MMW Identification of Explosives

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Approach

- Dielectric Signatures of Explosives and Materials
- Identification of Explosives
- Summary

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Motivation for Dielectric Measurement

- Image characterization:
  - A material's dielectric constant characterizes how it appears in millimeter wave images.
- Frequency dependence requires specification at a frequency:
  - Dielectric parameters must pertain to the specific frequency or range used by the imaging system.
- Other uses:
  - Develop explosive simulants by matching dielectric constants of explosives to inert materials.
  - Identification of Explosives (IDX).

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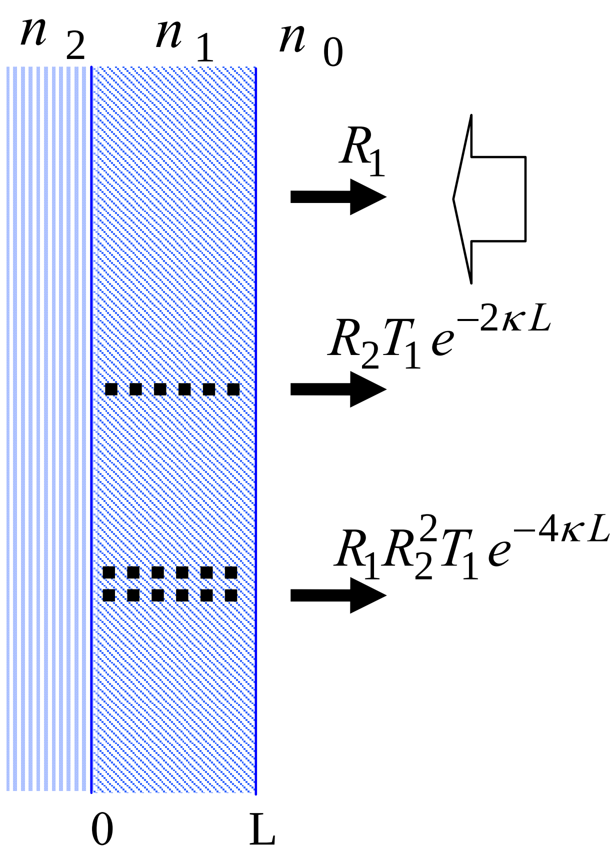
Millimeter wave imaging

Image contrast depends on how the reflectivity from an object differs from the (human) background

And for low loss materials, partial transmission and reflections from back surface can be important

Optics of dielectric media

Fresnel equations for transmission and reflection



$$E(x,t) = E_0 e^{-n''(\omega/c)x} e^{in'(\omega/c)x - i\omega t}$$

- Reflection coefficients

$$R_1 = \left| \frac{n_1 - n_0}{n_1 + n_0} \right|^2 \qquad R_2 = \left| \frac{n_2 - n_1}{n_2 + n_1} \right|^2$$

- Transmission coefficient

$$T_1 = \left| \frac{2n_1}{n_1 + n_0} \times \frac{2n_0}{n_1 + n_0} \right|^2$$

- Beer's law

$$\kappa = 2n''\omega / c$$

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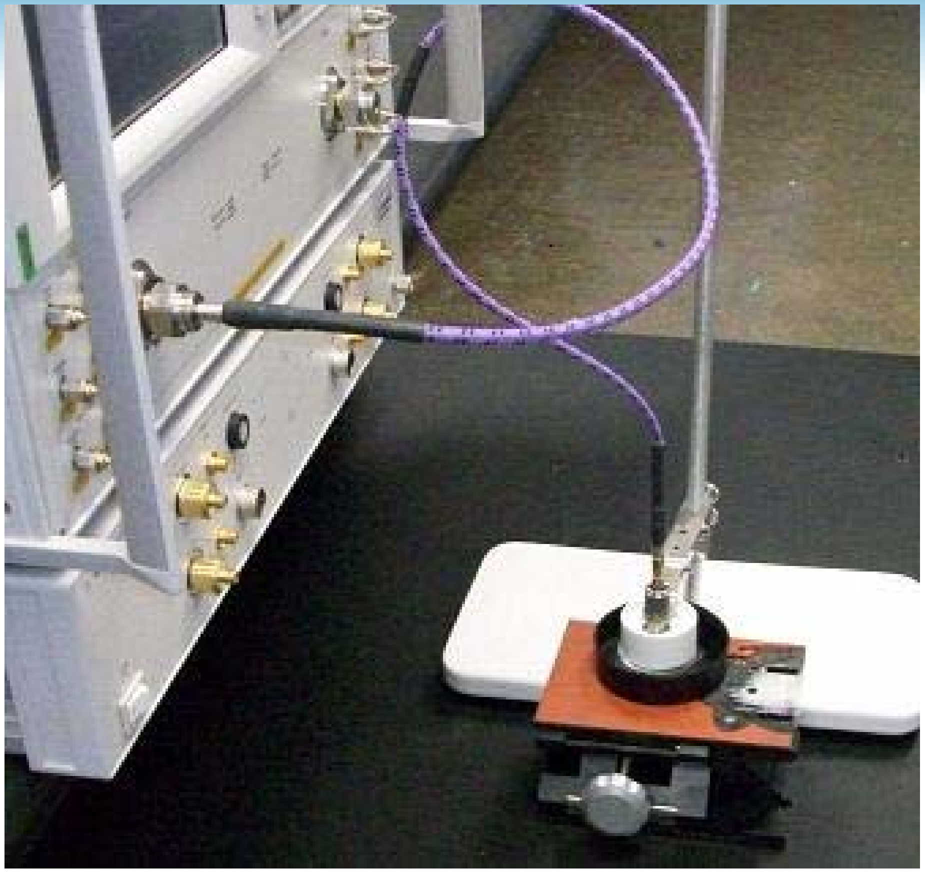
Dielectric constant



- Complex refractive index, *n*, is related to the dielectric constant:

$$n = \sqrt{\mu \varepsilon}$$

- The dielectric constant describes the polarization response of a material to an electric field. Measured by:
  - Radiation transmission/reflection
  - Waveguide probes
  - Cavity resonance methods

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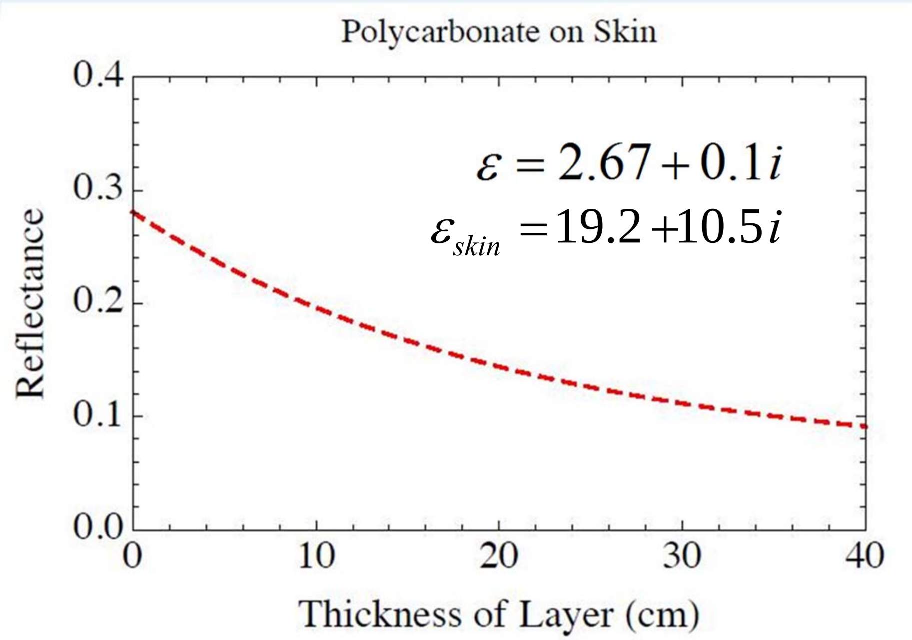
Simulation based on dielectric values

Significance of imaginary component of dielectric constant



- Optically thin layers have reflections on front and back surfaces
- A thick layer can have a significantly different reflection signature from a thin layer of the same material
  - Precision measurement of imaginary component is important

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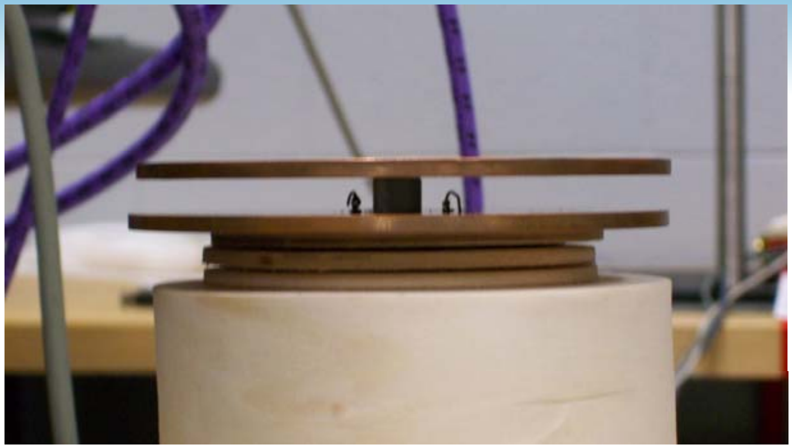
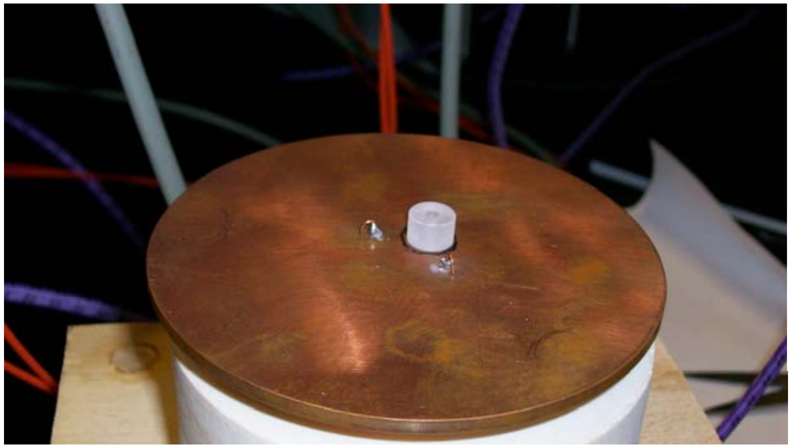
Dielectric-post resonator system





- Precision measurement of imaginary component of dielectric constant
- 22 – 23 GHz, as determined by geometry of post
- Rigid Rexolite post with cylindrical column removed to hold sample
  - Small volume, 0.11 ml
  - Non-contact
  - Perturbative in frequency
  - Liquids and powders

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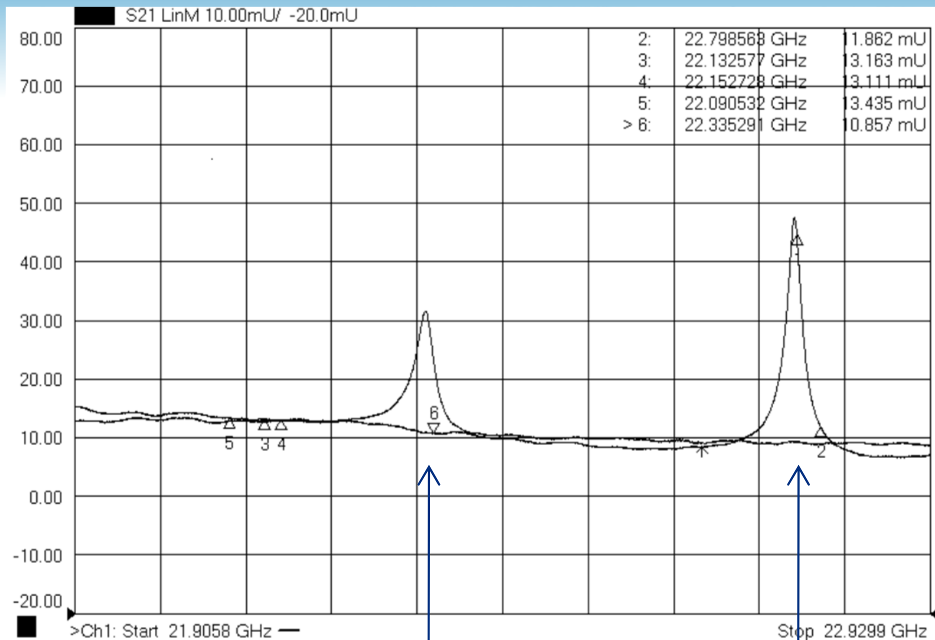
Resonant spectrum, TE011



filled fixture empty fixture

2011 SPIE - Proc. of SPIE Vol. 8019 80190F-1

- Electromagnetic resonances occur with modes “trapped” in dielectric material.
- Real part of dielectric derives from frequency shift
- Imaginary part of dielectric derives from line width (or quality factor)

$$\Delta f = \frac{f}{2Q}$$

- Quality factor “corrected” for non-dielectric loss

$$\frac{1}{Q_{corr}} = \frac{1}{Q} - \frac{1}{Q_{empty}}$$

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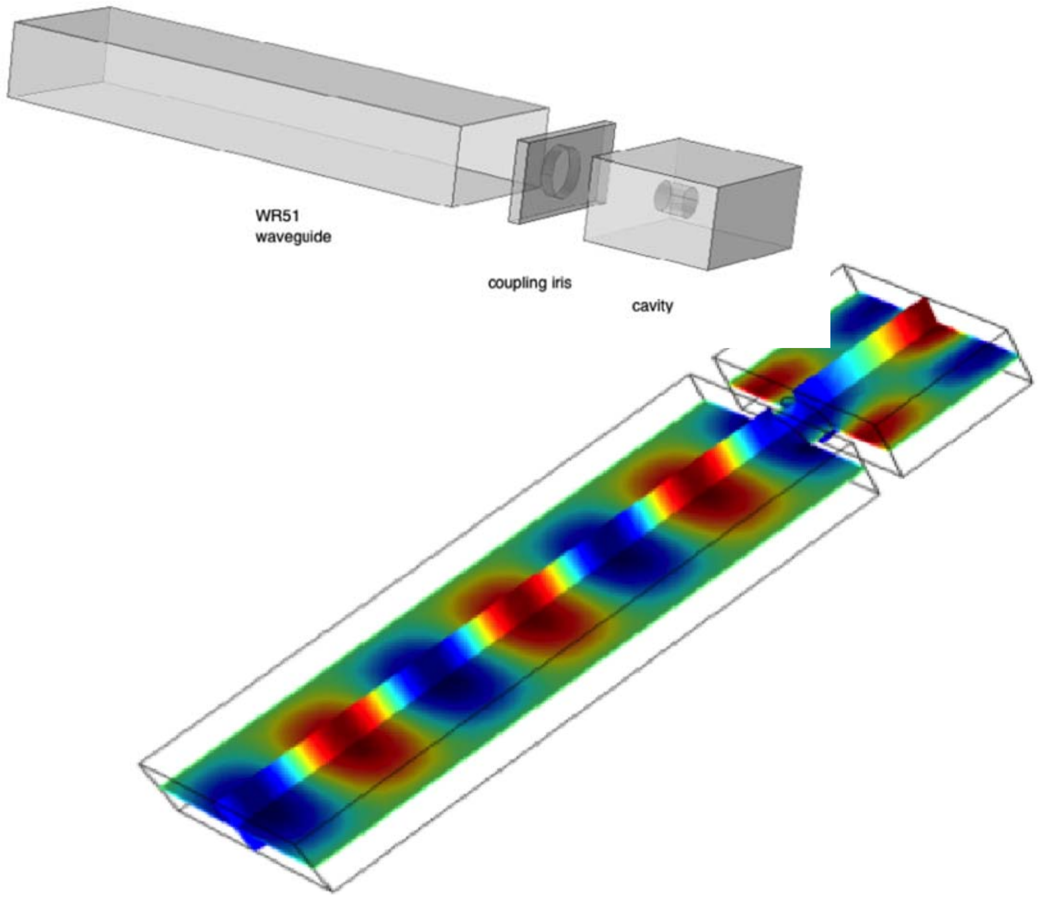
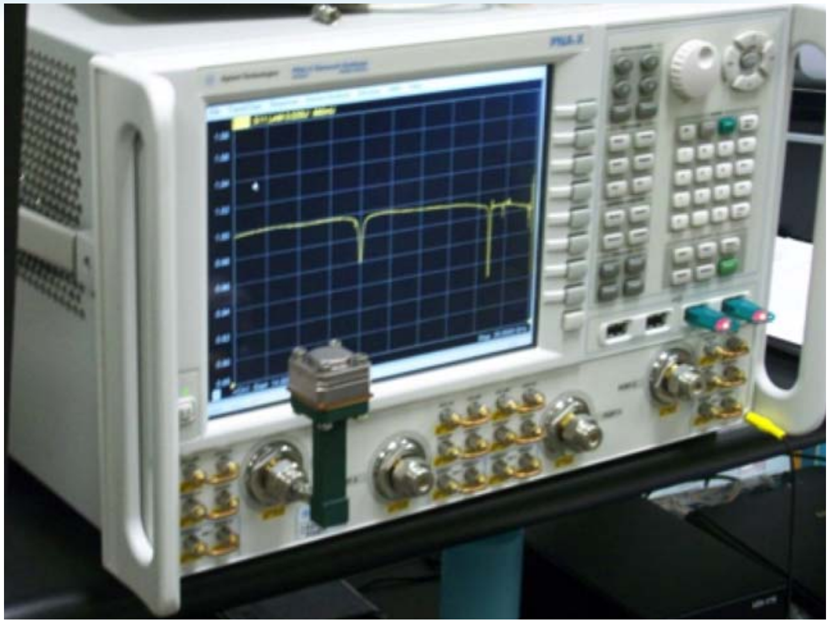
WR51 Resonant Cavity





Patent Pending

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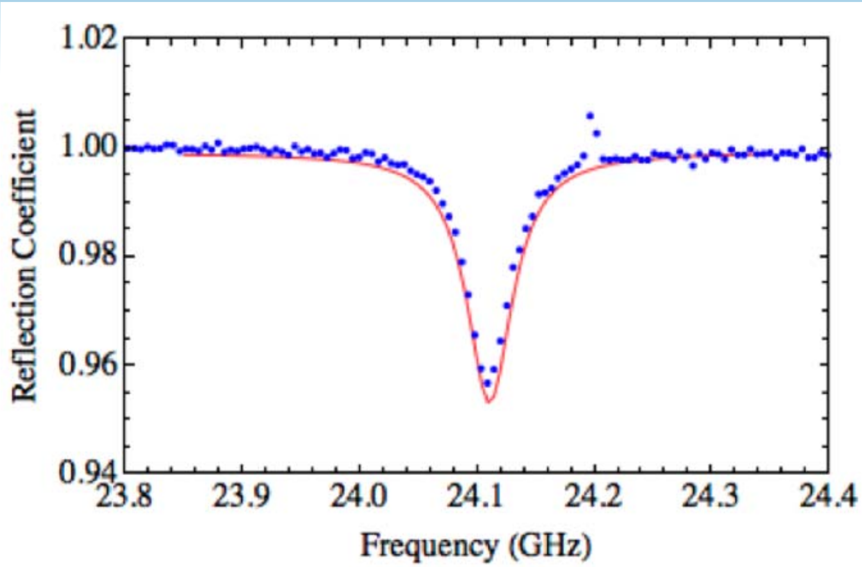
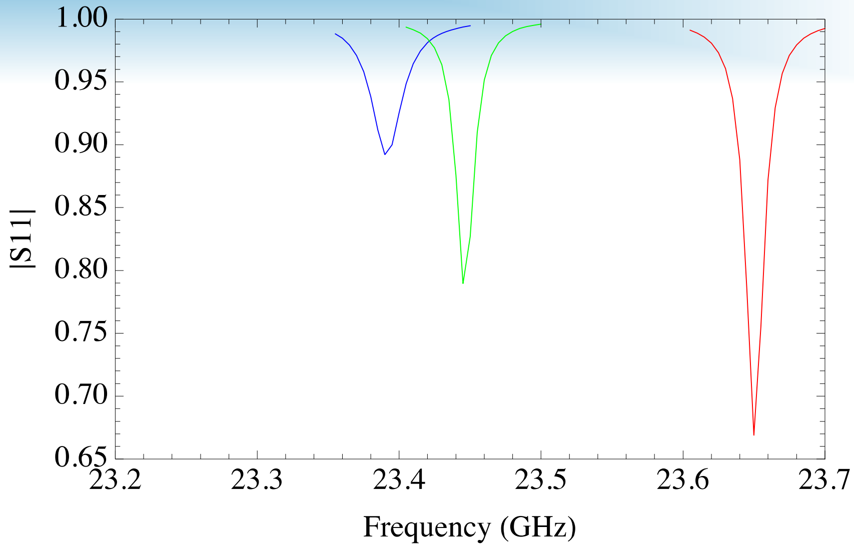
Resonant Response



TE301 reflection coefficient with HDPE-filled cavity: experimental data (discrete points) and simulation (line).



Resonant response of cavity to different samples: (left to right) lossy dielectric sample, uniform plastic, and empty sample.

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Creation of Simulants

- Measurements on explosives and candidate base materials

- Landau & Lifshitz, Looyenga Equation

$$\left(\varepsilon_{mixture}\right)^{1/3} = \upsilon_1\left(\varepsilon_1\right)^{1/3} + \upsilon_2\left(\varepsilon_2\right)^{1/3}$$

- Use of inert materials to adjust dielectric constants of base materials

- Iterative refinement of simulants

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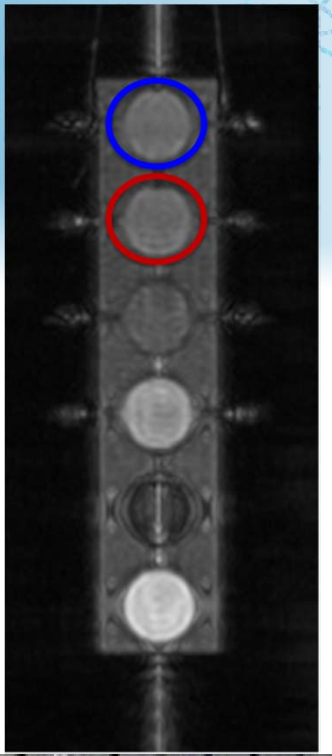
Motivation

- Developed prototype test objects and simulants for explosives/precursors
- Further development of image quality tools (IQT) for millimeter wave imaging
- ANSI N42.59
- Consensus standard begun February 8-9 2016.



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Dielectric Constant

Measurement of dielectric constant defines optical characteristics for

- Electromagnetic signatures for explosive detection
- Development of simulants for explosives
- Standards for active and passive millimeter wave detection systems

Technique based on resonance cavity can be used to measure small amounts of low loss materials

- Liquids and powders, as well as solids
- Imaginary dielectric component between **0.002 and 0.2**.

New Technique under development for lossy materials at any frequency

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Identification of Explosives
IDX

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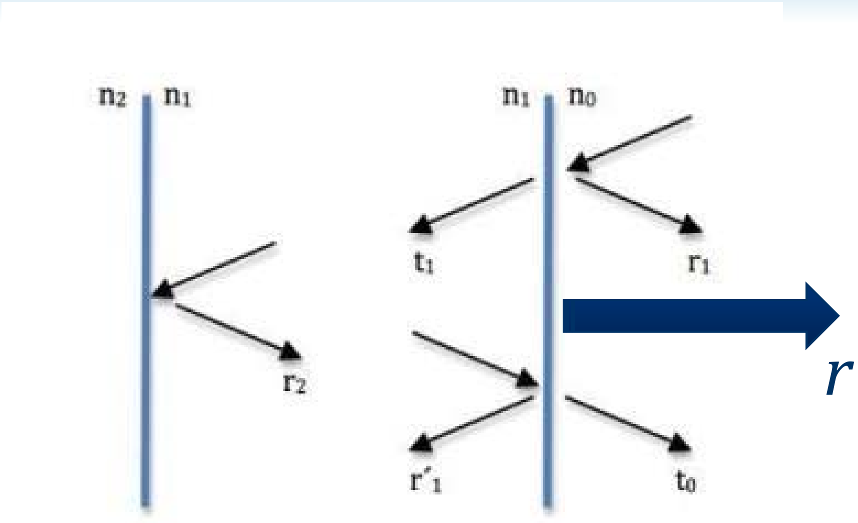
Identification of Explosives

- Technique uses the reflectivity collected over a wide range of frequencies.
- Detects real and imaginary components of dielectric constants.
- Identification accomplished by comparing detected values to those of actual explosive.

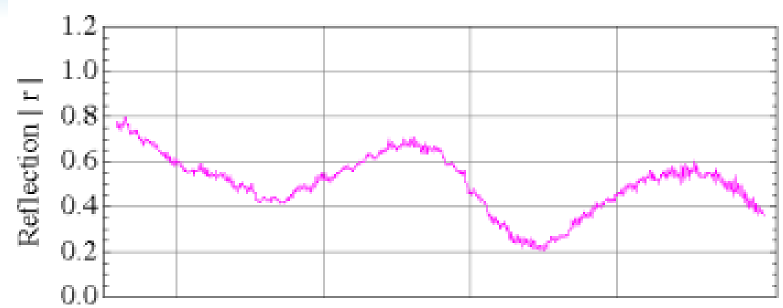
Intensity Resolution Requirement

Reflection model



$$r = r_1 e^{i\theta_0} + t_0 r_2 t_1 \left(e^{i\theta_1} + (r_1' r_2) e^{i\theta_2} + (r_1' r_2)^2 e^{i\theta_3} + \cdots \right)$$

Paper, 1 cm thickness metal backing



P1000, 1 cm thickness metal backing

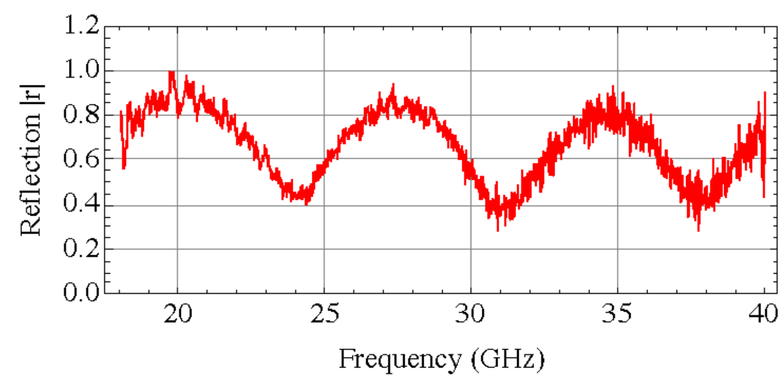


Image intensity depends on:

- Frequency
- Composition (refractive index or dielectric)
- Configuration (thickness, backing material)

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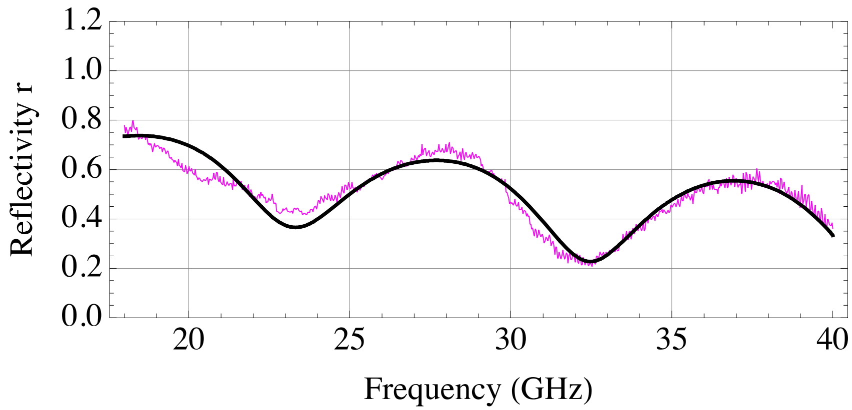
Parameter Extraction from Reflectivity Data

- Analysis uses built-in MATHEMATICA functions.
- Fits the reflectivity model parameters ΔL, n', and n'' to the experimental data.

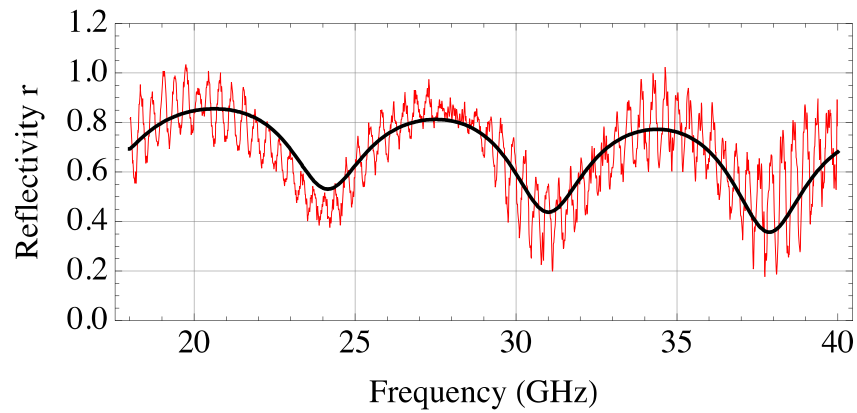
Paper

$\varepsilon = 2.34(3)+0.18(4)$



P1000

$\varepsilon = 2.86(7)+0.11(2)i$



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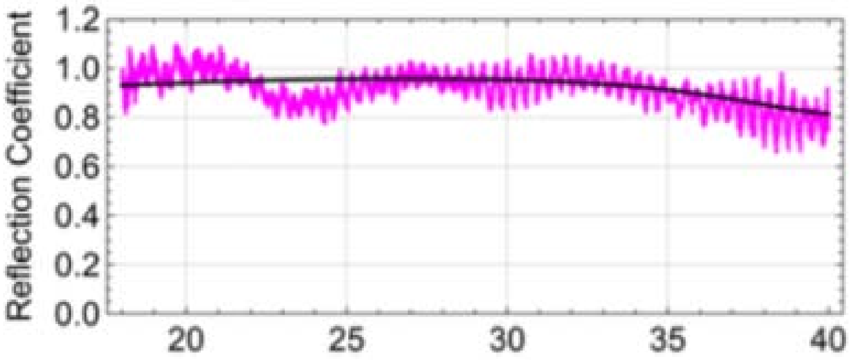
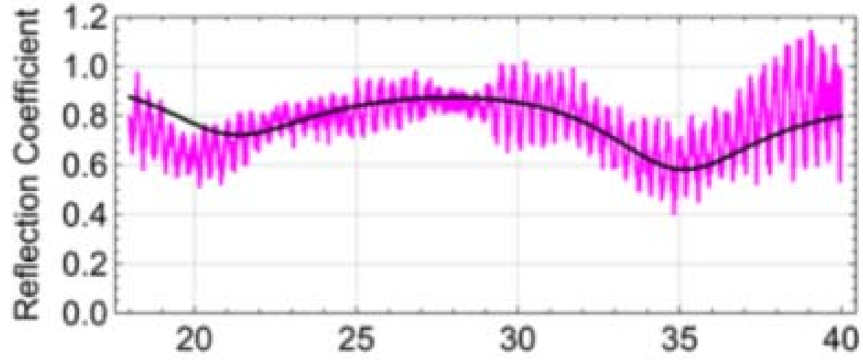
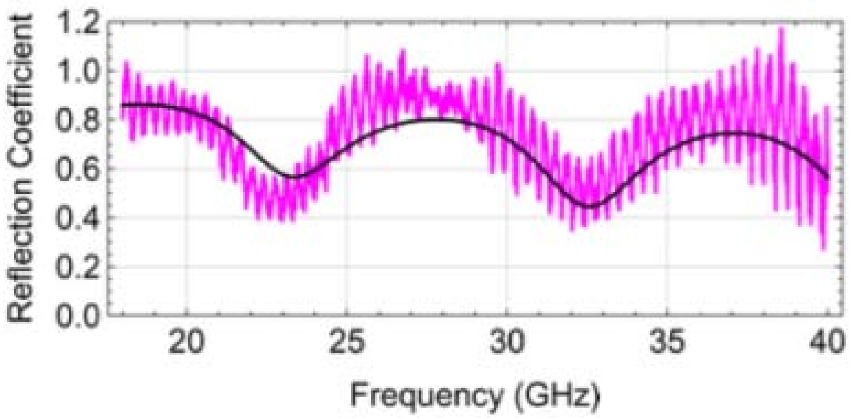
P1000 samples of various thickness



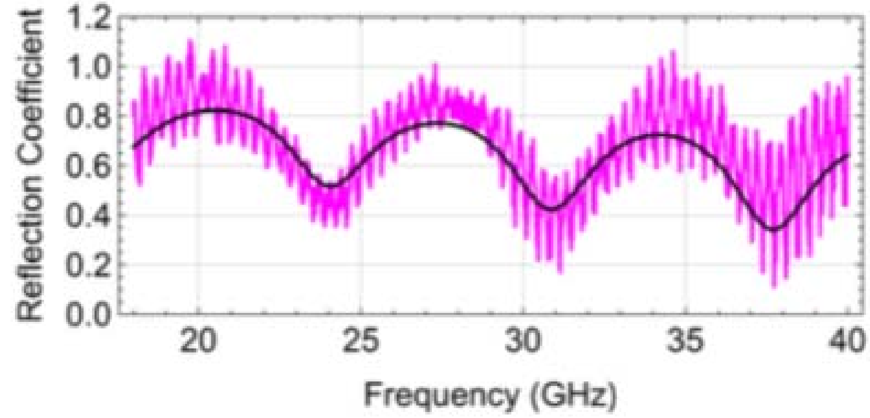
(a) 1/4 layer; L=0.316cm, n'=1.777, n"=.031



(b) 1/2 layer; L=0.626cm, n'=1.736, n"=.052



(c) 3/4 layer; L=0.954cm, n'=1.684, n"=.039



(d) full layer; L=1.280cm, n'=1.730, n"=.029

$n' = 1.73 \pm 0.03$

$n'' = 0.04 \pm 0.01$

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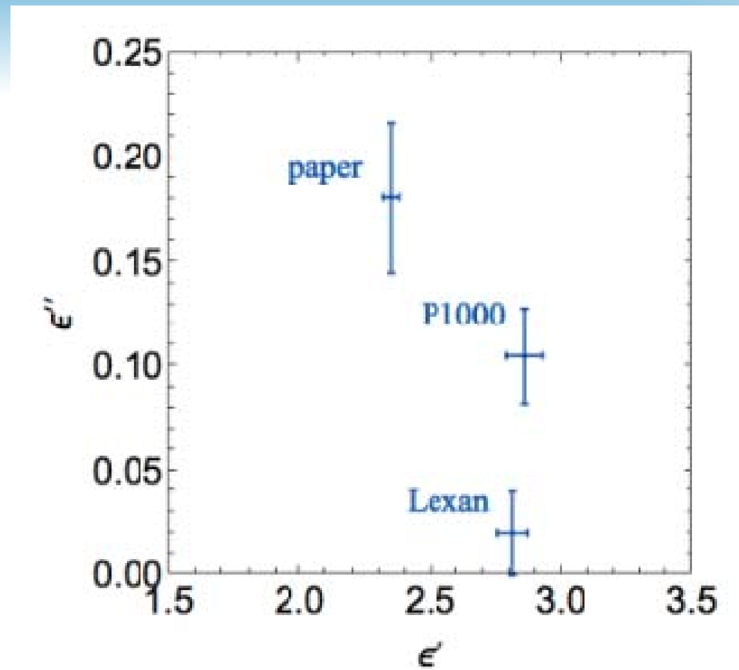
Proof-of-Principle



Weatherall, J.C., Barber, J., and Smith, B.T., "*Spectral Signatures for Identifying Explosives with Wide-Band Millimeter-Wave Illumination*", IEEE Transactions on Microwave Theory and Techniques, Vol. 64, NO. 3, pp 999-1005, March 2016

Standoff detection with 6% reflection error (4 bit resolution) and 5° phase error

Summary

- Optical properties characterize MMW imaging.
- Dielectric measurements define optical characteristics;
- New techniques for measuring dielectric constant.
- Identification of Explosives using MMW.

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Transportation Security Laboratory Visiting Scientist Program

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Award Description

- **Monthly stipends commensurate with degree level, research areas and experience**
- **Stipends starting at $70,000/year for postdoctoral fellows**
- **Medical/health insurance allowance and plan availability**
- **Limited travel/moving reimbursement and professional travel**
- **On-site interview travel reimbursement for prospective candidates**

The Transportation Security Laboratory (TSL) Visiting Scientist Program is designed to allow researchers across multiple levels the opportunity for research training and education on DHS mission-relevant science and technology at a one-of-a kind federal research laboratory. The overall objective of this program is to enhance the quantity, quality and diversity of the future DHS scientific and engineering workforce. In addition, this program will be a catalyst for new ideas and skills to achieve the DHS mission and enhance interactions with the wider academic and private sector communities. Participants in this program can include undergraduate and graduate student interns, recent graduates including postdoctoral fellows, faculty researchers, and other visiting scientists. Applications are accepted on an on-going basis.

Appointments can be short-term or up to 12-months with an option for renewal for additional years.

Applicant Eligibility Requirements

All positions at TSL require natural-born or naturalized U.S. citizenship. Applicants that are selected must be able to secure at least a Secret clearance and Department of Homeland Security Suitability. Once a position is accepted, the Security Officers at TSL will provide assistance in preparing forms and submitting a complete package for processing.

Additional Information and Application Forms

http://www.orau.gov/DHS-TSLvisSciProg




Concealed Explosives Detection 2016 Workshop

19 – 24 September

Downing College, Cambridge, UK

Registration will open at

www.concealedexplosives.org in the near future.

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