Non-Contact Imaging of Internal Structures in Opaque Media

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Stanford | ENGINEERING
Electrical Engineering

Introduction

Imaging Small Targets in High-Loss Environments:

1. Imaging Depth ~ Signal Quality
2. Resolution (Cross and Axial)
3. Contrast

- Safety (e.g. tissue heating in medical imaging)
- Imaging Artifacts
- System cost and portability

…

λ

10um

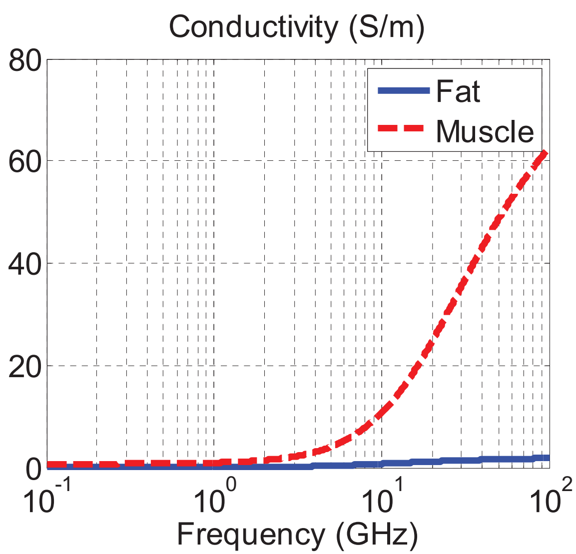
9mm

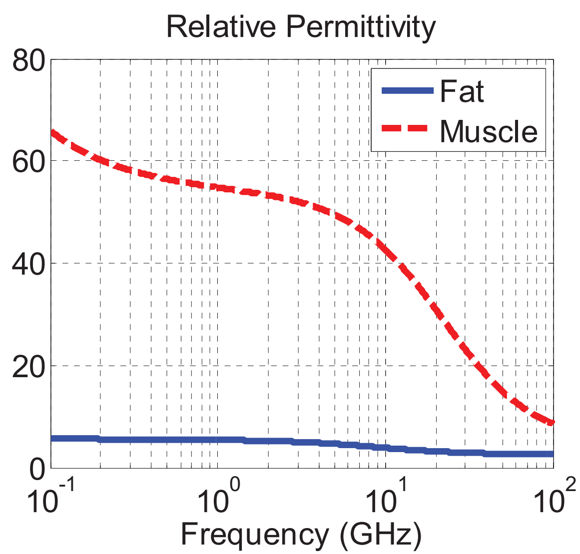
3cm

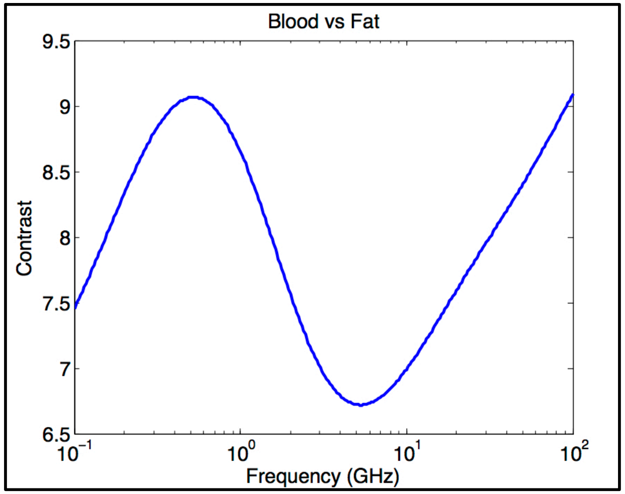
Edrich, "Imaging Thermograms at Centimeter and Millimeter Wavelengths," Annals New York Academy of Sciences, 1980

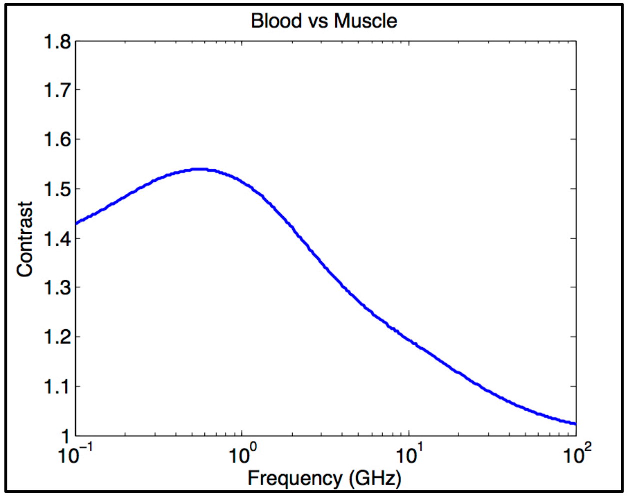
Microwave Contrast

- Dielectric Properties at Microwave Frequencies (e.g. water content)



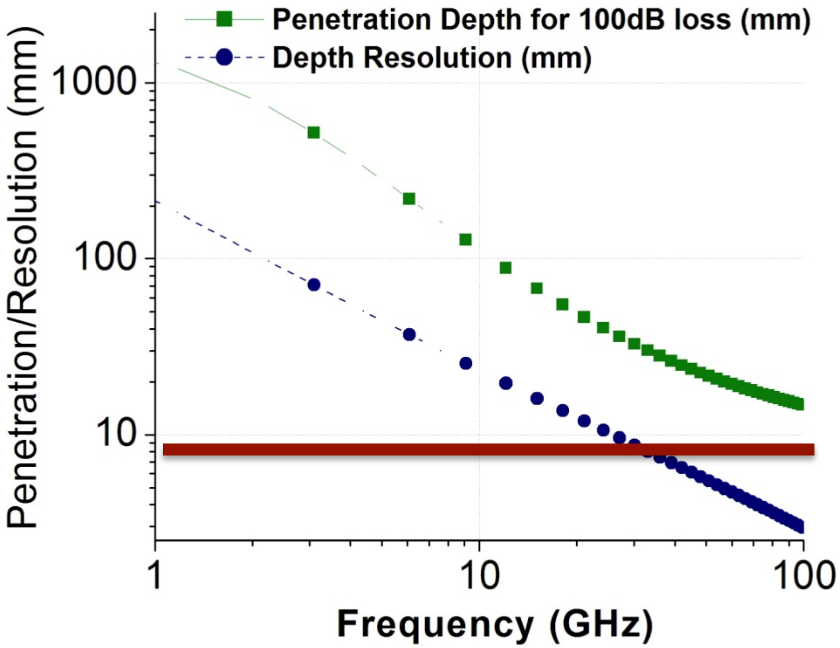




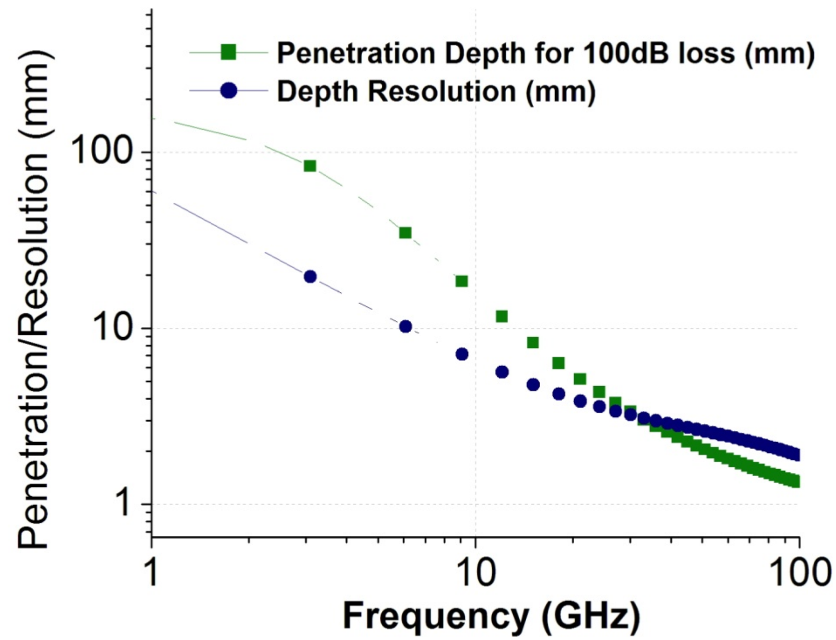


Microwave Radar Trade-offs

- Tradeoff in Penetration Depth & Resolution
- No additional degree of freedom for contrast



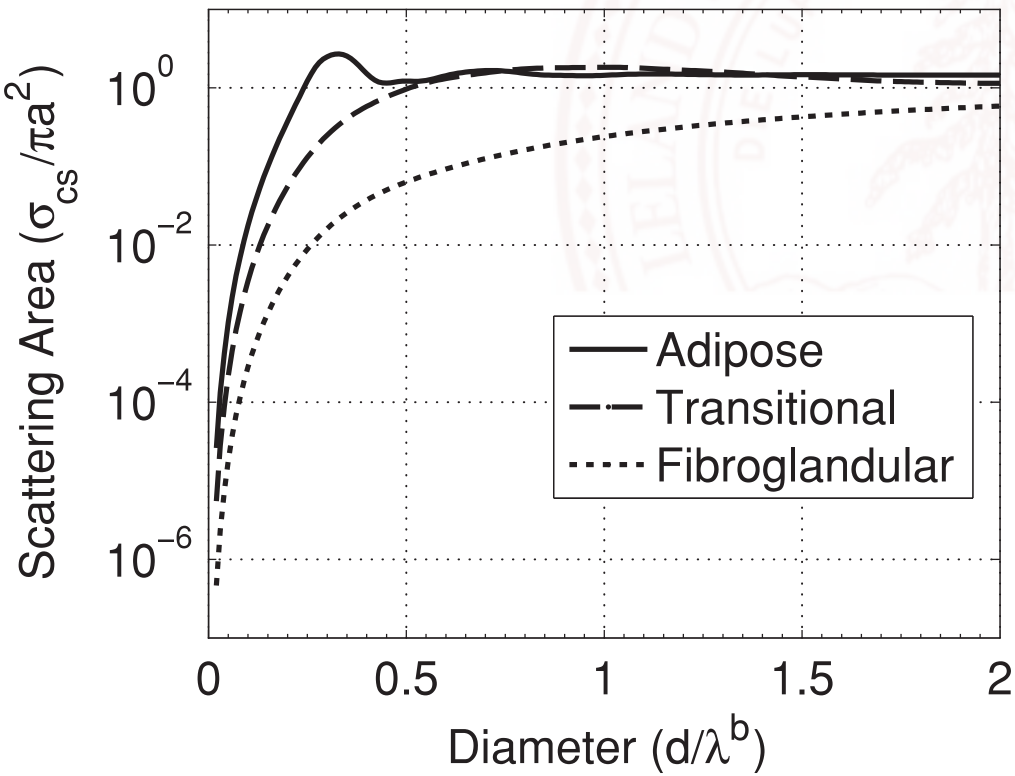
Low-Loss Tissue (Body Fat)



High Loss (Body Fluid)

Radar Cross-Section

- LF Reconstruction→ ill-posed, Reduced scattering from targets, lost resolution



Shea et al. *Inverse Problems* 2010

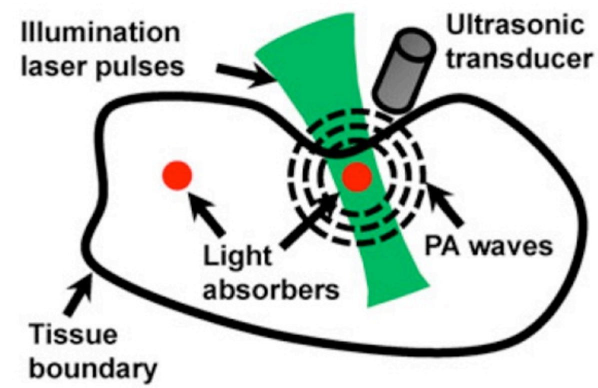
The Thermo-Elastic Response

UPON THE PRODUCTION AND REPRODUCTION OF SOUND BY LIGHT.

BY ALEXANDER GRAHAM BELL, PH.D.

(A Paper read before the American Association for the Advancement of Science, in Boston, on the 27th August, 1880.)

…While working on the "Photophone"



Junjie Yao, Contrast Media Mol Imaging, 2011.

- Generation of stress due to heating

$$(\nabla^2 - \frac{1}{v_s^2}\frac{\partial^2}{\partial t^2})p(r,t) = -\frac{\beta}{C}\frac{\partial H(r,t)}{\partial t}$$

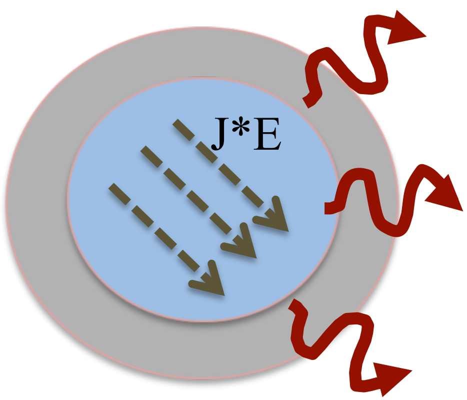
- v_s : *speed of sound*
- β : *thermal expansion coefficient*
- C : *specific heat capacity*
- $p(r,t)$: *stress*
- $H(r,t)$: *heating function*

<u>Can we use microwave as "heat source"?</u>

EM – US Interactions

Thermo-Acoustic
Thermal expansion

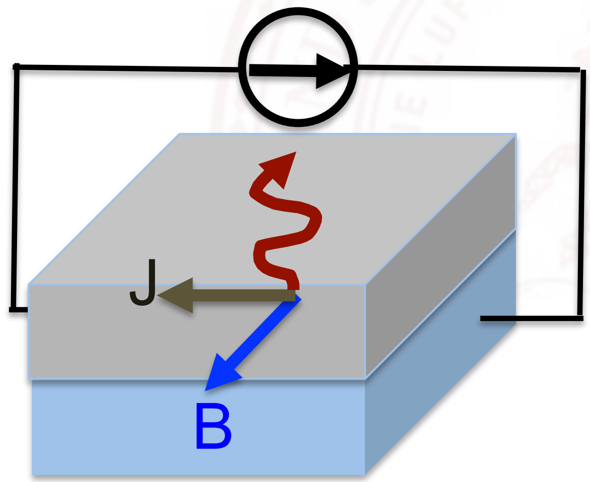
$$SAR = J \bullet E / \rho$$



US normal to
Expanding Surface

Magneto-Acoustic
(Lorentz Force)

$$F = J \times B$$

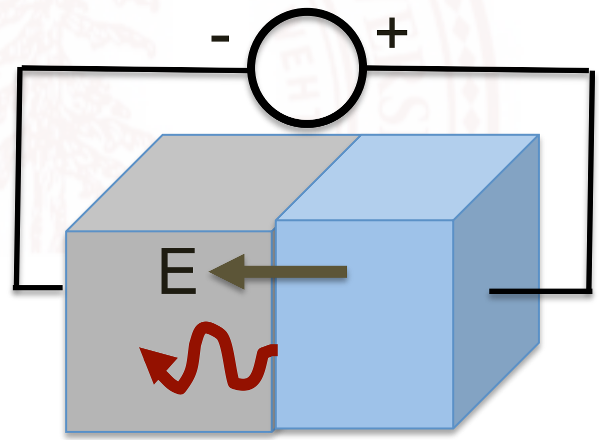


US normal
to J & B

Presence of Static Magnetic Field

Electro-Acoustic
Electrostatic Force

$$F = qE$$



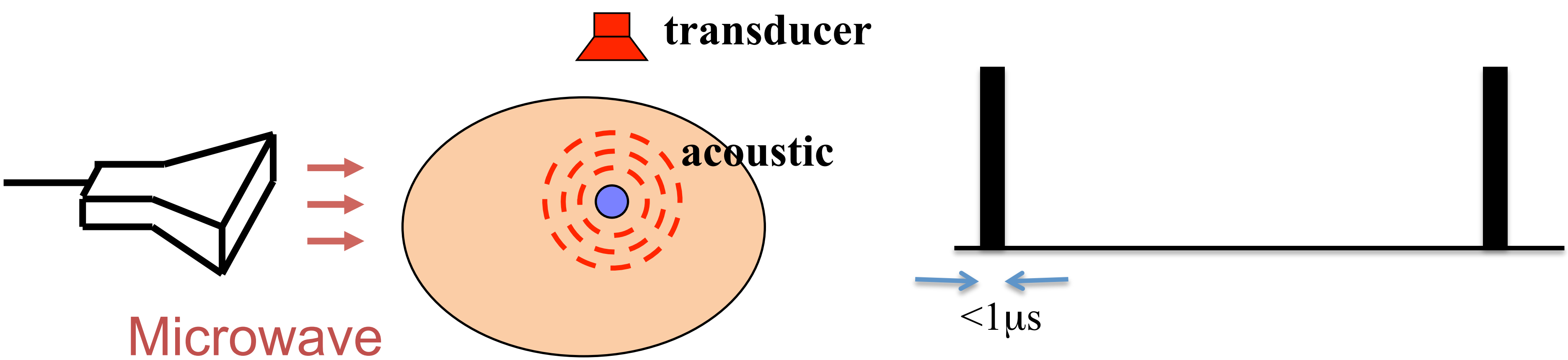
US parallel
to E

Thermoacoustic Imaging

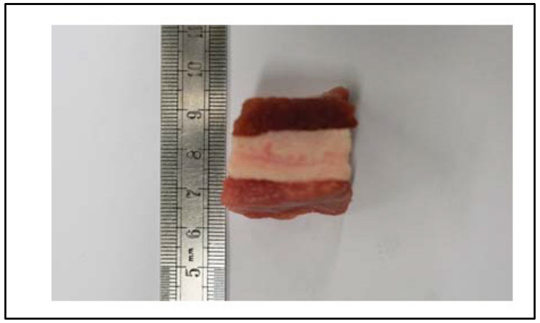
- Microwave Imaging
  - Spectral Information
  - Contrast

- Ultrasound Imaging
  - Structural Information
  - Resolution

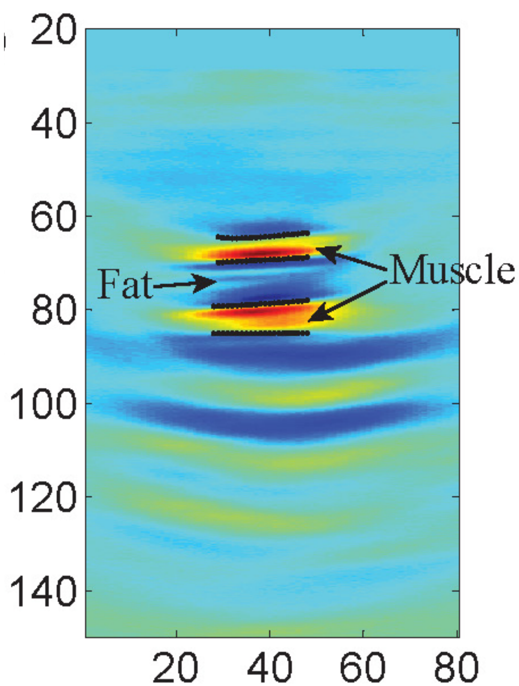
Thermoacoustic Imaging

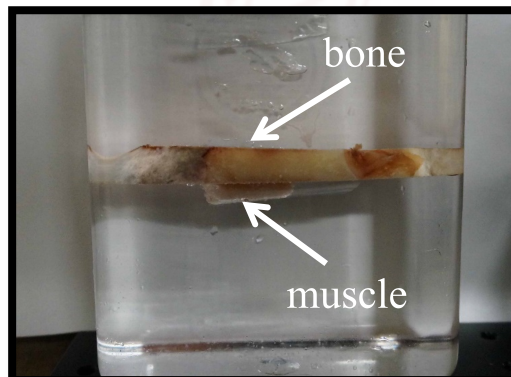


Imaging Examples



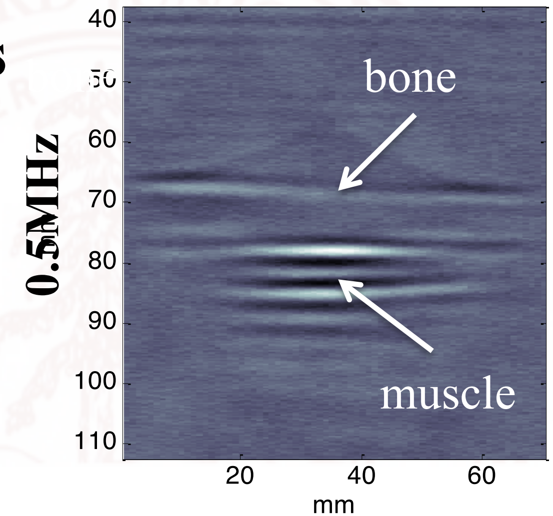
Immersion Transducers

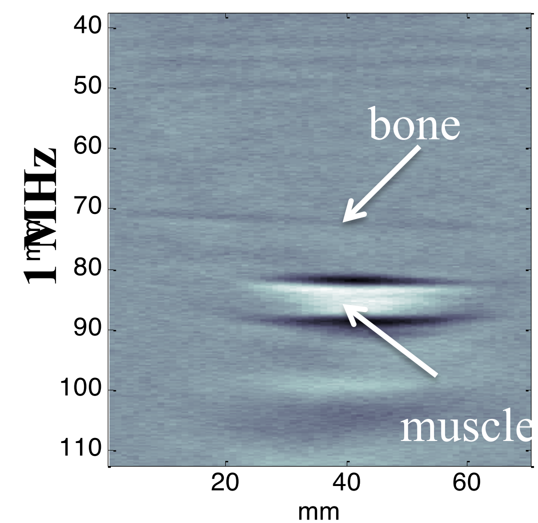




Resolution approaching millimeters

After Reconstruction





DARPA awards three contracts to detect IEDs hidden in mud, meat, and dead animals

April 12, 2013
By John Keller
Editor

Non-Contact Detection in Material with Very High Loss

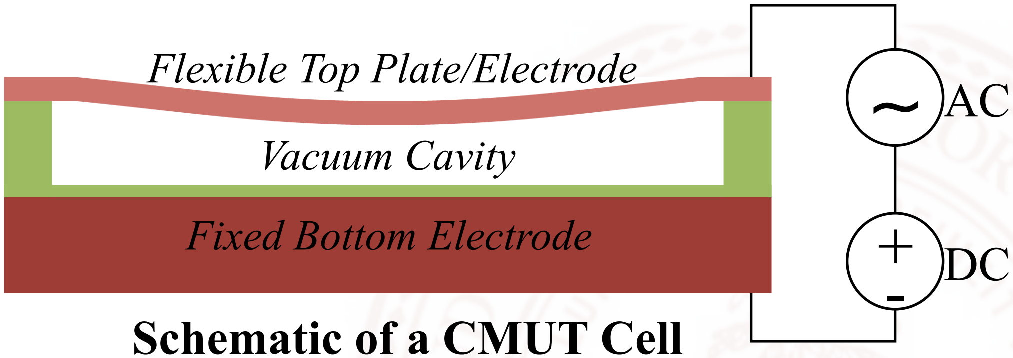
ARLINGTON, Va., 12 April 2013. Improvised explosive device (IED) experts at three research organizations are working to develop non-
hidden in opaque media
mud, meat, and animal
the U.S. Defense Advan
Arlington, Va.

Quasar Federal System
Arizona in Tucson, Ariz.
Va., are working on the
Detection at Standoff (M
and imaging methods to

packaged in mud or meat.

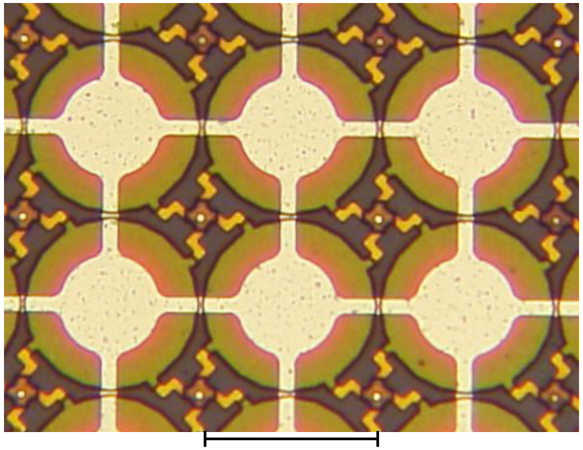
http://www.militaryaerospace.com

Capacitive Micromachined Ultrasonic Transducer (CMUT)

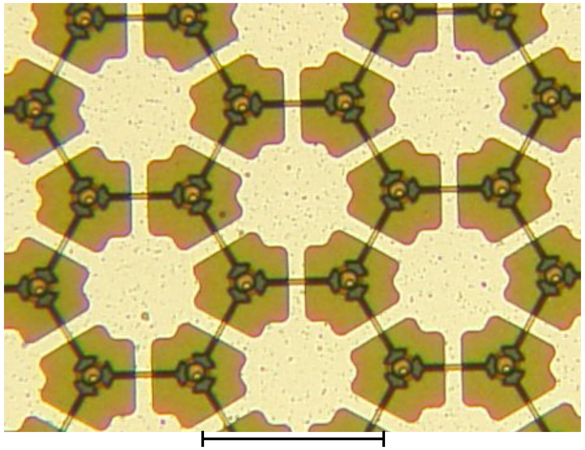


Schematic of a CMUT Cell

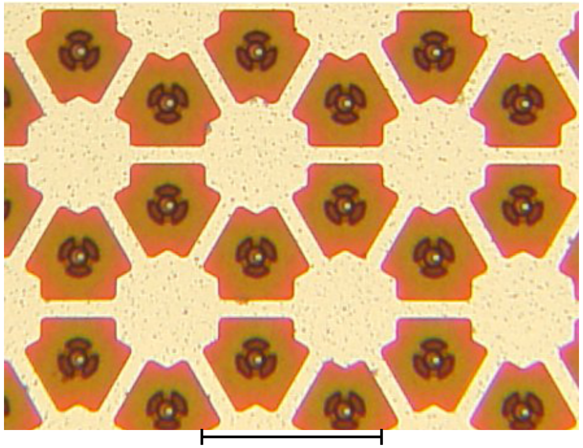
In a typical realization, many CMUT cells operate in parallel.
CMUT Cells can be circles, squares, rectangles, tent structures, etc.



80 µm
Circular cells



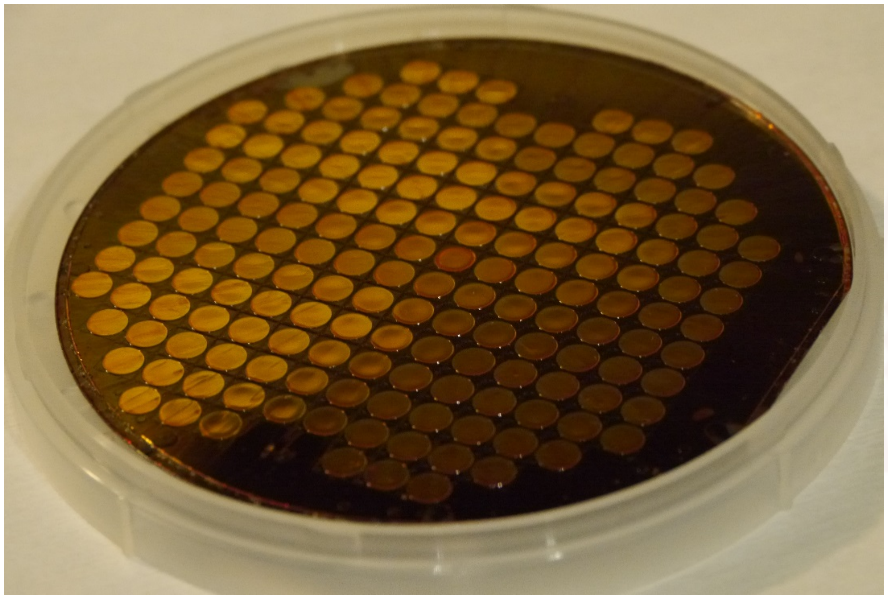
80 µm
Hexagonal cells



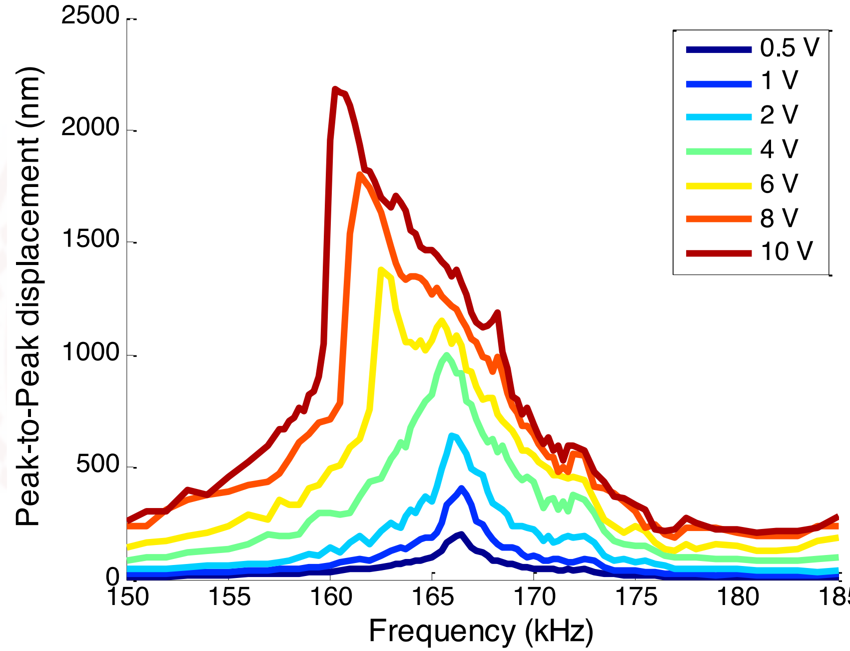
80 µm
Tent cells

Fabricated Airborne CMUTs

Vented CMUTs



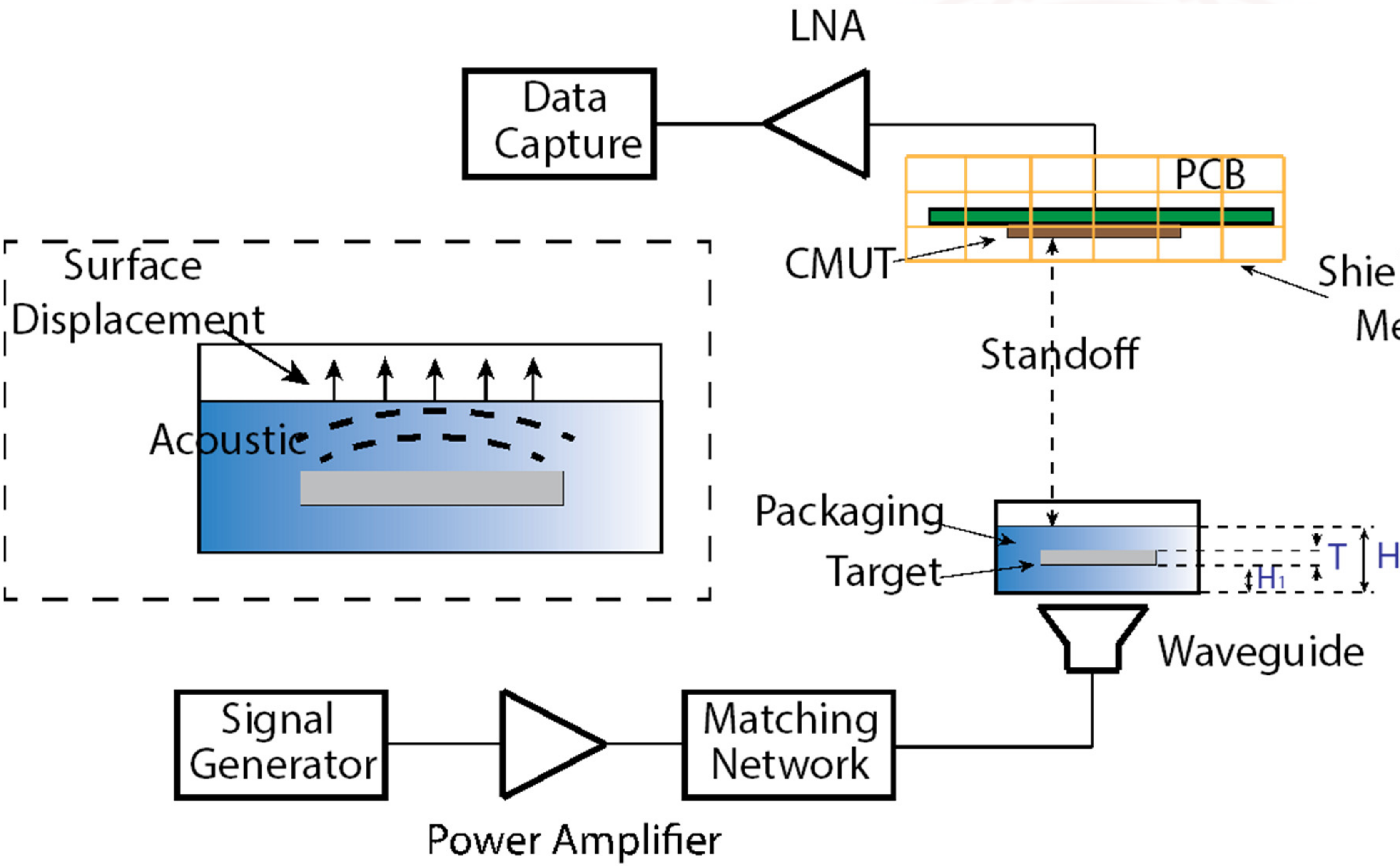
Photograph of a completed 4” wafer



Laser Doppler vibrometer measurement results

- Optimized transducer/ signal chain for sensitivity
  - Custom CMOS RX + vented CMUTs w/ squeeze film damping
  - Minimum detectable pressure: 240 µPa (unfiltered)
  - Within **6dB of the mechanical noise floor**

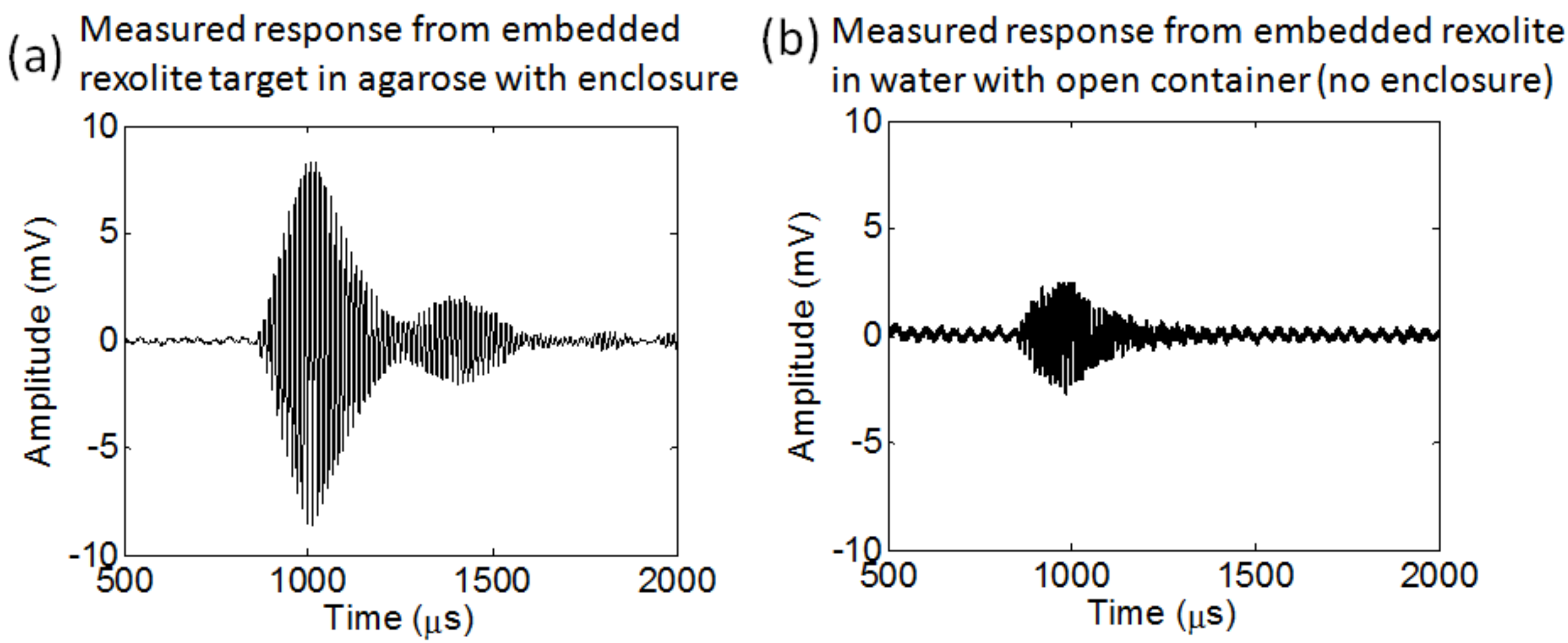
Imaging Setup



Rexolite- Agarose Interface

Agarose target above 4mm of Rexolite

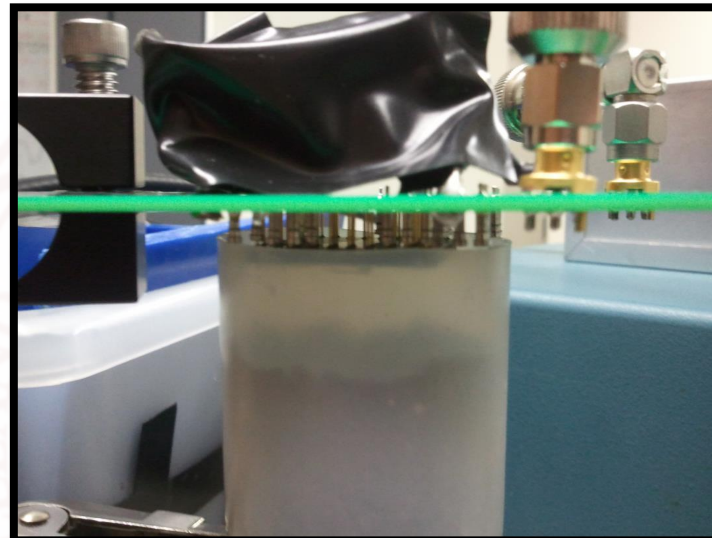
- **36 dB SNR for Non-Contact Detection**

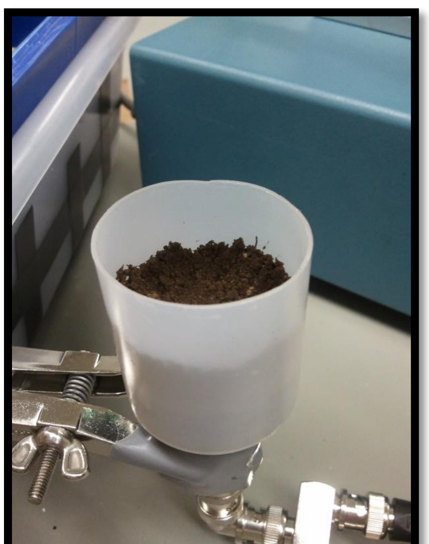


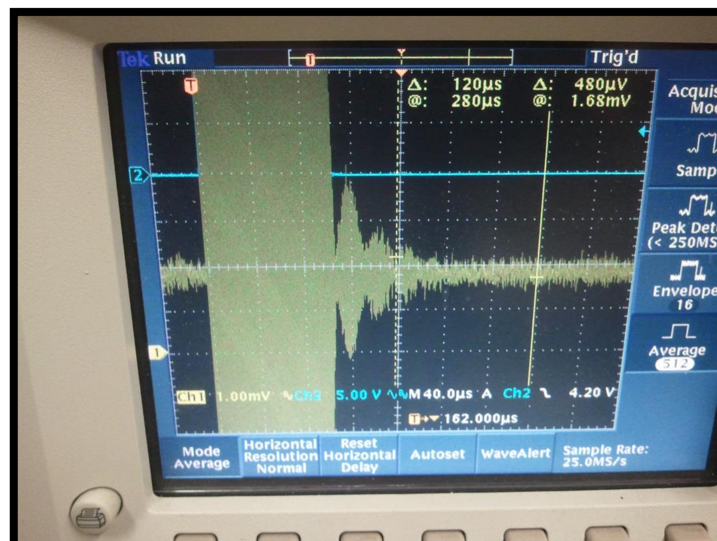
H. Nan and A. Arbabian, "Stepped-Frequency Continuous-Wave Microwave-Induced Thermoacoustic Imaging," *Appl. Phys. Letters*, Vol. 104, pp. 224104, 2014.

Early Experiments in Soil

- Pitch-Catch Measurements in Soil (@ 1MHz)







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