MSFC-394

Sources of and Remedies for Removing Unwanted Reflections in Millimeter Wave Images of Complex SOFI-Covered Structures

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ABSTRACT

In the recent years, continuous-wave (CW) near-field and lens-focused millimeter wave imaging systems have been effectively used to demonstrate their utility for producing high-resolution images of metallic structures covered with spay on foam insulation (SOFI) such as the space shuttle external tank. These systems have produced images with a spatial resolution of ~2 mm at a frequency of 150 GHz, and can easily interrogate thin as well as thick SOFI (> 9") enabling detection and evaluation of flaws such as voids, disbands, delaminations and corrosion. These systems are relatively simple, inexpensive, easy-to-use, require little to no signal processing of the raw data, on-site friendly, real-time and small. However, for some specific structures a certain interference pattern may be superimposed on the produced images. Generally, this occurs when the SOFI surface is at a relatively significant angle with respect to the surface of the substrate (or other sub-structures) on which it is sprayed. Consequently, the reflection from the surface of the SOFI and that from the substrate (or sub-structure) coherently combine into an interference pattern as the SOFI surface is scanned. There are methods by which the influence of this unwanted interference can be reduced, such as the incorporation of an incidence angle and the proper use of signal polarization. This paper presents the basics of this problem and describes the use of the methods for reducing this unwanted influence through several specific examples. A discussion on how the use of a swept-frequency or pulsed method may also alleviate this problem is also presented.

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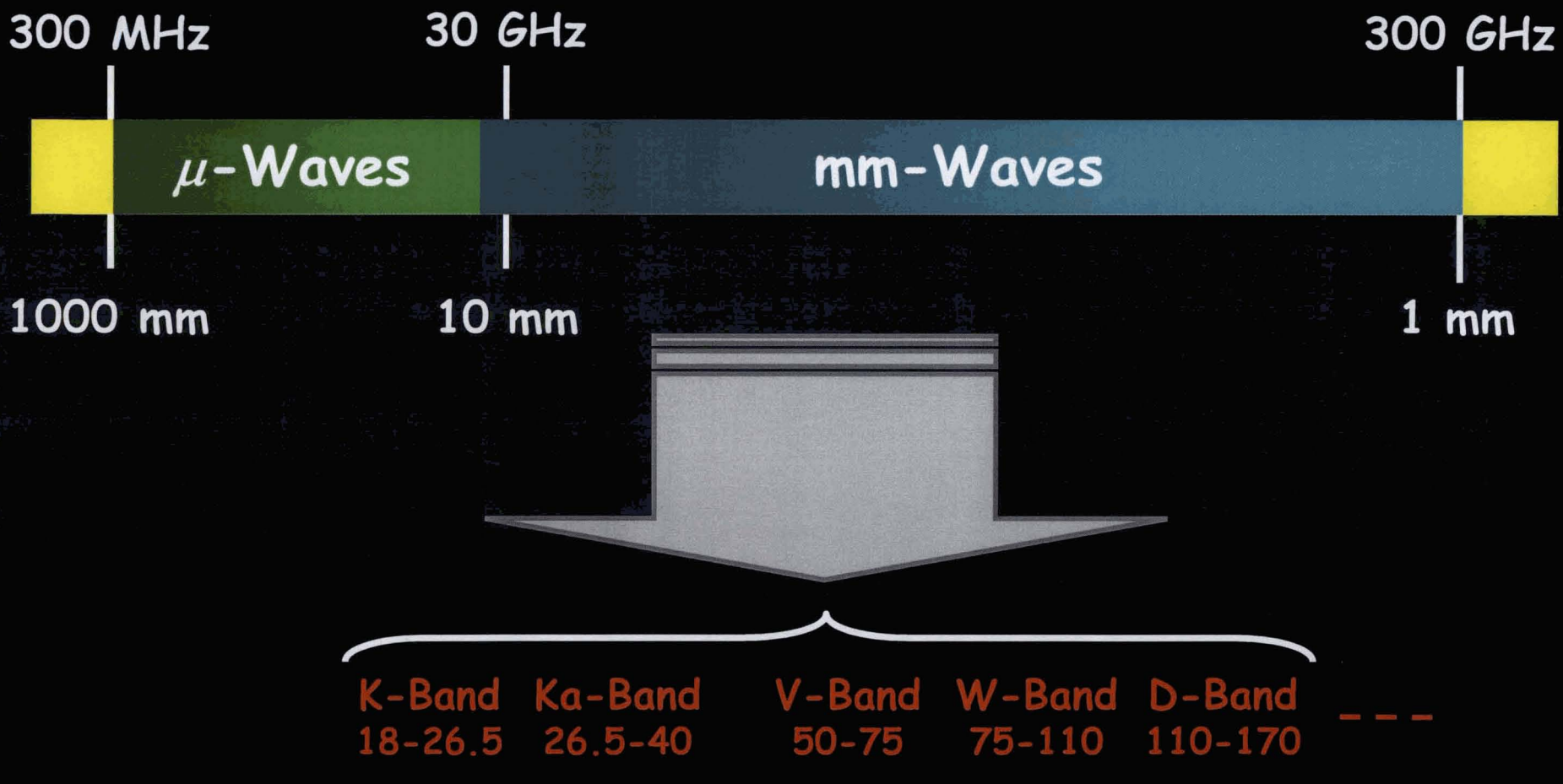
Outline

- Attributes of millimeter (mm) waves
- Brief review of imaging SOFI panels using continuous-wave near-field and lens-focused mm-wave systems
- Sources of unwanted indications in the mm-wave images
- Remedies for reducing these indications
- Discussion and summary

μ-Wave & mm-Wave Spectrum



Attributes

- SOFI is in the family of low permittivity and low loss dielectric materials.
- mm-wave signals readily penetrate into low loss dielectrics.
- These signals are sensitive to dielectric property variations (i.e., boundaries).
- Polarization, frequency, measurement parameter & probe type diversity.
- Obtain images with high spatial resolution.
- No need for pulsed systems.

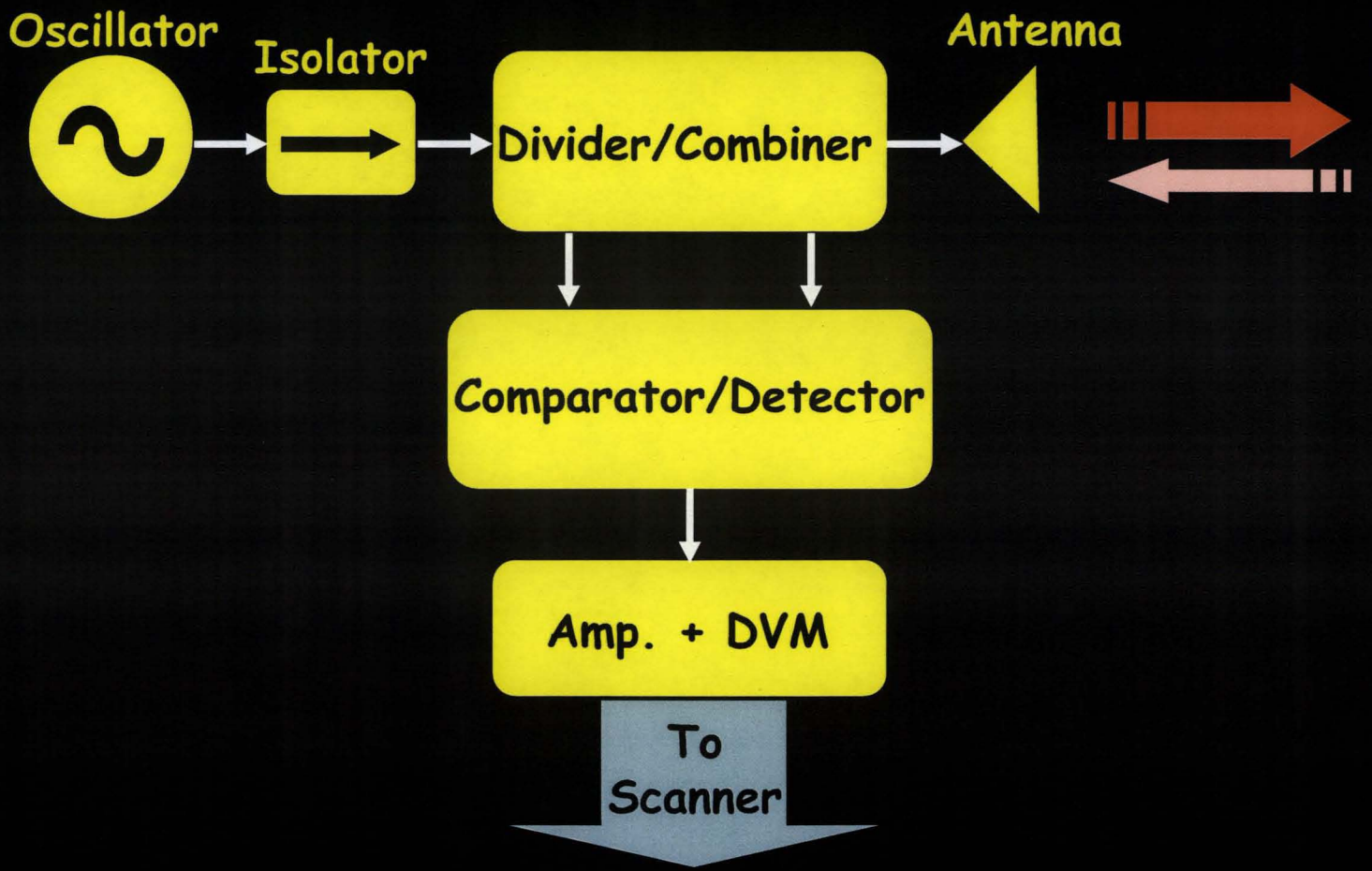
Attributes

- No need for a separate transmitter and receiver (i.e., mono-static systems).
- Defects at different depths are detected within thick SOFI with no double image effect.
- For real focused systems the "focusing" characteristics may be manipulated to accommodate a particular measurement.
- For synthetic aperture focusing methods, the measurements are conducted once and the processing to produce high resolution images takes only a few seconds.

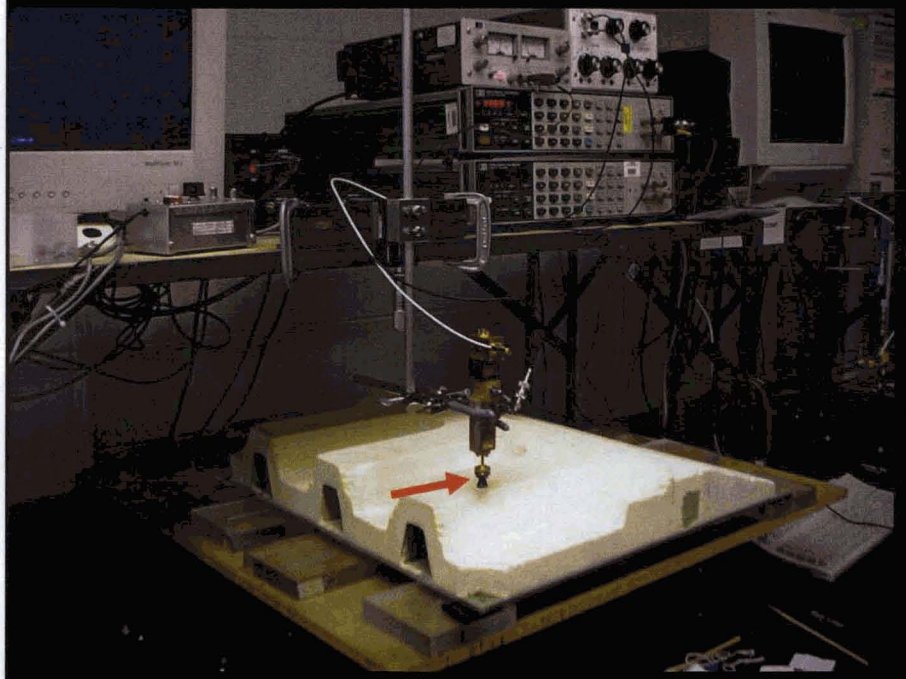
Attributes

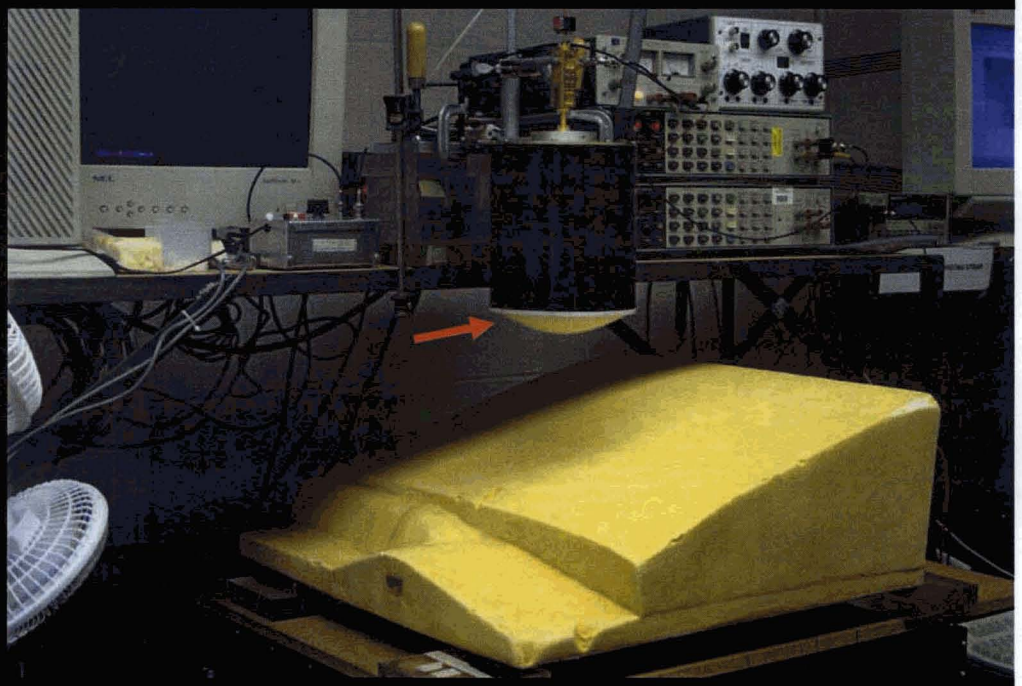
- Measurement systems are:
  - ✓ non-contact
  - ✓ one-sided
  - ✓ mono-static
  - ✓ compact and small
  - ✓ low power
  - ✓ in-field & operator friendly
  - ✓ adaptable to existing scanning platforms
  - ✓ robust & repeatable
- Relatively inexpensive.

System Schematic

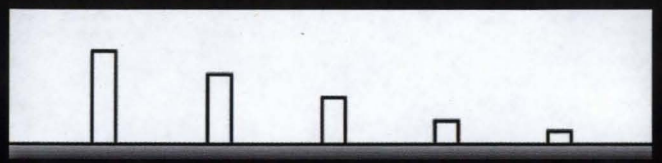


System Hardware





SOFI Slab with Calibrated Holes



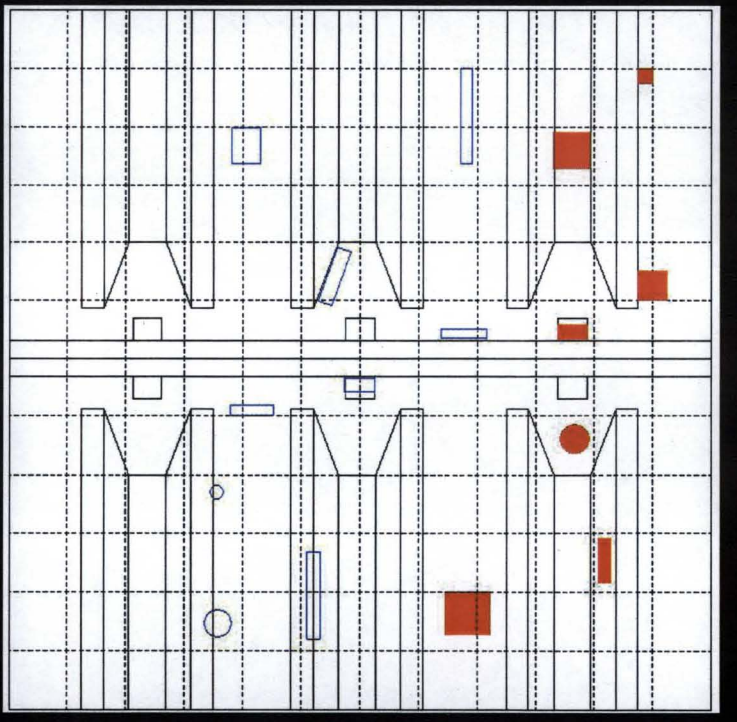
Images with

small horn antenna at 73 GHz

small horn antenna at 100 GHz

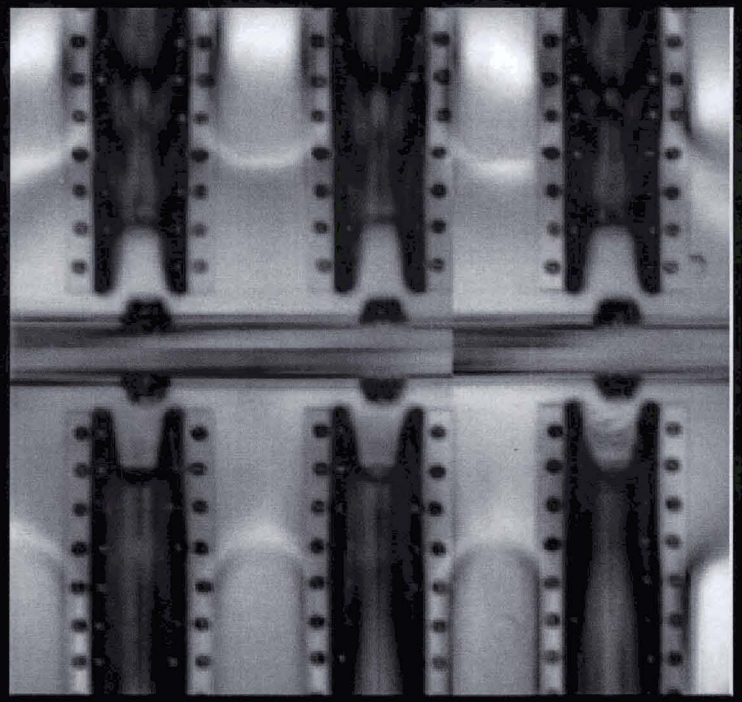
lens antenna at 100 GHz and footprint of 0.5"

POD-50R Panel

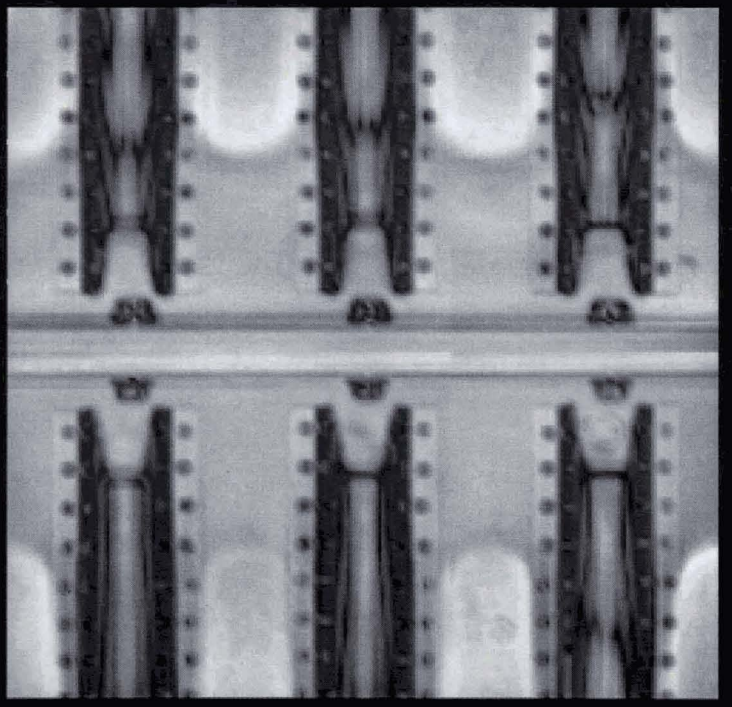


POD-50R Panel – 100 GHz Images

Lens (0.25") & Perpendicular Polarization

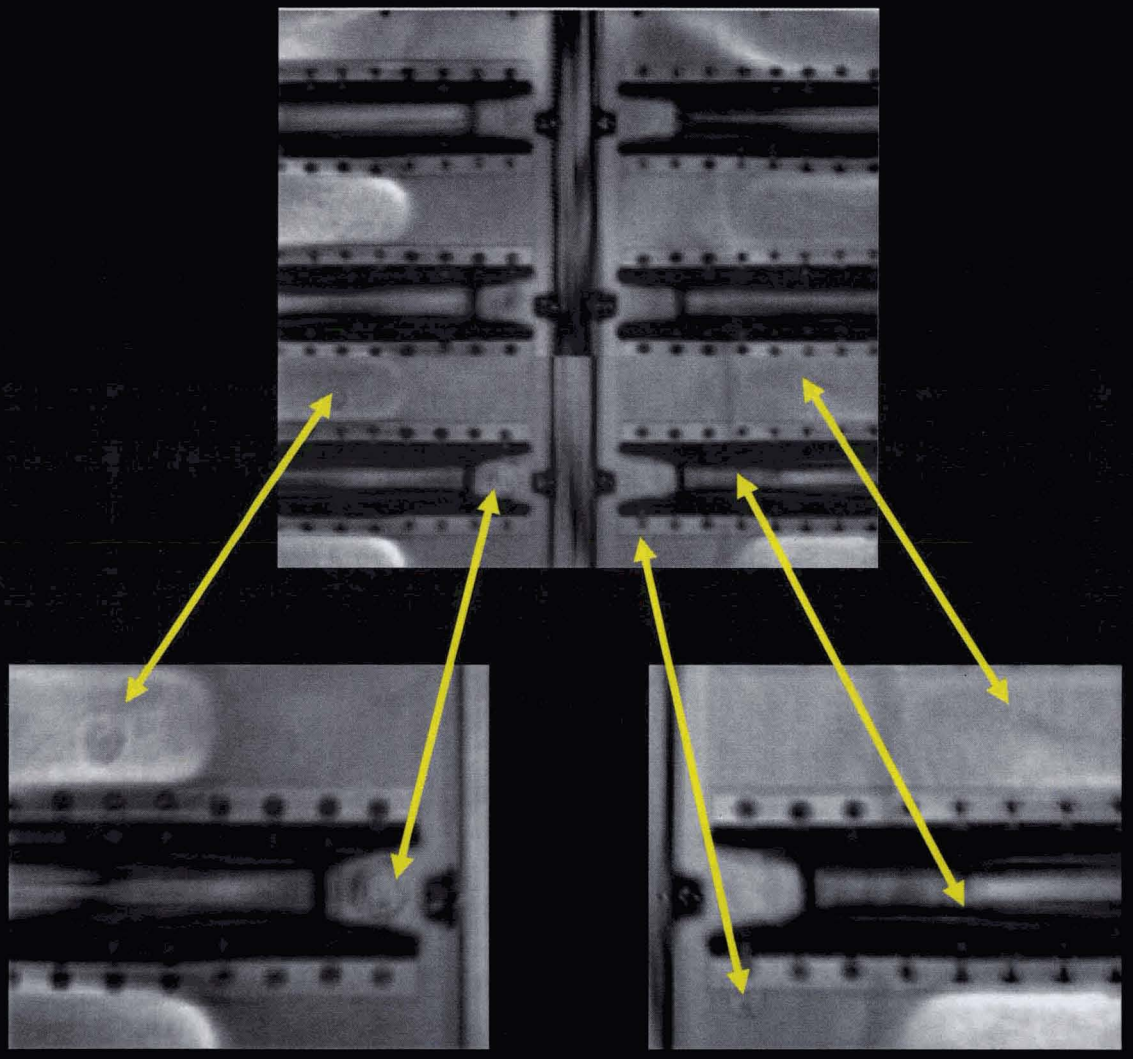


Focused at Substrate

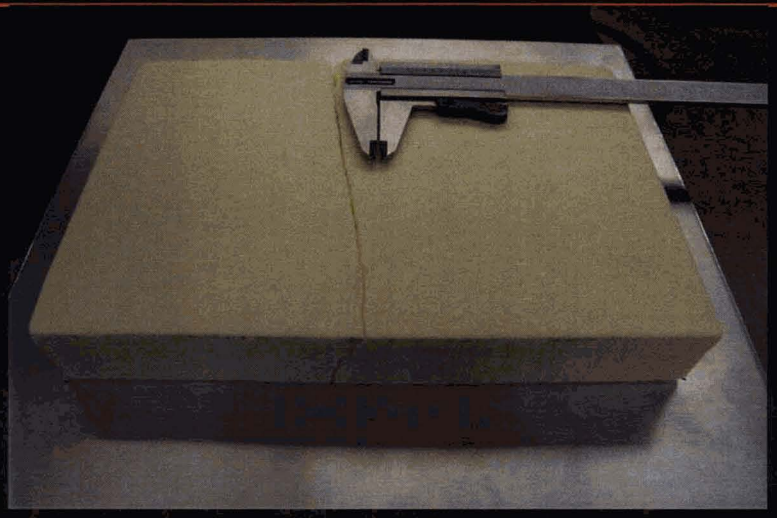


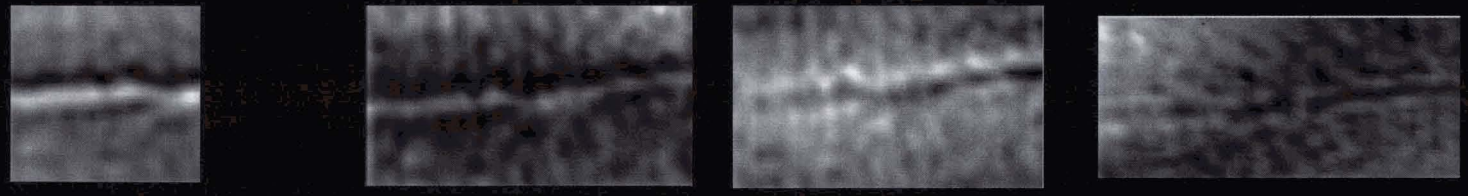
Focused at Flange Top

POD-50R Panel – 100 GHz Lens

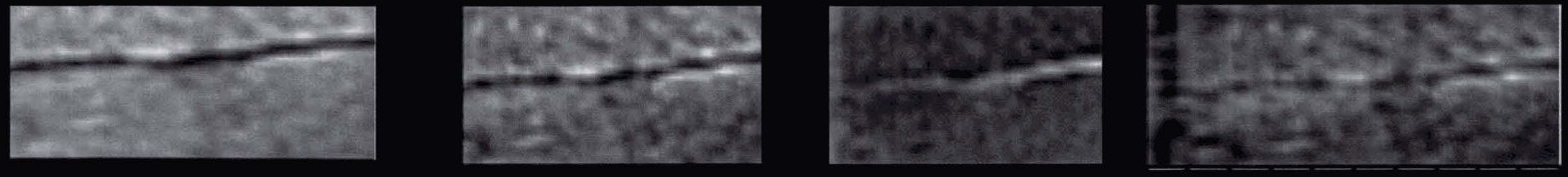


Vertical Crack – 150 GHz Images





Focused at SOFI Surface



Focused at Substrate

1-2 mm ~1 mm ~0-1.5 mm "kissing"

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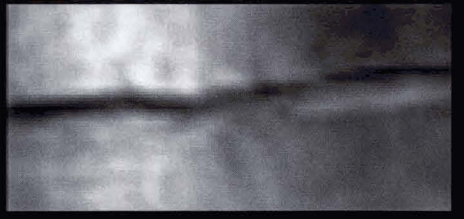
Vertical Crack – 150 GHz Images



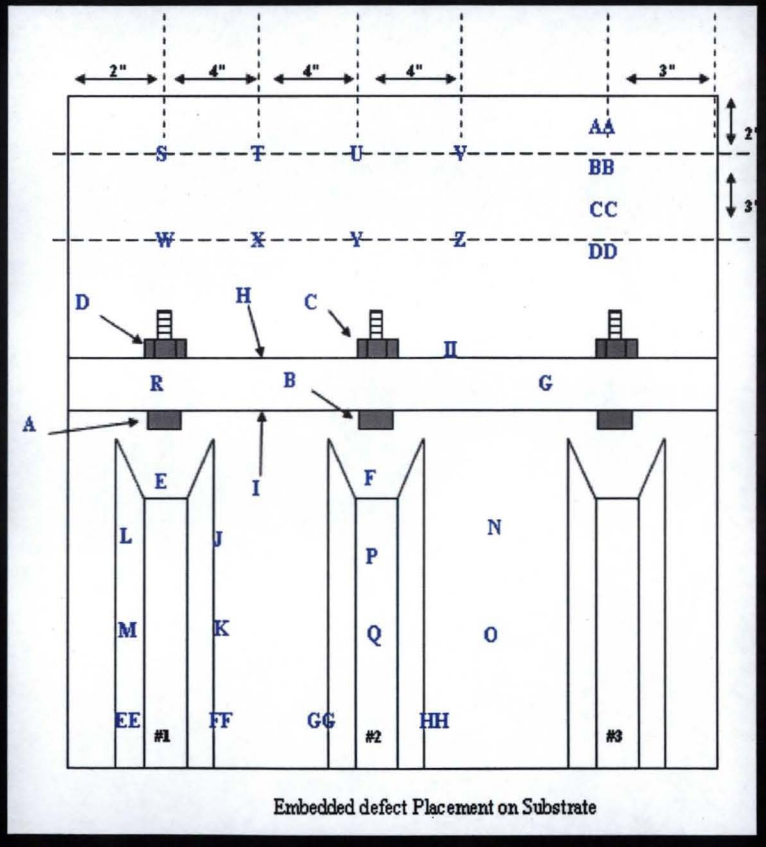
Focused at Substrate

1-1.5 mm

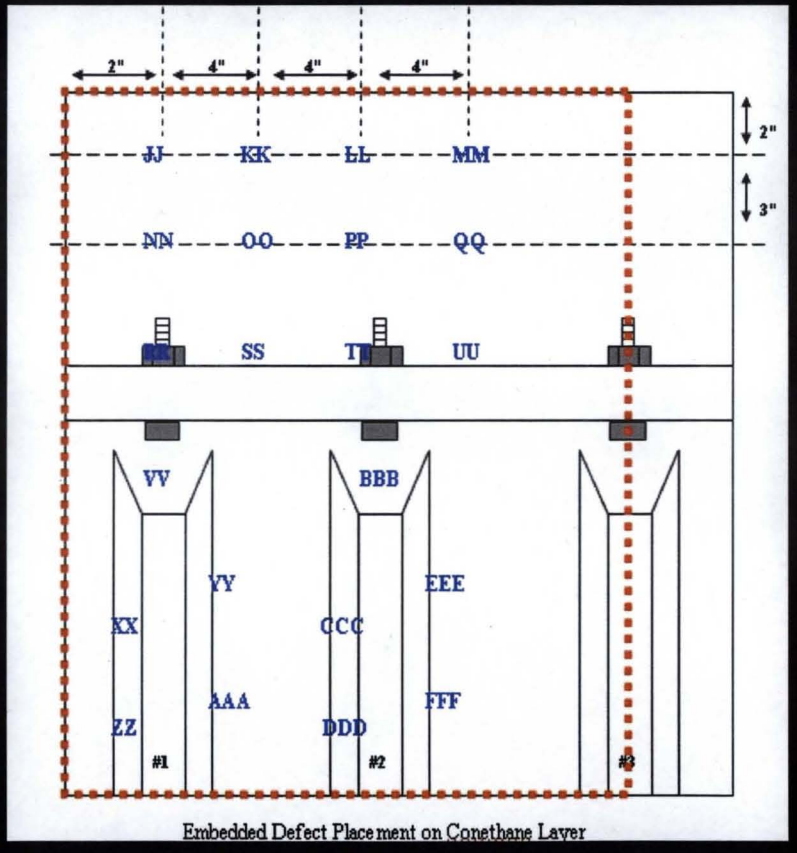
~1 mm

PAL Ramp

Schematic of the panel at two levels with embedded flaws



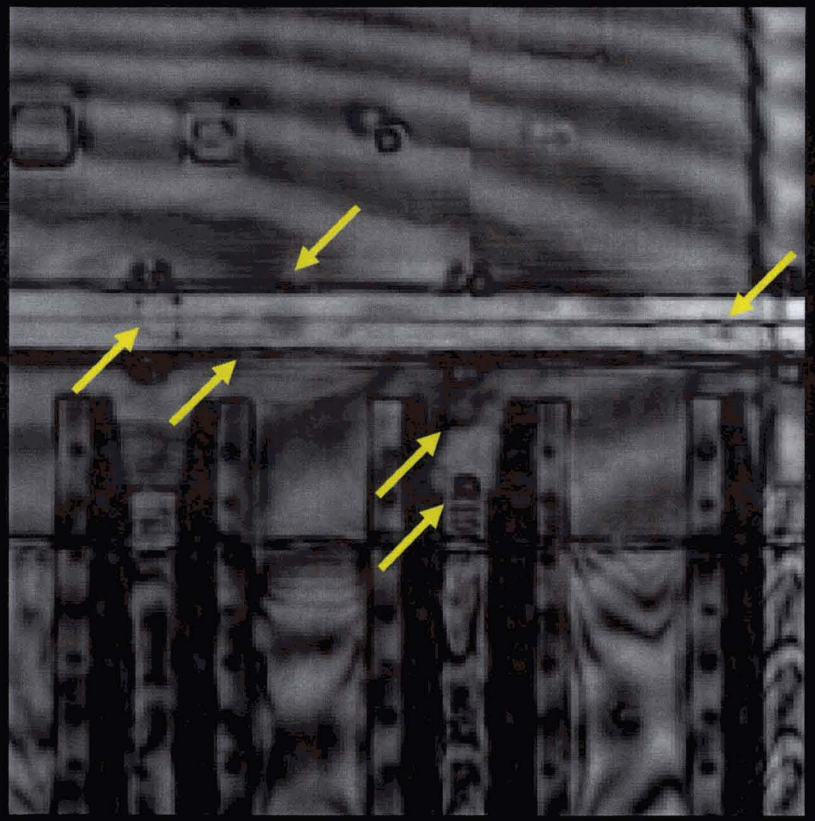
Embedded defect Placement on Substrate



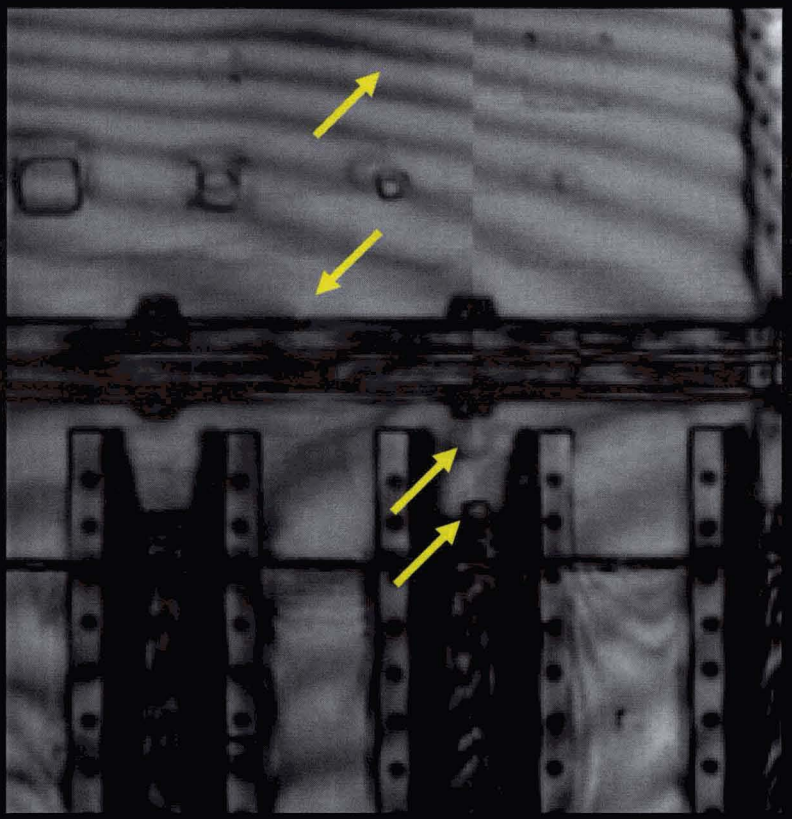
Embedded Defect Placement on Conethane Layer

PAL Ramp – 150 GHz Images

Focused at Conethane



Focused at Substrate

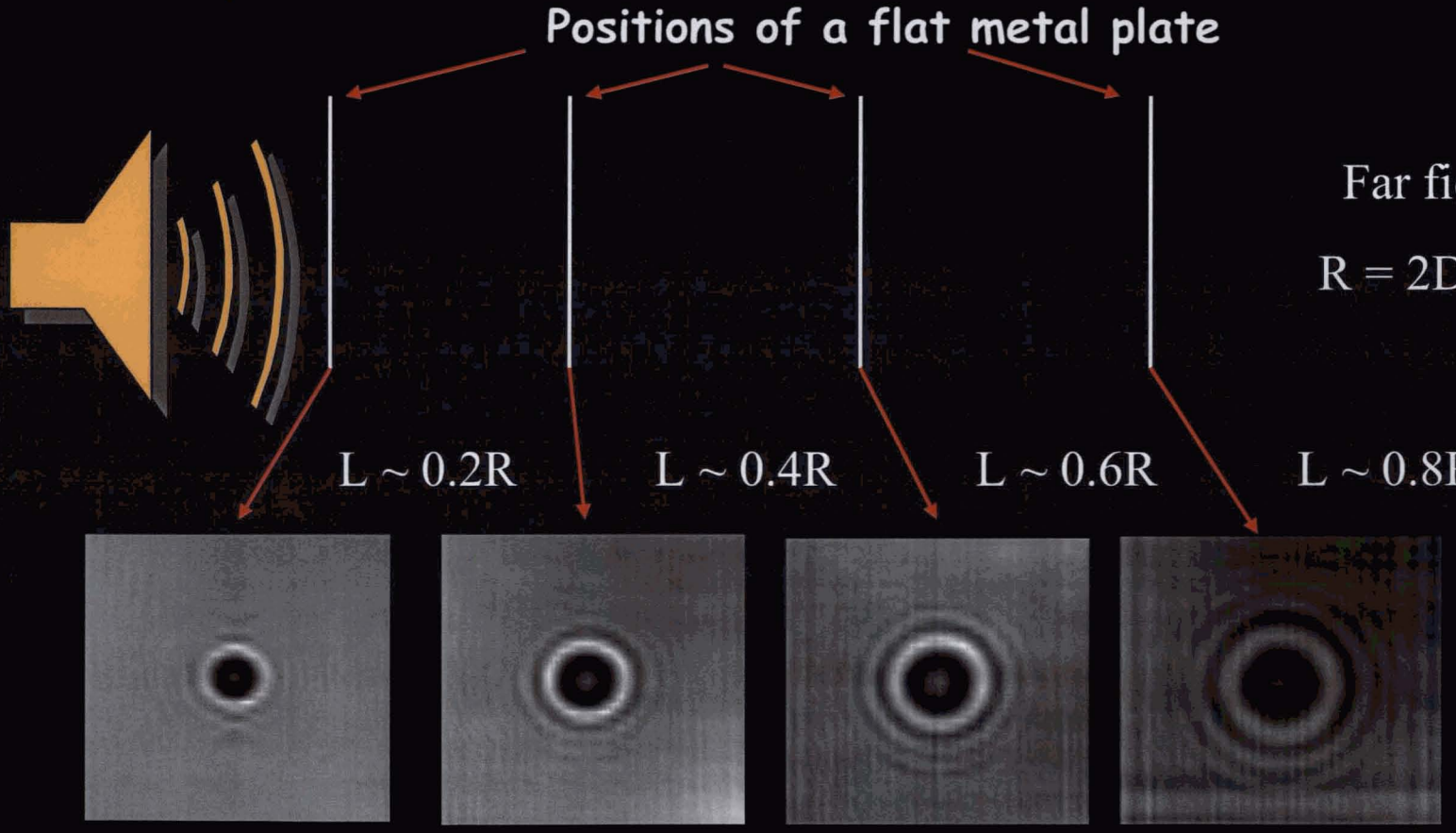


Sources of Unwanted Indications

- Complex phase and magnitude field distribution in near-field of radiators (antennas).
- Side-lobes and complex field distribution in the different cross sections of the lens-focused electromagnetic beam outside of its focal range.
- Reflection signals from the SOFI and substrate of complex geometry (stringers, flanges, bolts, etc.), and their interference (multiple signals).
- Polarization influence.

Sources of Unwanted Indications

Complex near-field distribution of a horn antenna



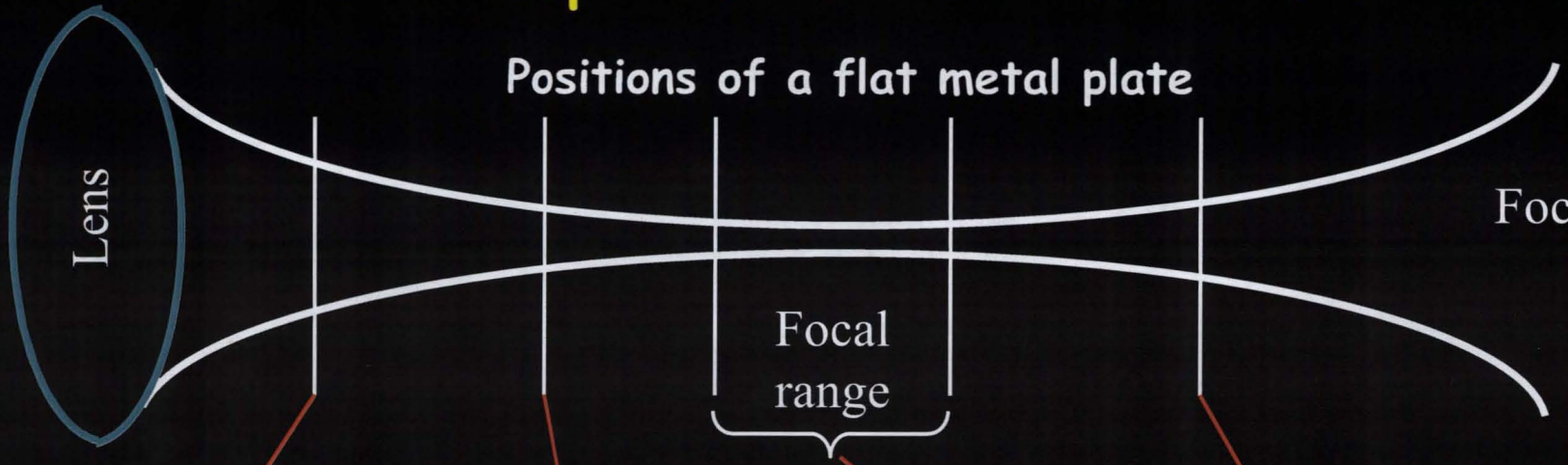
Far field distance:

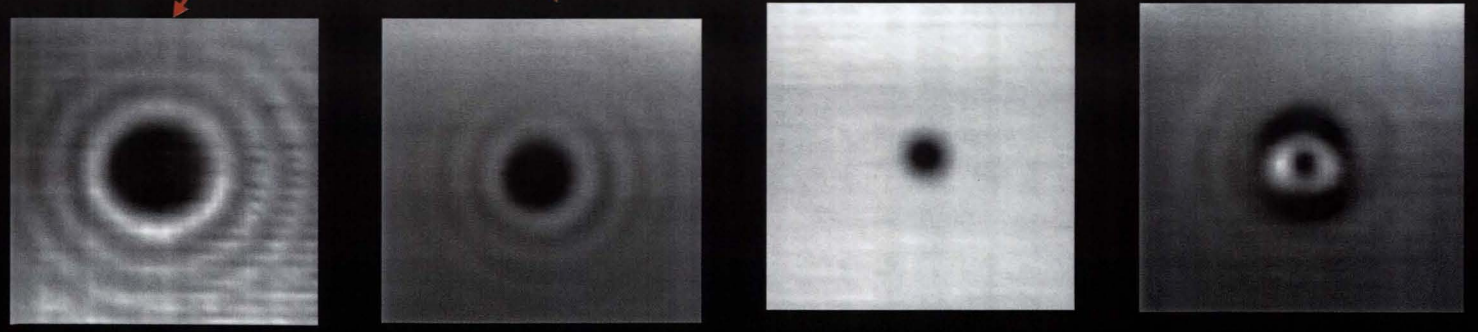
$R = 2D^2/\lambda = 217$ mm

The 36-GHz field distributions on the plate at different distances

Sources of Unwanted Indications

Side lobs and complex field distribution of focused beam

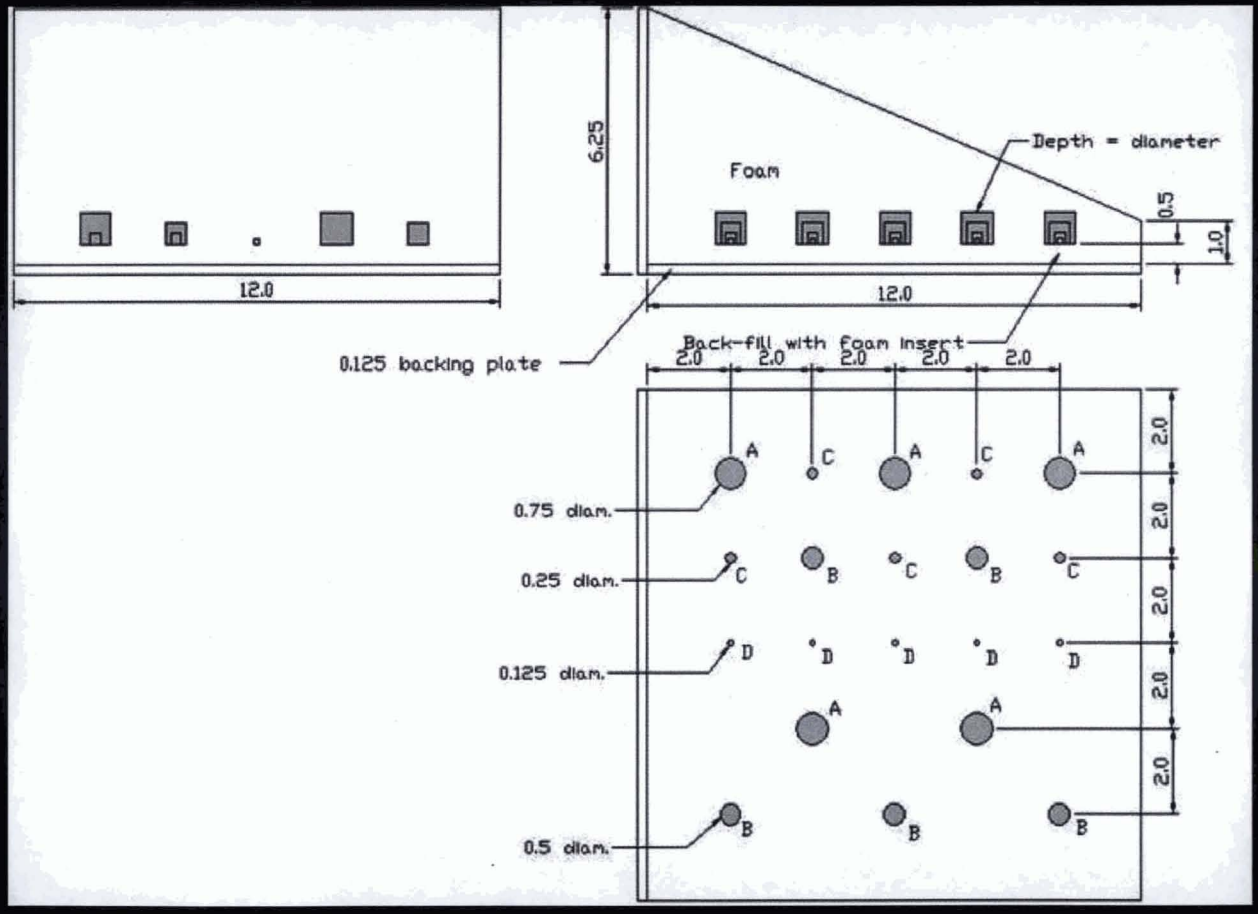




Footprints of the 100-GHz focused beam on the plate

Sources of Unwanted Indications

SOFI Wedge Sample

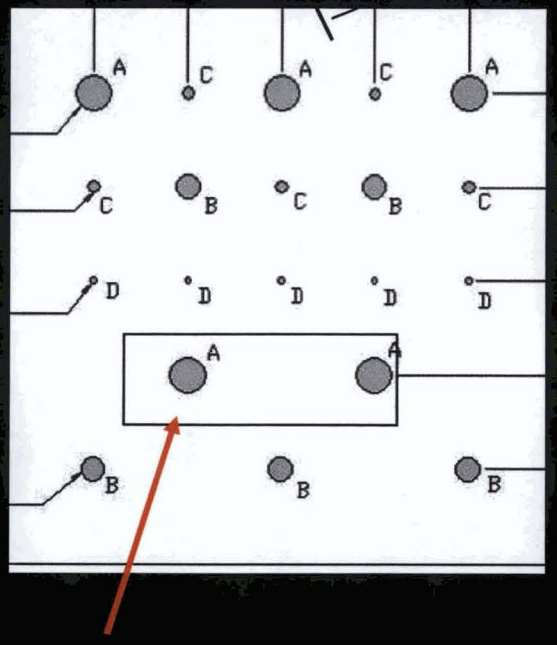


Schematic of the sample with embedded voids

SOFI Wedge Sample

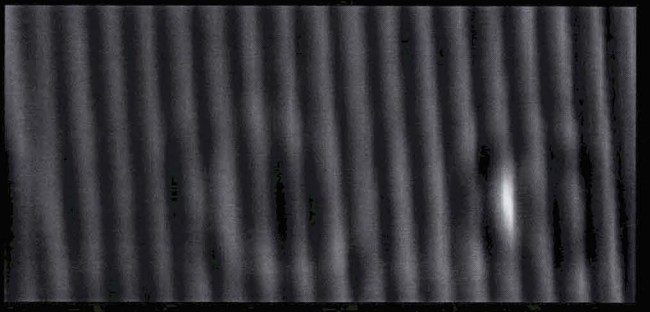
Tilted substrate

SOFI Wedge Sample

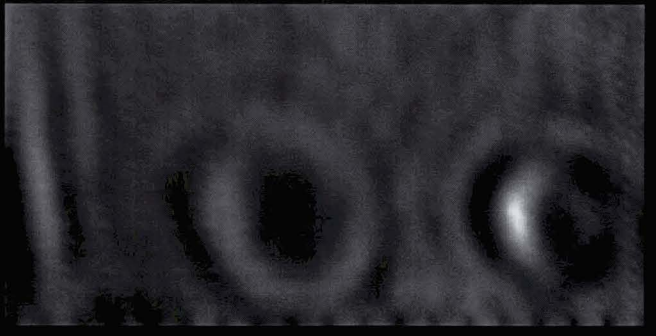


Scanned Area

33-GHz Raw Image



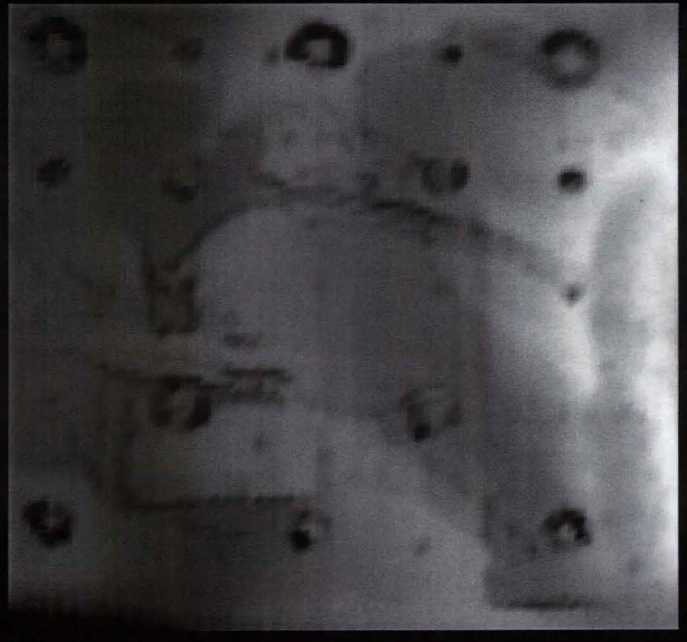
Processed Image



SOFI Wedge Sample

SOFI ramp

SOFI Wedge Sample-100 GHz Images



Focused at the substrate

Focused at 2.5" above the substrate

Tilted SOFI Wedge Sample

SOFI ramp and slightly tilted substrate

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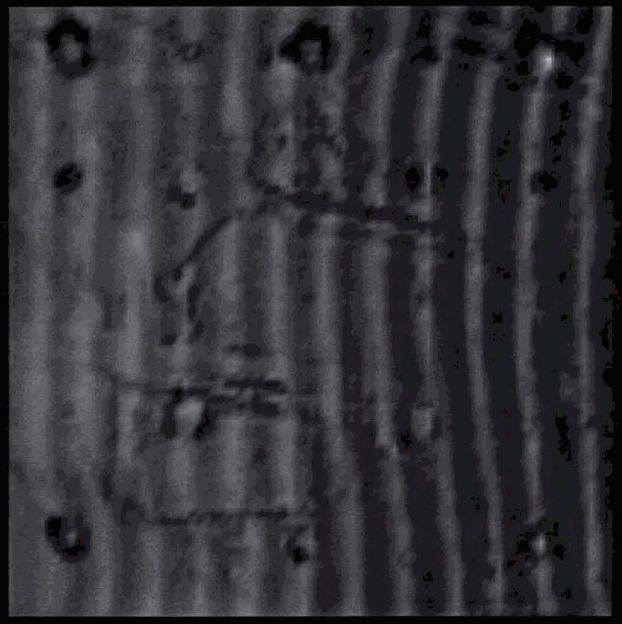
Tilted SOFI Wedge Sample



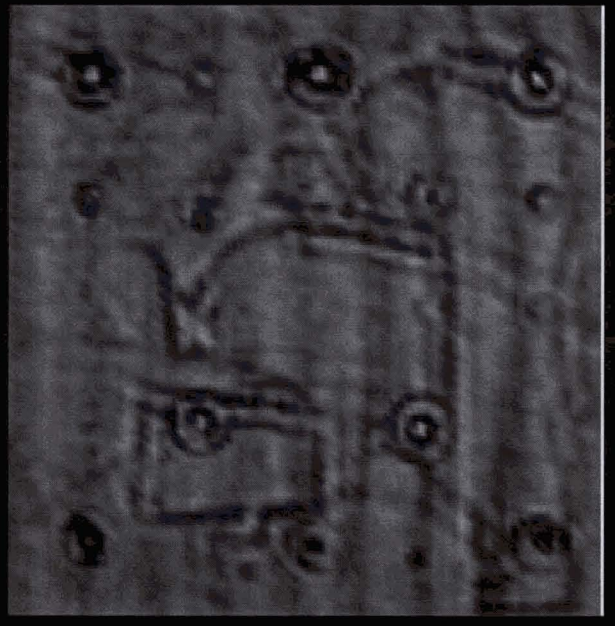
Parallel polarization

Perpendicular polarization

Tilted SOFI Wedge Sample

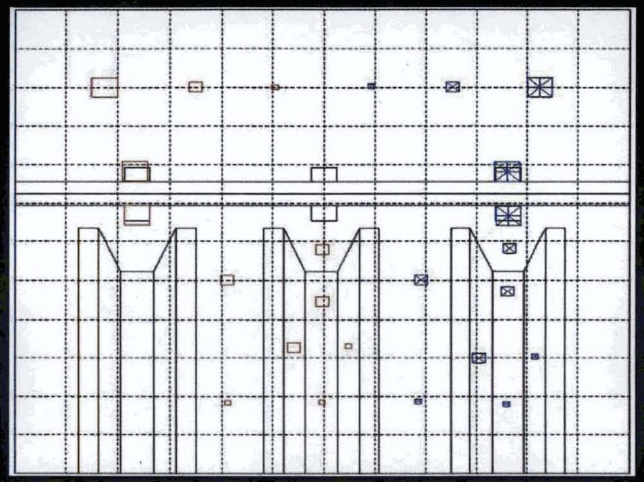
Focused at 2.5" above the substrate

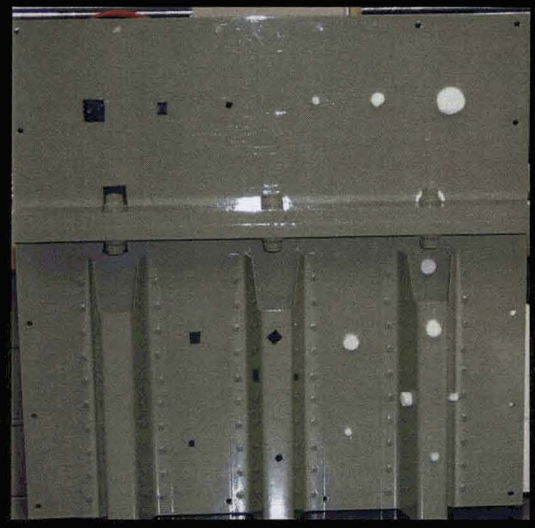
Parallel polarization

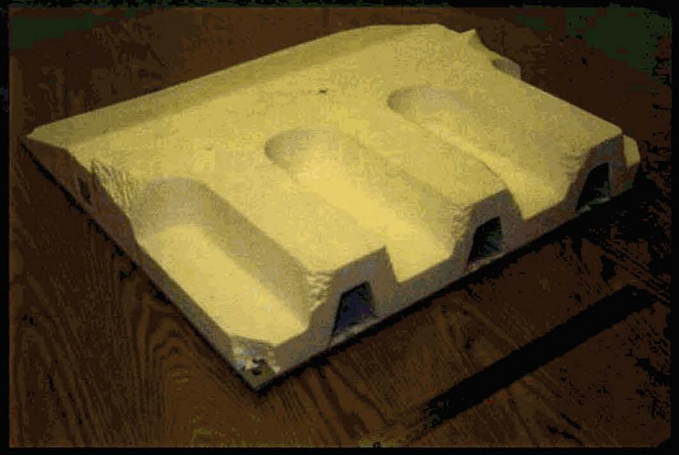


Perpendicular polarization

POD Panel

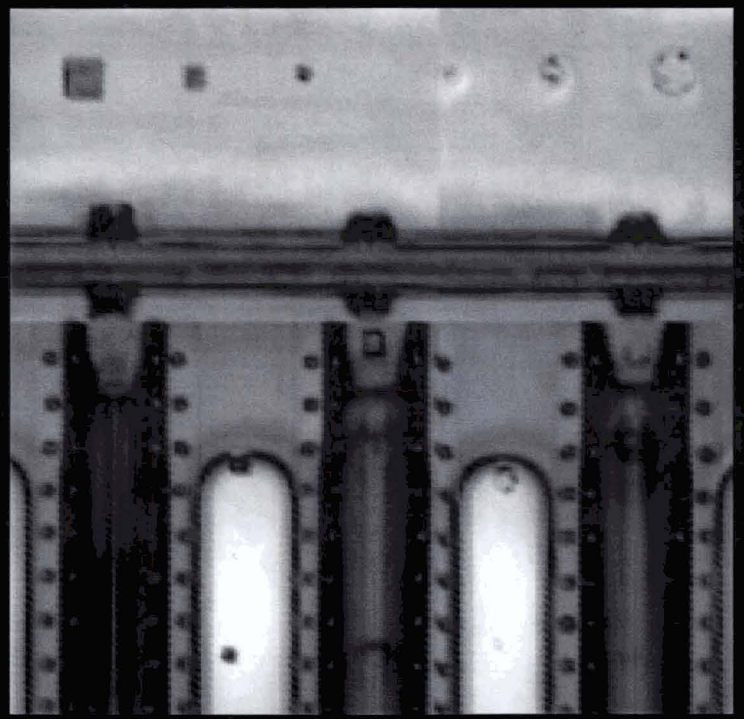




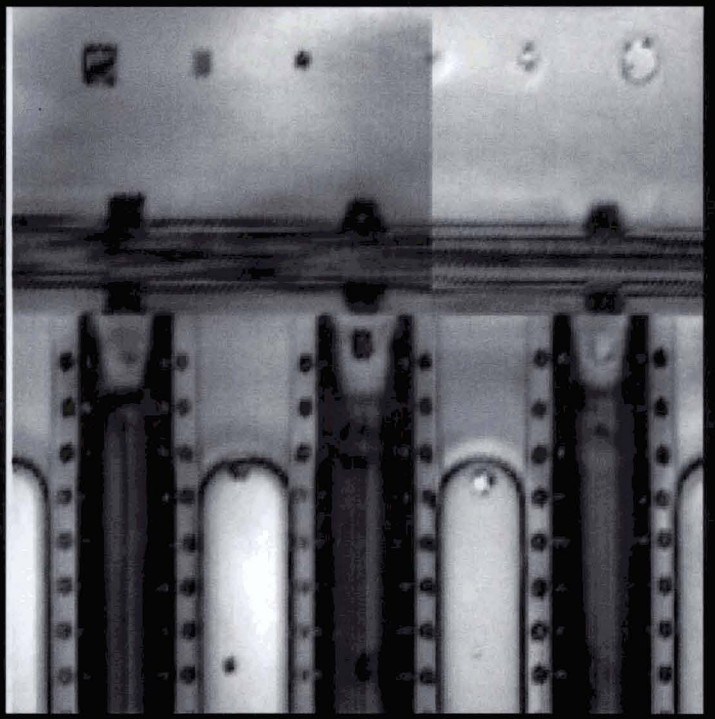


POD Panel – 100 GHz Images

Perpendicular



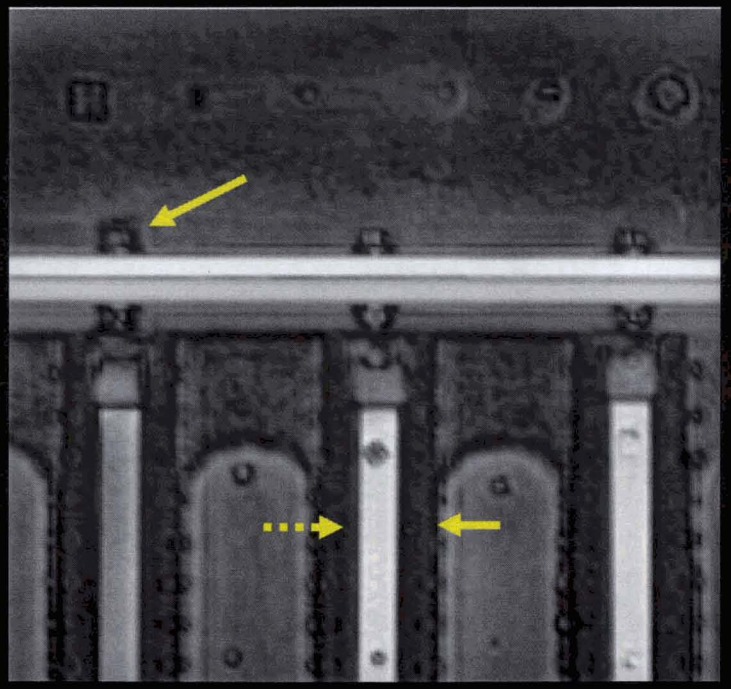
Parallel



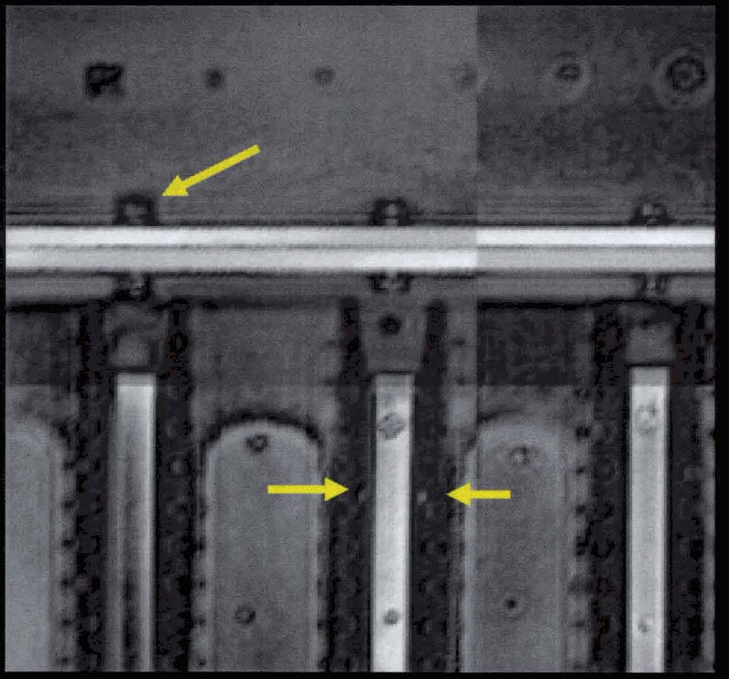
Lens Focused at Substrate

POD Panel – 100 GHz Images

Perpendicular

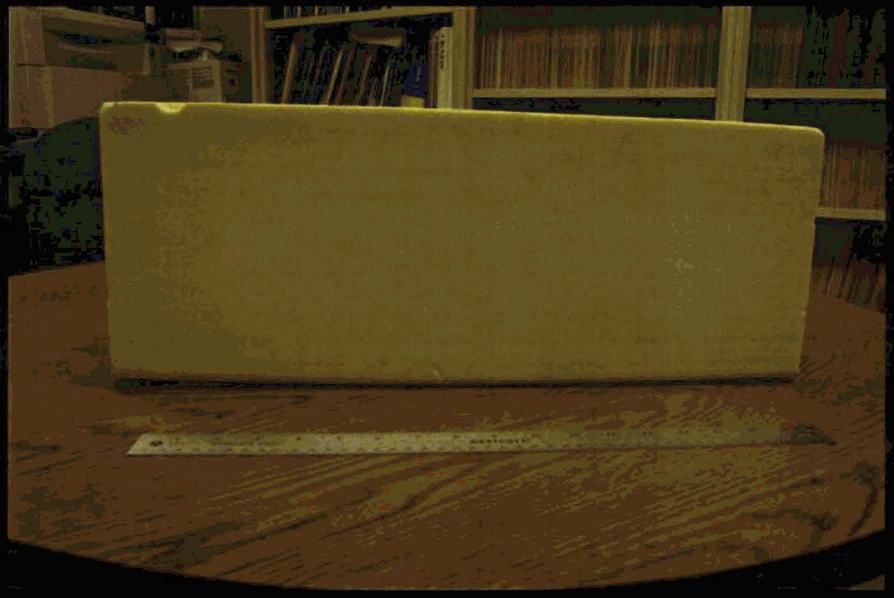


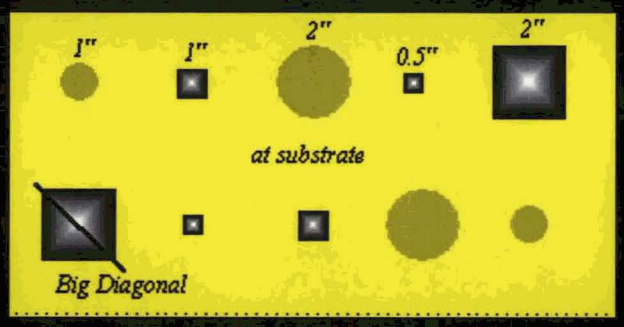
Parallel



Lens Focused at Top of Stringers

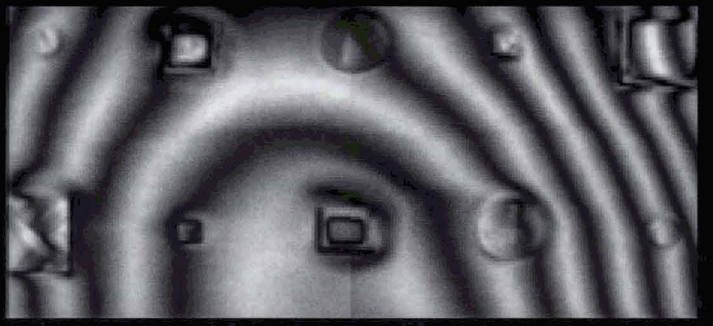
PNL Panel



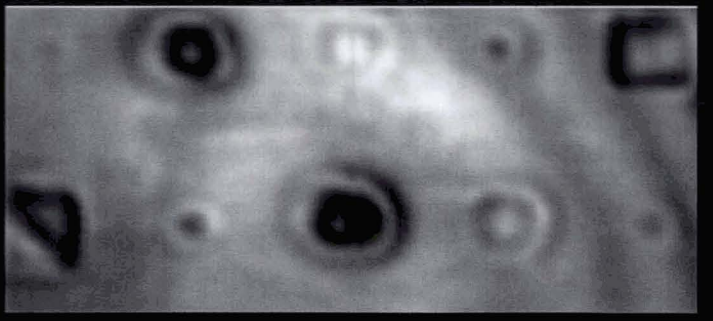


PNL Panel - Lens

150 GHz
Focused at substrate



100 GHz & long depth of focus
Focused at 8" above substrate



Discussion and Summary

- Indications of flaws can be masked by unwanted reflections caused by a combination of sources which are:
  - Complex phase and magnitude field distribution in near-field of radiators (antennas).
  - Side-lobes and complex field distribution in the different cross sections of the lens-focused electromagnetic beam outside of its focal range.
  - Reflection signals from the SOFI and substrate of complex geometry (stringers, flanges, bolts, etc.), and their interference.

Discussion and Summary

- Remedies for removing or reducing unwanted reflections/indications/influences can be
  - Suitable selection of the radiators (i.e., horn and lens antennas) and their performances (e.g., far field distances for the horn antennas, focus distance and focal range for the lens antennas) and arrangements (e.g., standoff distance, incidence angle).
  - Use of suitable polarization of the signals for the regions with stringers, flanges, bolts and tilted/curved substrate.
  - Signal processing.
  - Swept-frequency and pulsed methods.

Thank You.

Questions?