

Defect Detection in ISC Cylinder using Spoof Plasmon Polaritons

William (Cy) Wilson, Eric Tucker

**Langley Research Center
Hampton, VA, USA**

TechConnect World

June 17-19, 2024, National Harbor, MD



Outline

- **Motivation**
- **Spoof Plasmon Polaritons Background**
- **Test Setup**
- **Test Parameters**
- **Raw Response**
- **Post Processing Method**
- **Results**
- **Conclusions**
- **Funding Opportunities**



Motivation



Need for Improved Aviation Safety

Can we detect changes in the structure before accidents happens?



Forward fuselage, Aloha Airlines (1 person killed)



Vertical Tail, American Airlines Flt 587 (265 killed)

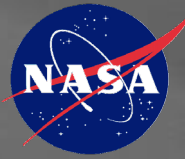


U.S. Forest Service C-130, near Walker, CA (3 killed)

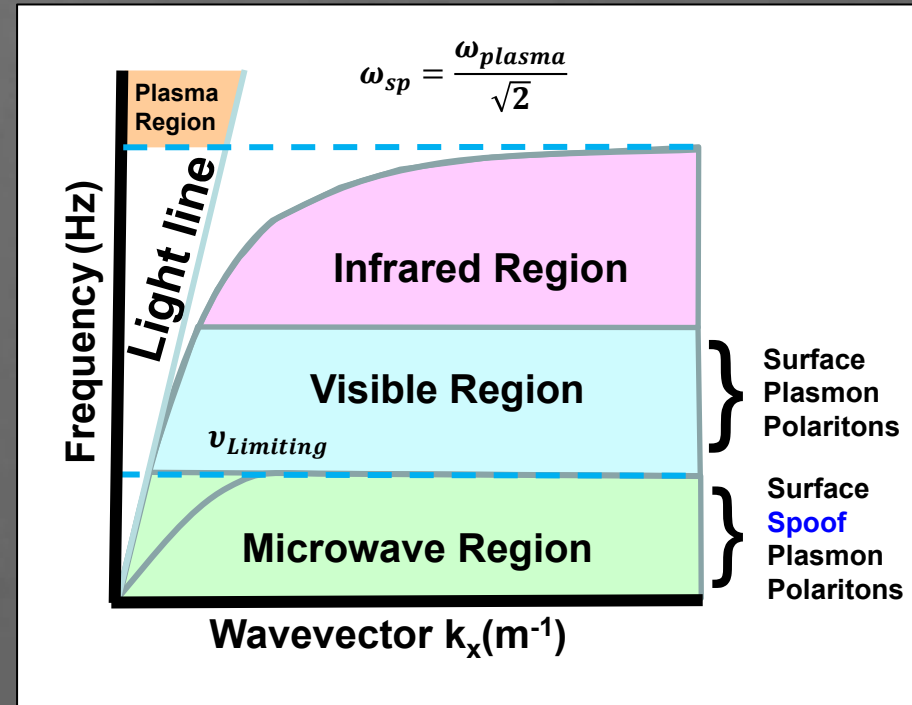


Can we insure the structural integrity of new autonomous aircraft?

Spoof Plasmon Background



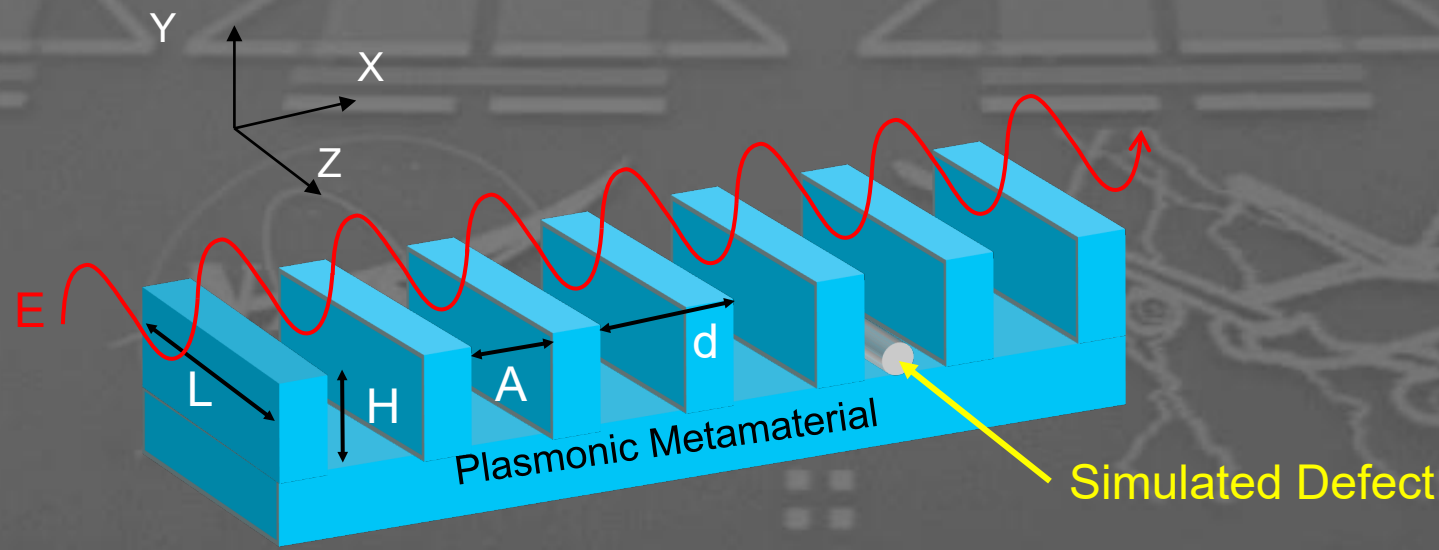
- Spoof plasmon polaritons are electromagnetic surface waves that exhibit a non-radiative mode where the energy of the mode is concentrated at the interface.
- The waves decay exponentially from the interface between a dielectric and a metal.
- The spoof plasmon polaritons act as a series chain of microwave cavity resonators.
- “Any array of cavities with subwavelength geometry that individually support a resonance, such as a waveguide mode, can be used as a metamaterial structure that will support a surface wave.” [1]



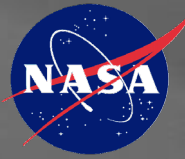
Spoof Plasmon Background



- Microwave resonators can be described using basic electrical properties such as the electrical impedance.
- Anything that is placed within the grooves of the plasmon grating will affect the impedance due either to the change of the cavity shape and/or a change of the dielectric coefficient.
- Our hypothesis is that any material added to the ideal grating will cause changes in the impedance, and that these changes can be used to indicate defects in manufacturing if the changes are caused by the addition of unintentional metal during manufacturing.



End Application - Defect Free Faster Fuselage Manufacturing



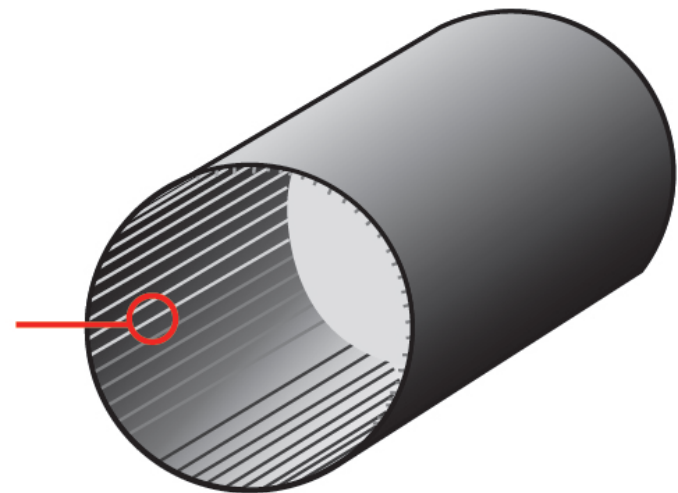
Advanced Air Transport Technology (AATT) project is exploring the use of metallic integrally stiffened cylinder (ISC)

- Significant reduction in cost, weight, and manufacturing time.
- Reduction in part count and eliminating lap joints and rivets (fasteners).



Integrally Stiffened Cylinder Process
- Single-Piece, Net Shape Construction -

Stiffeners





Spoof Plasmons on Integrally Stiffened Cylinder (ISC)



The stiffeners are 12.7 mm high and are spaced every 58.42 mm.

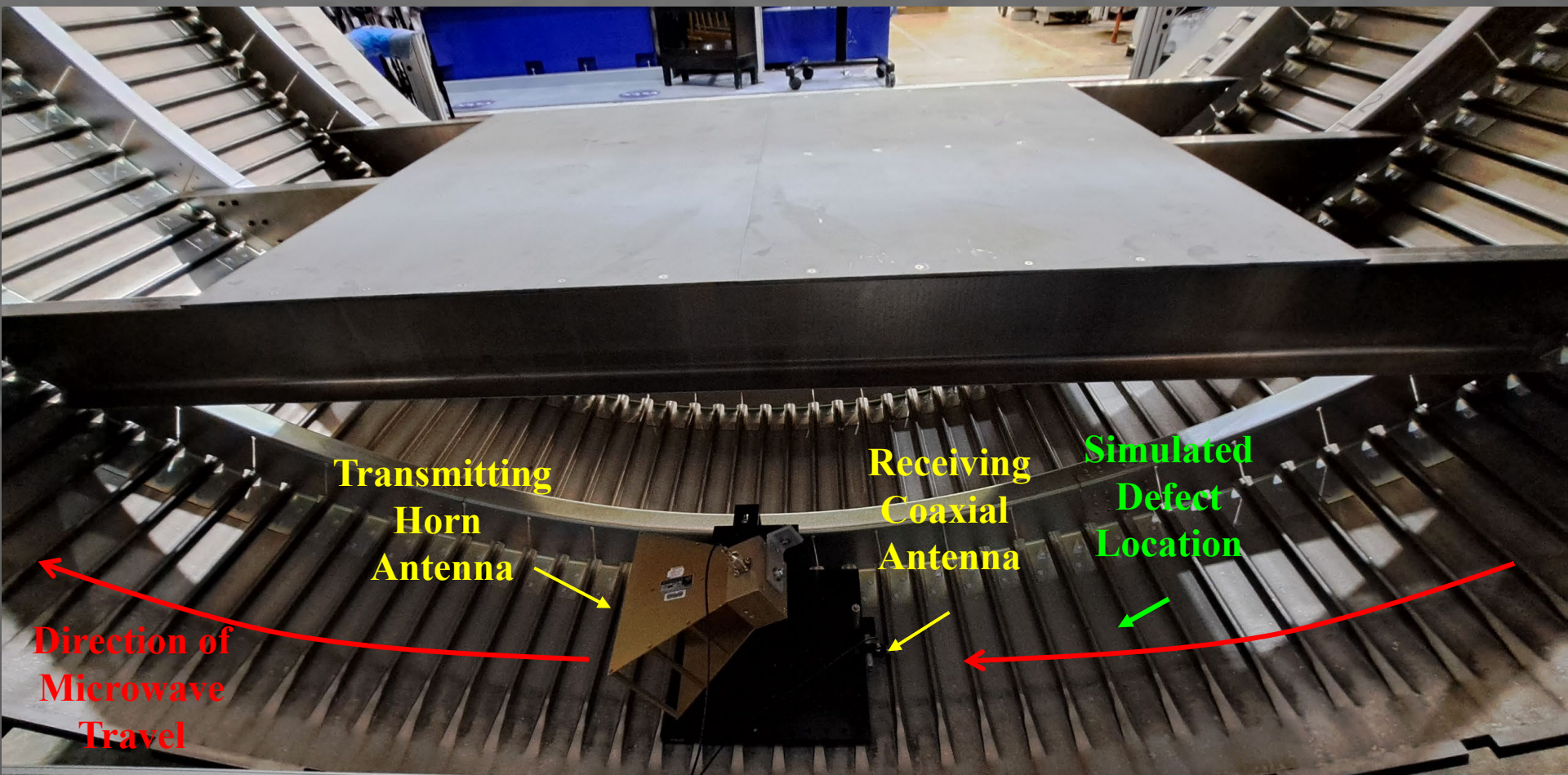
The cylinder diameter is 3.048m (10ft).

The cylinder length is 1.542m (5ft).



Test Setup

- The coaxial antenna (31 mm long) is aligned vertically and is located in the center between the stiffeners.
- The simulated defects are placed 292.1 mm from the coaxial antenna.
- The horn antenna is located 432 mm (at 45°) from the coaxial antenna.

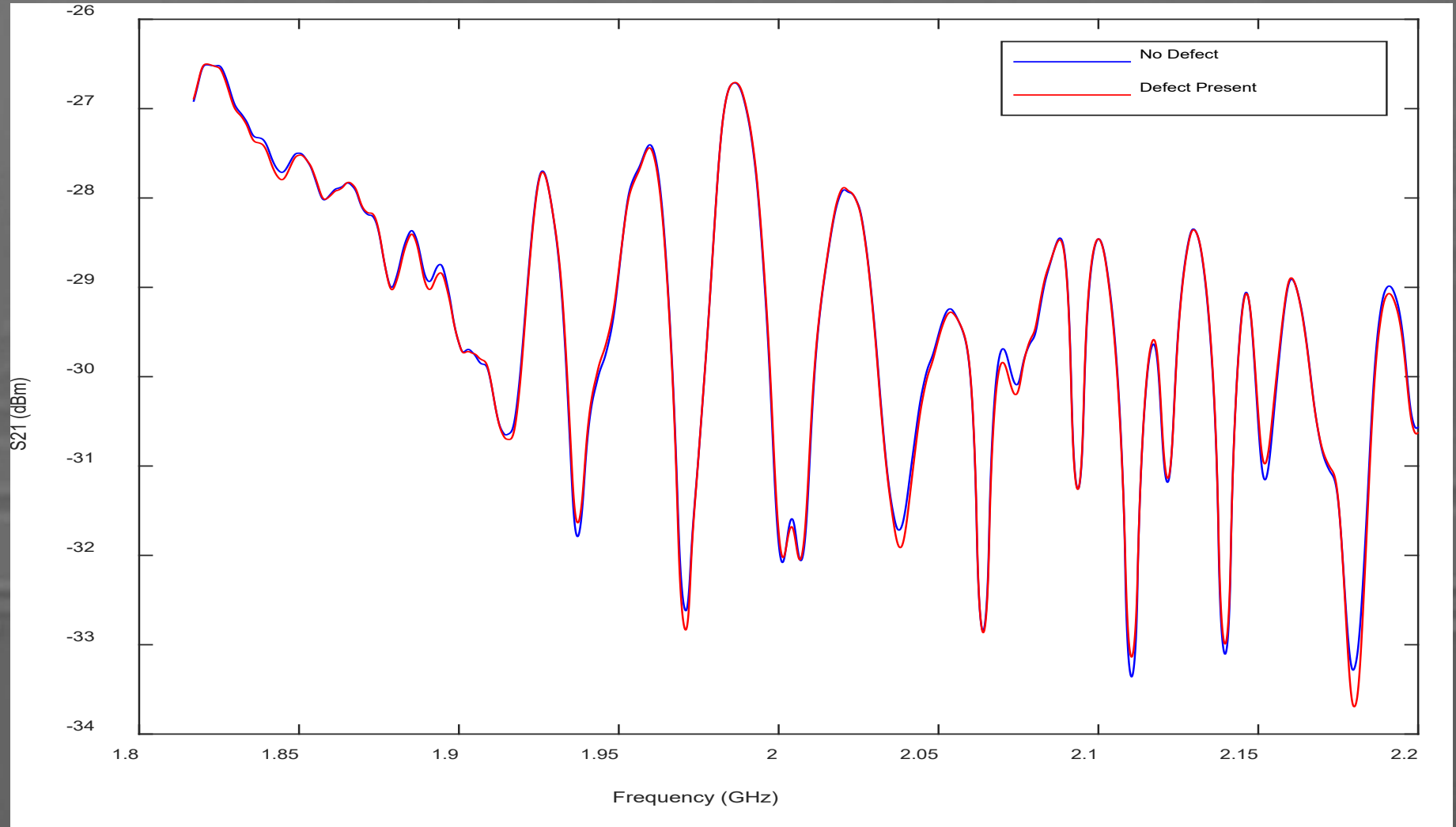
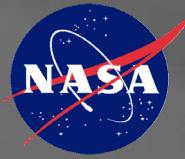




Test Parameters

- The network analyzer raw data consists of 10001 points of magnitude and phase angle for the S21 scatter parameter across 1.817 GHz to 2.2 GHz.
- Each test run consists of 3 data sets.
- Each run starts and ends with a dataset without a simulated defect present while the second data set consists of a simulated defect placed 292.1 mm from the coaxial in between stiffener elements.

Raw S_{11} Response



The electromagnetic response (log magnitude S_{21} response) of the ISC with and without a simulated defect. S_{21} is the transmission S-parameter.



Post Processing Method

Calculate the Impedance from S_{21}

$$Z = Z_0 \frac{2(1 - S_{21})}{(S_{21})}$$

Calculate the Delta Impedance

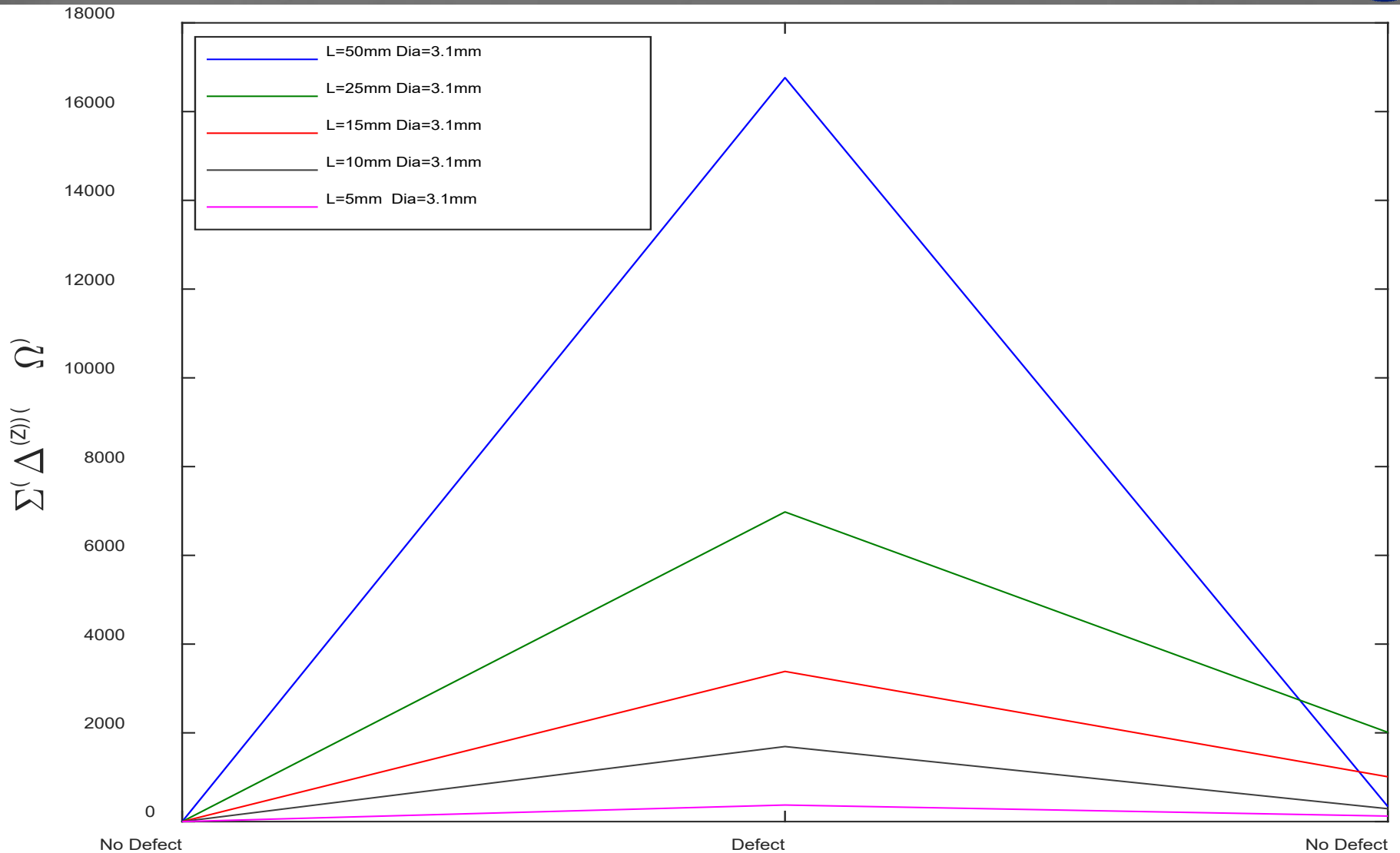
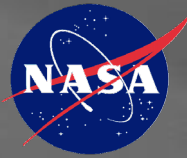
$$\Delta Z = Z_i - Z_{nd_i}$$

Calculate the Sum of the Delta Impedance

$$SZ = \sum_{i=1}^{10001} (\Delta Z_i)$$



Results



The sum of the delta impedance results with and without simulated defects.

Project Goals



- One of the main goals of this work was to develop the initial parameters for use on later testing:
 - Interrogation frequency $\sim 12\text{GHz}$
 - The bandwidth $\sim 100\text{MHz}$
 - Polarization direction, across strap 25.4mm width (horizontal when strap is hanging)
 - Post processing method Spectral Centroid
 - Fitting Parameters





Conclusions

- Spoof plasmon polaritons for defect detection have been demonstrated using simulated defects (wires placed in a grooved metal surface).
- The sum of the change in the impedance across all frequencies has been utilized as the indication for detecting the different sizes of simulated inclusions.
- This technique was used to detect a wire as small as 10 mm in length and 3.1 mm in diameter.
- Future work will investigate voids and cracks to determine if other defect types can be detected, as well as investigating limitations and optimization methods to find the smallest defects can be detected.



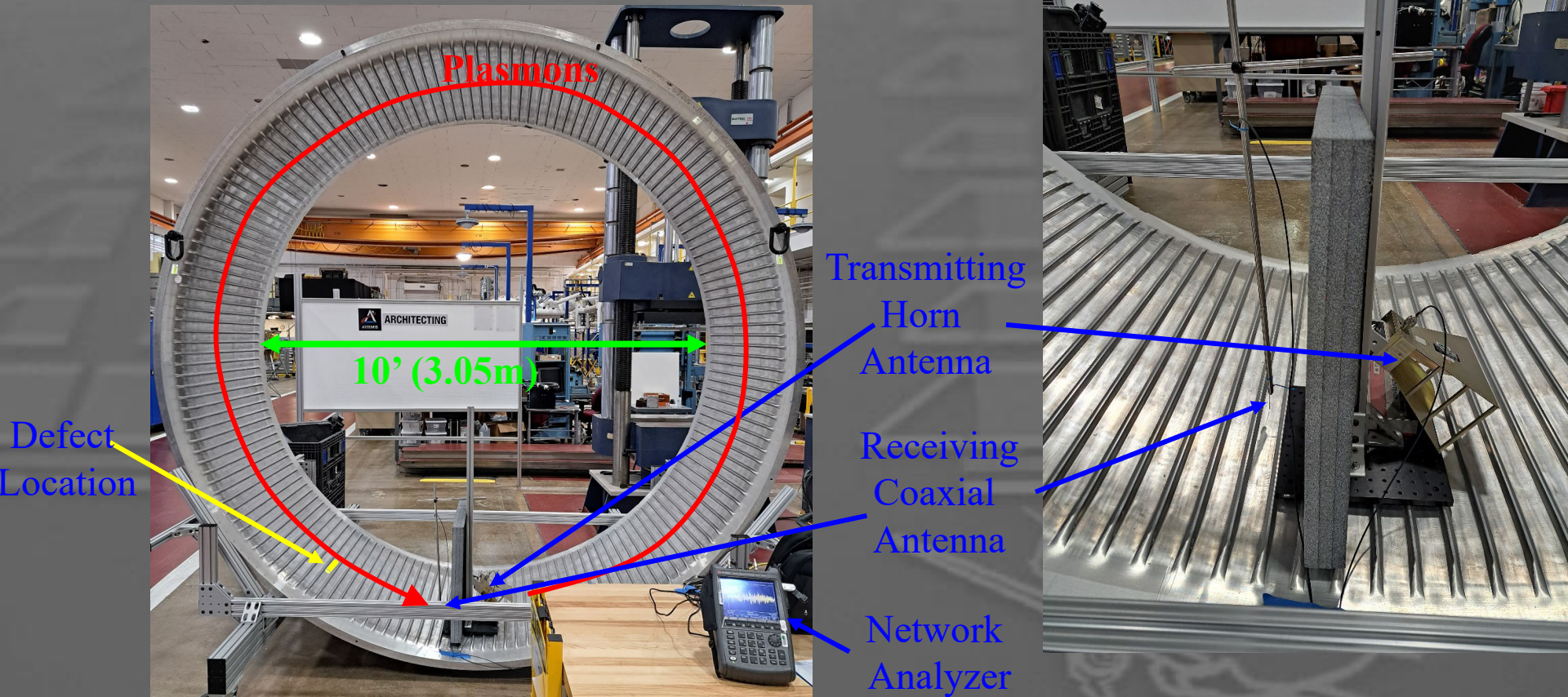
Funding/Partnership Opportunities

- **NASA Research Opportunities (NRAs)
Grants & Contracts**
 - <http://nspires.nasaprs.com/>
- **Small Business Innovation Research (SBIR)**
 - <http://sbir.gsfc.nasa.gov/>
 - Z4.05 Nondestructive Evaluation (NDE) Sensors, Modeling, and Analysis
- **Space Act Agreements (SAA)**
 - Partnerships with and without exchange of funds

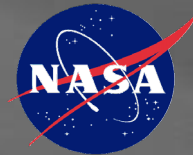
Auxiliary Slides



Spoof Plasmons on Integrally Stiffened Cylinder (ISC)



Periodic Structures Supporting Spoof Plasmons



- Surface waves can be supported on a variety of shapes including slotted structures, wires on cylinders, discs on cylinders and even planar structures.
- Corrugations can be rectangular, triangular, trapezoidal, rounded, etc.

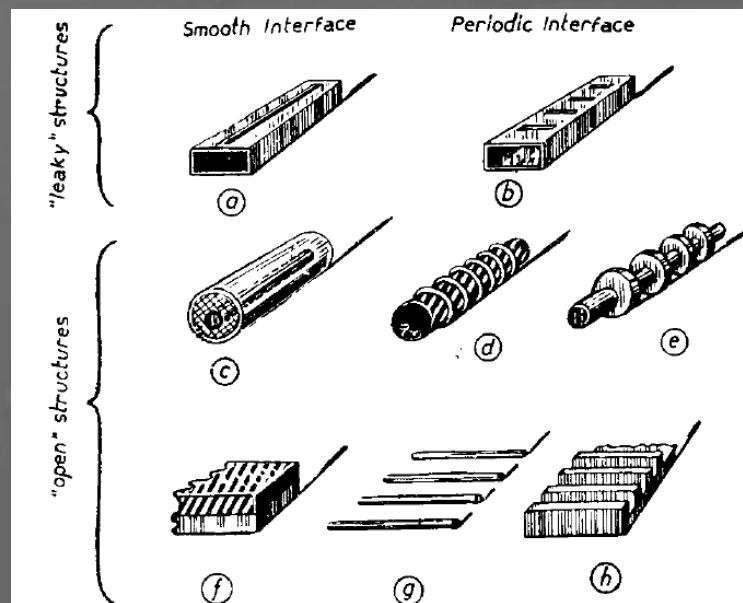
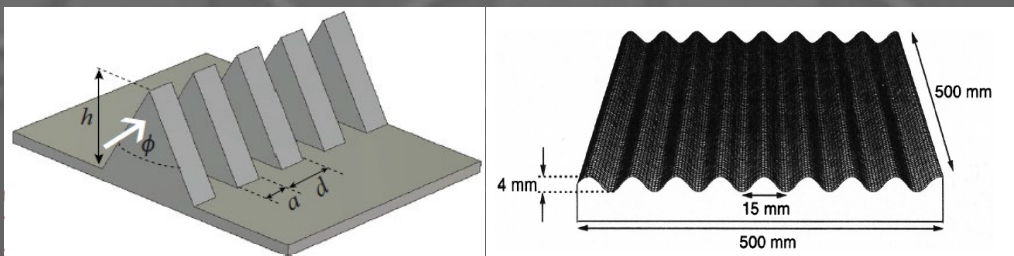


Fig. 3. – Types of surface waves II. Free modes (discrete spectrum; transmission).

a) channel guide; b) slotted guide; c) Goubau wire (dielectric rod); d) helix (rings); e) corrugated rod; f) slab (« ducts »); g) wire grid (Yagi); h) diffraction grating.

F. J. Zucker, "Theory and Applications of Surface Waves," *Il Nuovo Cimento*, vol. 9, no. 3, pp. 450-473, 1952.