Virtual Research Presentation Conference

Enhanced Broadband Multi-beam Luneburg-like Metamaterial Lens Antenna

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Program: SURP

Presentation RPC-152

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Tutorial Introduction

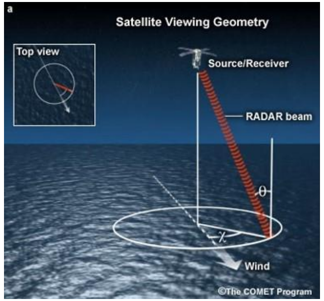
Abstract: The objective of this research is to develop novel inhomogeneous lens antennas for NASA next-generation spaceborne wind scatterometer weather radar satellites that will be integrated with JPL's ongoing and future missions. The proposed lens will create the desired spinning spot beam all electronically while avoiding moving parts and will replace the existing rotating parabolic reflector which is prone to failure through mechanical wear. UCLA has completed the development of a mature and powerful software package for the design of shaped, inhomogeneous engineered material lenses. This software is based on a novel linkage between Curved-Ray Geometrical Optics, a numerical method for wave propagation in inhomogeneous media, and Particle Swarm Optimization, a global stochastic nature-inspired optimization technique. Extensive efforts to validate the software have shown that the software is accurate and hence capable of developing next-generation lenses. This project leverages UCLA's recent development of the revolutionary new lens design synthesis package to develop antenna technology that directly addresses the latest Earth Science thrust for technology developments that enable new low-cost mission concepts. This project concentrates on new designs that are fabricated using the 3D-printing technology as well as new thin and lightweight lenses that are fabricated using metamaterial-based fabrication techniques.

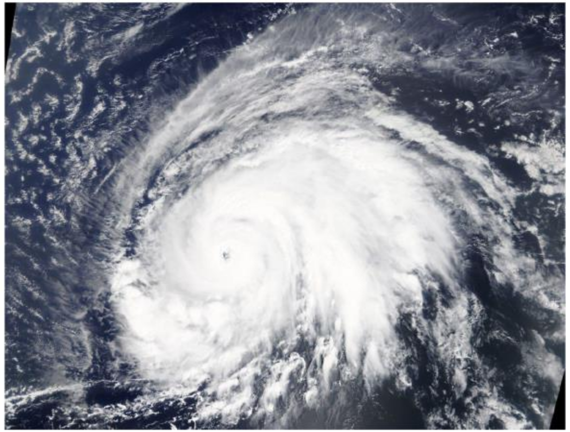
Problem Description

Why is Wind Scatterometry Important?

How Climate Change May Be Impacting Storms Over Earth's Tropical Oceans

By Alan Buis,
NASA's Jet Propulsion Laboratory





Hurricane Lorenzo moving through the eastern North Atlantic Ocean, as seen from NASA's Terra satellite. Credit: NASA Worldview, Earth Observing System Data and Information System (EOSDIS).

Mission*	Period of Service	Antennas	End Status
NSCAT	1996 - 1997	Six stick-like antennas	Solar Panel Failure
QuikSCAT	1999 - 2009	Rotating reflector	Mechanical failure
ADEOS II	2002 - 2003	Rotating reflector	Solar panel failure
RapidScat	2014 - 2016	Rotating reflector	Space station Power failure

***No future NASA scatterometer mission has been planned. This is a good time for the development of next-generation scatterometer technologies.**

NASA Scatterometers

Wind Causes Surface Waves to Pick Up

High winds and rough sea: stronger signal returned

Calm Flat Ocean Returns No Reflection

The wind velocity is measured by emitting a pulse of energy towards the ocean and measuring the echo.

NASA JPL 2018 Technology Highlights

"New Earth-observing satellites will require multi-band, electronically scanned antennas to replace mechanically steered beams that are prone to wear and have limited lifespan."

Methodology

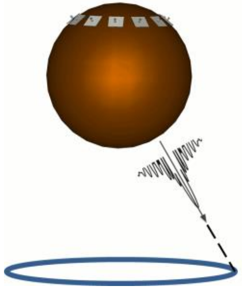
Conical Electronic Scanning Lens Development

Current Solution:
Parabolic Reflector mounted on a mechanical motor.

Moving parts.

Problem:
Mechanical motor is single point of failure.

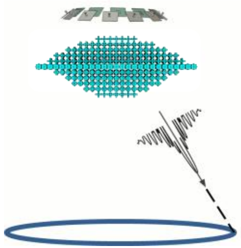
Alternate Solution:
Spherical Luneburg Lens with ring of feeds.



No moving parts.

Problem:
Spherical Lens weight and size are impractical.

3D Printed Lens
Low cost lens technology with ring of feeds.



No moving parts.

Solution 1:
Reduced mass
High potential for 3D print advances

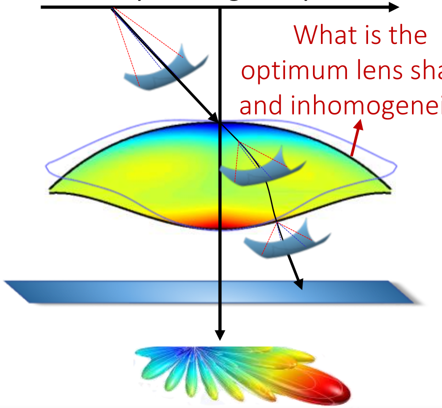
Multi-layer Membrane
Flat-layered, potentially collapsible meta-lens with ring of feeds.

No moving parts.

Solution 2:
Low aerial mass density. Low TRL mechanical design

Lens Synthesis Algorithm

Geometrical Optics (GO)
Ray Tracing Analysis

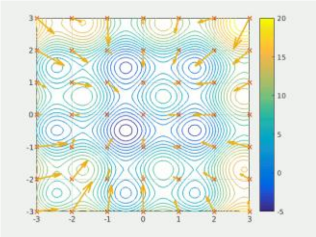


What is the optimum lens shape and inhomogeneity?

Fitness

Lens shape and inhomogeneity

Particle Swarm Optimization
Nature Inspired Optimization

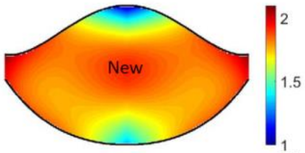


Synthesis Loop

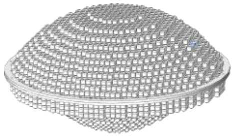
Best Lens Design

Results

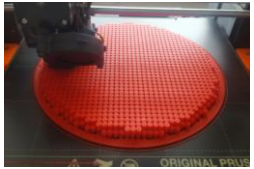
3D-Printed Lens Off Axis Results:



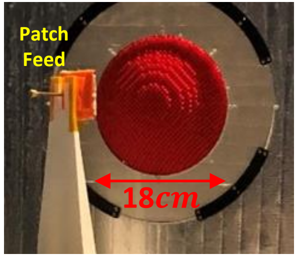
UCLA PSO-GO
Optimized Lens



JPL 3D Print
CAD Model

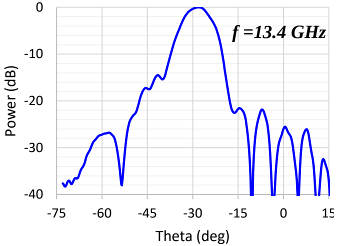


JPL 3D Print

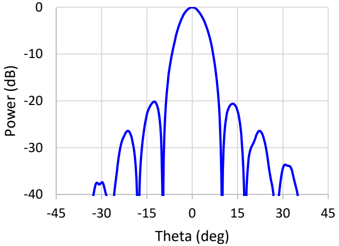


JPL Mesa Range Test

Scanning Lens Azimuth



Scanning Lens Elevation

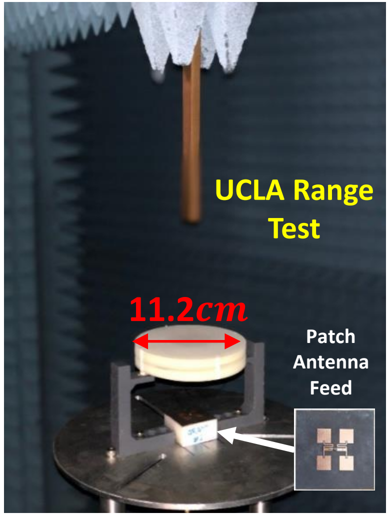


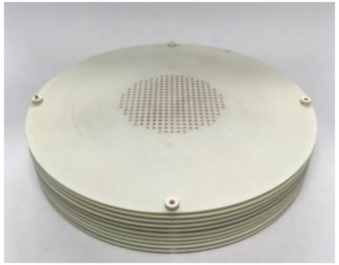
Measured Antenna Patterns

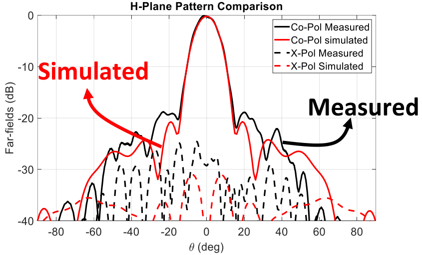
Measurements successfully demonstrate conical scanning lens capability

Next Steps: Optimize conical scanning lens for thin, low mass Titanium Oxide artificial dielectric 3D print material.

Meta-Flat-Lens On Axis Results:







Lens layers were printed on commercially available Rogers dielectric substrates.

Next Steps: a) Tensioned membrane mechanical design b) optimize for off axis performance.

Publications and References

Journal:

A. Papathanasopoulos, Y. Rahmat-Samii, N. C. Garcia and J. D. Chisum, "A Novel Collapsible Flat-Layered Metamaterial Gradient-Refractive-Index Lens Antenna," in *IEEE Transactions on Antennas and Propagation*, vol. 68, no. 3, pp. 1312-1321, March 2020

J. Budhu and Y. Rahmat-Samii, "3D-Printed Inhomogeneous Dielectric Lens Antenna Diagnostics: A Tool for Assessing Lenses Misprinted Due to Fabrication Tolerances," in *IEEE Antennas and Propagation Magazine*, vol. 62, no. 4, pp. 49-61, Aug. 2020

J. Budhu and Y. Rahmat-Samii, "A Novel and Systematic Approach to Inhomogeneous Dielectric Lens Design Based on Curved Ray Geometrical Optics and Particle Swarm Optimization," in *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 6, pp. 3657-3669, June 2019

J. Budhu, Y. Rahmat-Samii, R. E. Hodges, D. C. Hofmann, D. F. Ruffatto and K. C. Carpenter, "Three-Dimensionally Printed, Shaped, Engineered Material Inhomogeneous Lens Antennas for Next-Generation Spaceborne Weather Radar Systems," in *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 11, pp. 2080-2084, Nov. 2018

Conferences:

A. Papathanasopoulos and Y. Rahmat-Samii, Flat Meta-Lens Antenna Synthesis Via Geometrical Optics and Particle Swarm Optimization. 2020 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting.

Y. Rahmat-Samii, J. Budhu, R. E. Hodges, D. C. Hofmann and D. Ruffatto, "A Novel 60-cm Nonsherical 3-D Printed Voxelized Lens Antenna: Design, Fabrication and Measurement," *2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting*, Atlanta, GA, USA, 2019, pp. 1699-1700

J. Budhu and Y. Rahmat-Samii, "A Novel Diagnostics Method for Determining the Unknown Permittivity Profile of 3D Printed Lenses," *2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting*, Atlanta, GA, USA, 2019, pp. 87-88

A. Papathanasopoulos and Y. Rahmat-Samii, "A Novel Deployable Compact Lens Antenna Based on Gradient-Index Metamaterials," *2019 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting*, Atlanta, GA, USA, 2019, pp. 625-626

A. Papathanasopoulos and Y. Rahmat-Samii, "A Systematic Approach for the design of Metallic Delay Lenses," *2019 United States National Committee of URSI National Radio Science Meeting (USNC-URSI NRSM)*, Boulder, CO, USA, 2019, pp. 1-2

J. Budhu and Y. Rahmat-Samii, "Shaped-profiled and material-engineered inhomogeneous lens antennas: GO curved ray tracing and aperture fields," *2018 United States National Committee of URSI National Radio Science Meeting (USNC-URSI NRSM)*, Boulder, CO, 2018

J. Budhu and Y. Rahmat-Samii, "Synthesis of 3D-printed dielectric lens antennas via optimization of Geometrical Optics Ray Tracing," *2017 USNC-URSI Radio Science Meeting (Joint with AP-S Symposium)*, San Diego, CA, 2017, pp. 9-10

J. Budhu and Y. Rahmat-Samii, "Synthesizing thin dielectric lenses for conical scanning beams: A hybrid numerical algorithm," *2017 United States National Committee of URSI National Radio Science Meeting (USNC-URSI NRSM)*, Boulder, CO, 2017, pp. 1-2