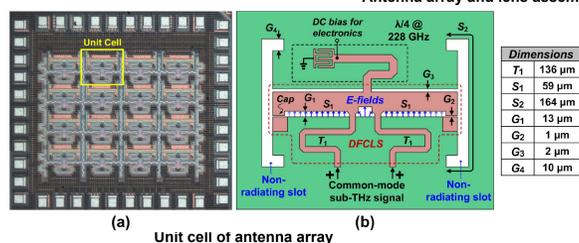
Layout: 4x4 array of 16 Tx / Rx antennas

Fabrication: 55 nm BiCMOS process

Transceiver: Autodyne FMCW



Antenna array and lens assembly



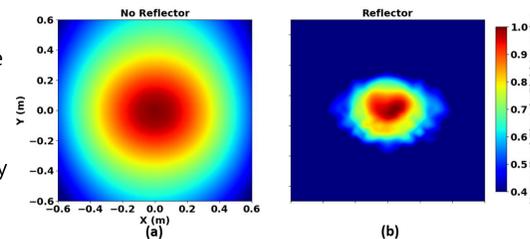
Unit cell of antenna array

Reflector Design

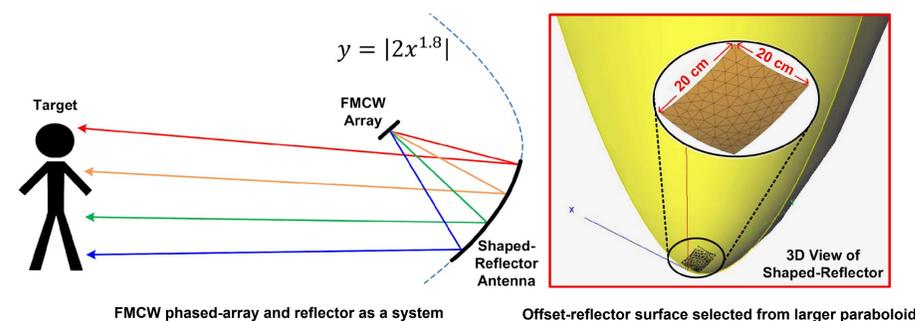
The FMCW phased-array offers a great deal of beam steering control. However, it has some limitations as an imaging system:

- **High beamwidth (20°):** The spot size will be very large at the target. For example, at a distance of 3 meters the spot will be almost 1 m².
- **Low resolution:** The phased-array by itself can only be used to resolve details of about 50 cm in size.

Because of these limitations, the array by itself will not work as an imaging system. A shaped-reflector is needed to collimate and redirect the beam.



Beam spot size without and with a secondary reflector

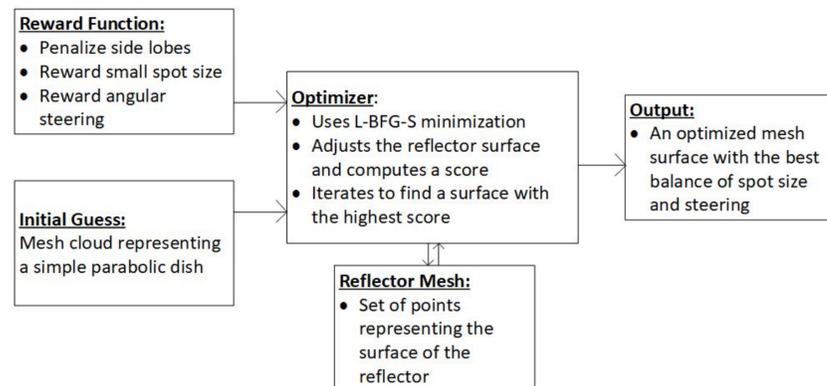


FMCW phased-array and reflector as a system

Offset-reflector surface selected from larger paraboloid

Numerical Optimization of Reflector

A complex reflector surface is needed to collimate and re-direct the beam from the phased-array while still allowing steering control in the target plane. Using numerical optimization, a reflector design is generated which offers a good trade-off between spot size and steering range.



Direct Imaging

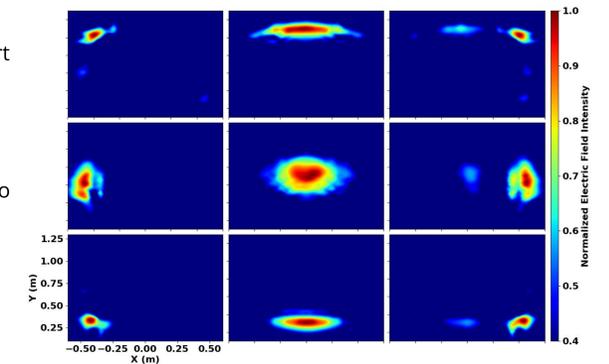
Together, the phased-array and shaped reflector system support a highly steerable beam with a tight spot size at a distance of 3 meters.

Beam characteristics:

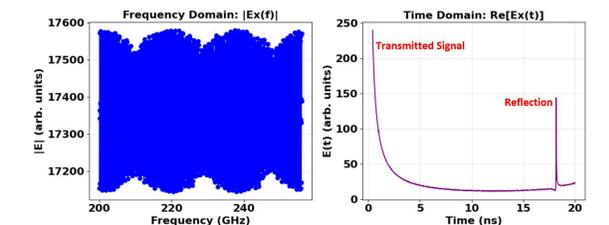
- **Steering range in X:** -0.5 m to +0.5 m
- **Steering range in Y:** +0.3 m to +1.2 m
- **Spot size:** Between 0.05 and 0.15 m

Single Measurement:

- For one beam steering angle, a chirp is transmitted from 200 to 257 GHz while the response is recorded
- Using an IFFT, the frequency domain data is transformed into the time domain
- Any reflections due to a target are clearly identifiable



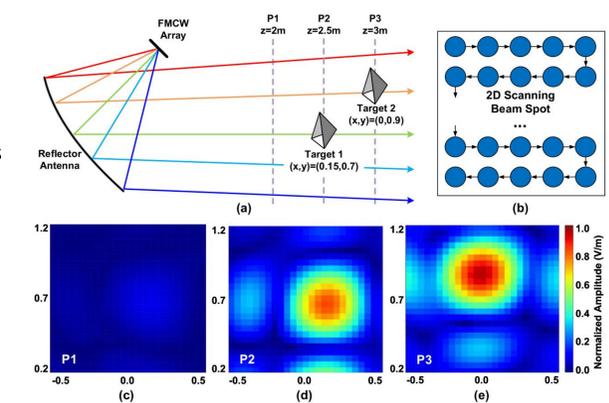
Beam steering in the target plane



Frequency and time domain signal of a chirp for one steering angle and 3 m target

Image Reconstruction:

- The beam is steered across the entire target plane
- At each position, the same chirp and time gating process is applied
- The results are compiled as a set of images
- Each image corresponds to what the system sees at a particular distance from the reflector



Direct imaging process and results for the pictured targets

Future Work, References, and Acknowledgments

SAR image synthesis techniques will leverage the spatially diverse aperture formed with the reflector surface and allow for much higher resolution image reconstruction.

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