

# DC-GHz Micromachined Capacitive Air Transducers

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## Report Documentation Page

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# Outline

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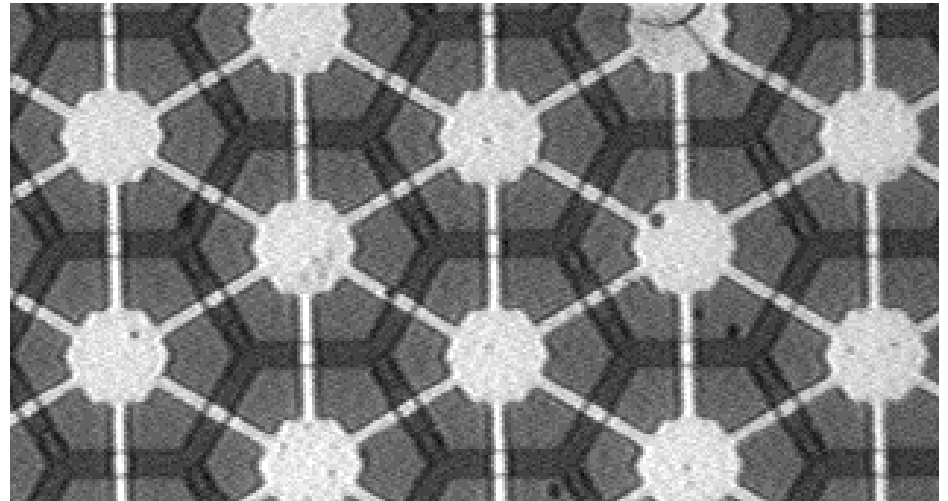
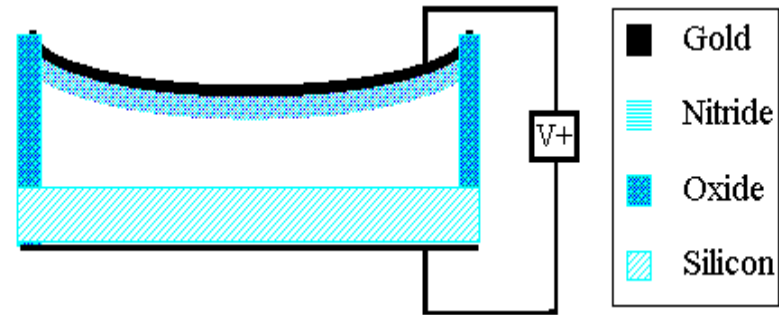


- Introduction and Approach
- Traditional detection and performance of resonant capacitor transducers
- Broad band detection and potential improvement in sensitivity
- Conclusions

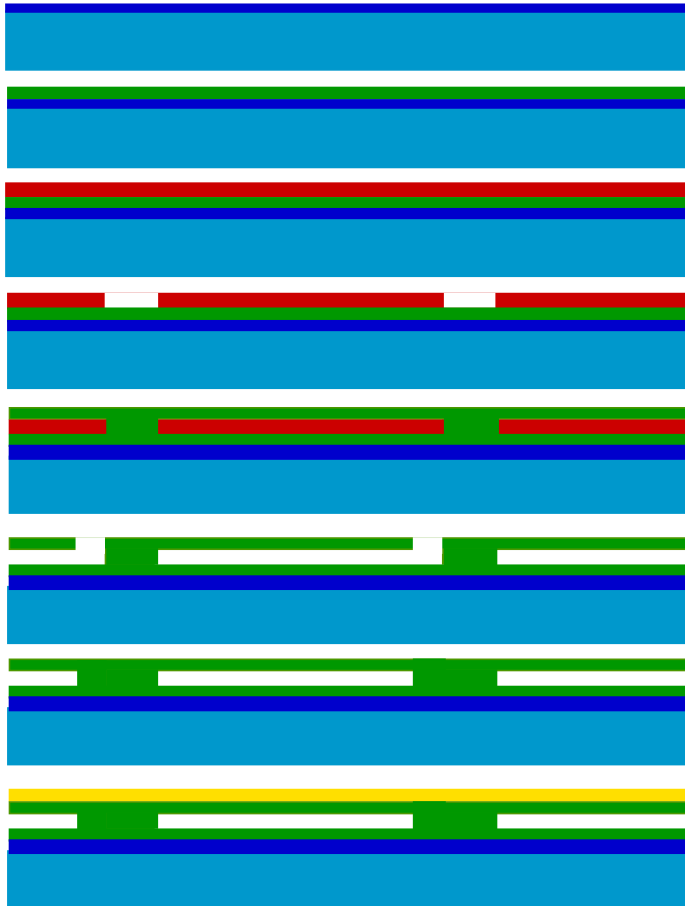
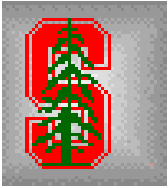
# Capacitor Micro-machined Ultrasonic Transducer (cMUT)



- Thin ( $\sim 1 \mu\text{m}$ ),  $50 \mu\text{m}$  radius, metalized nitride membranes suspended above silicon substrate.
- Several thousand electrically connected in parallel form the transducer.
- Resonant structure has dynamic range in excess of 100 dB.
- Electric field  $10^9 \text{ V/m}$

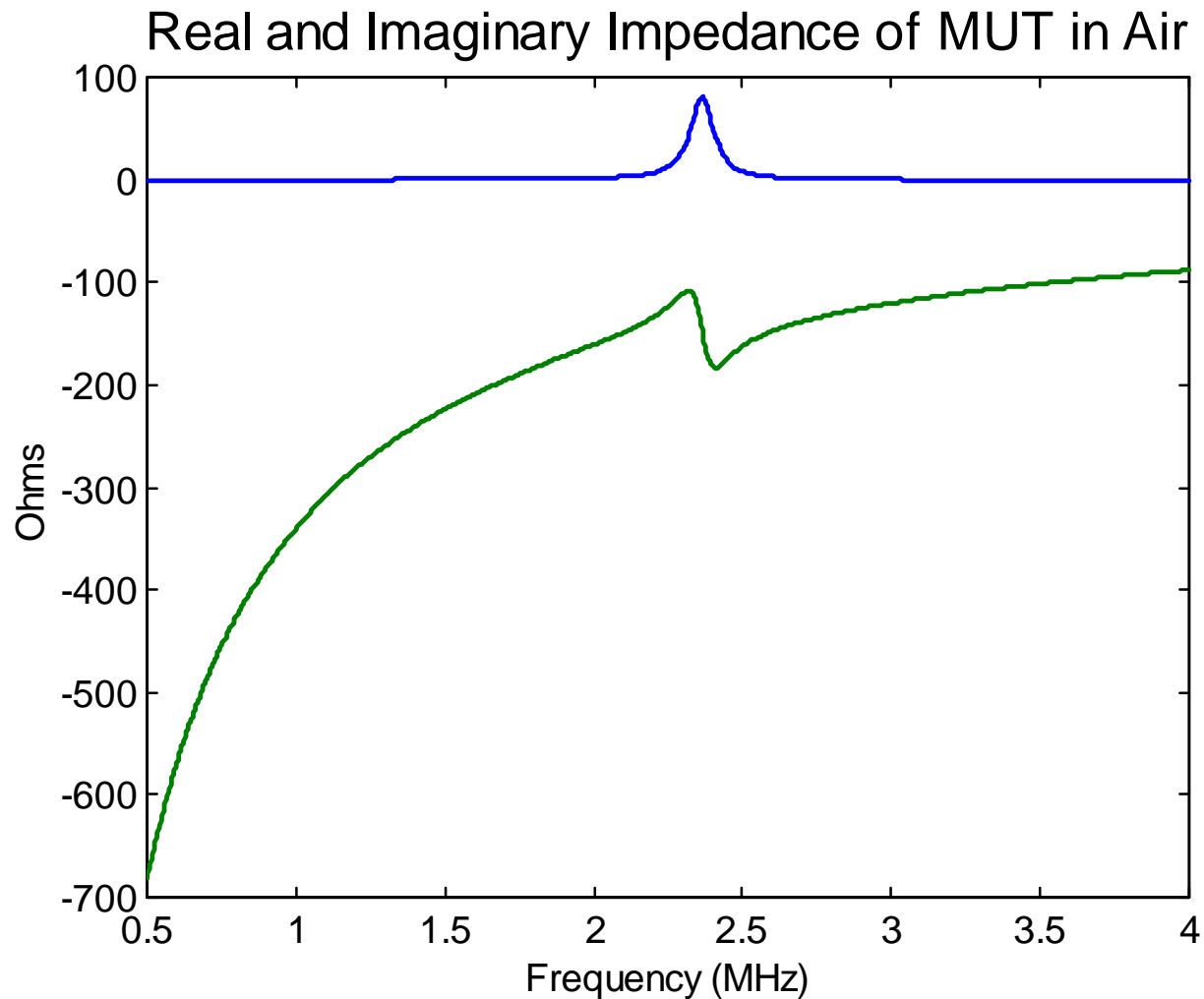
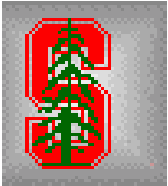


# Fabrication Process



- High density doping
- LPCVD nitride deposition
- Amorphous silicon deposition
- Lithography and etch
- LPCVD nitride deposition
- Via and sacrificial etch
- Vacuum sealing
- Metal deposition and patterning

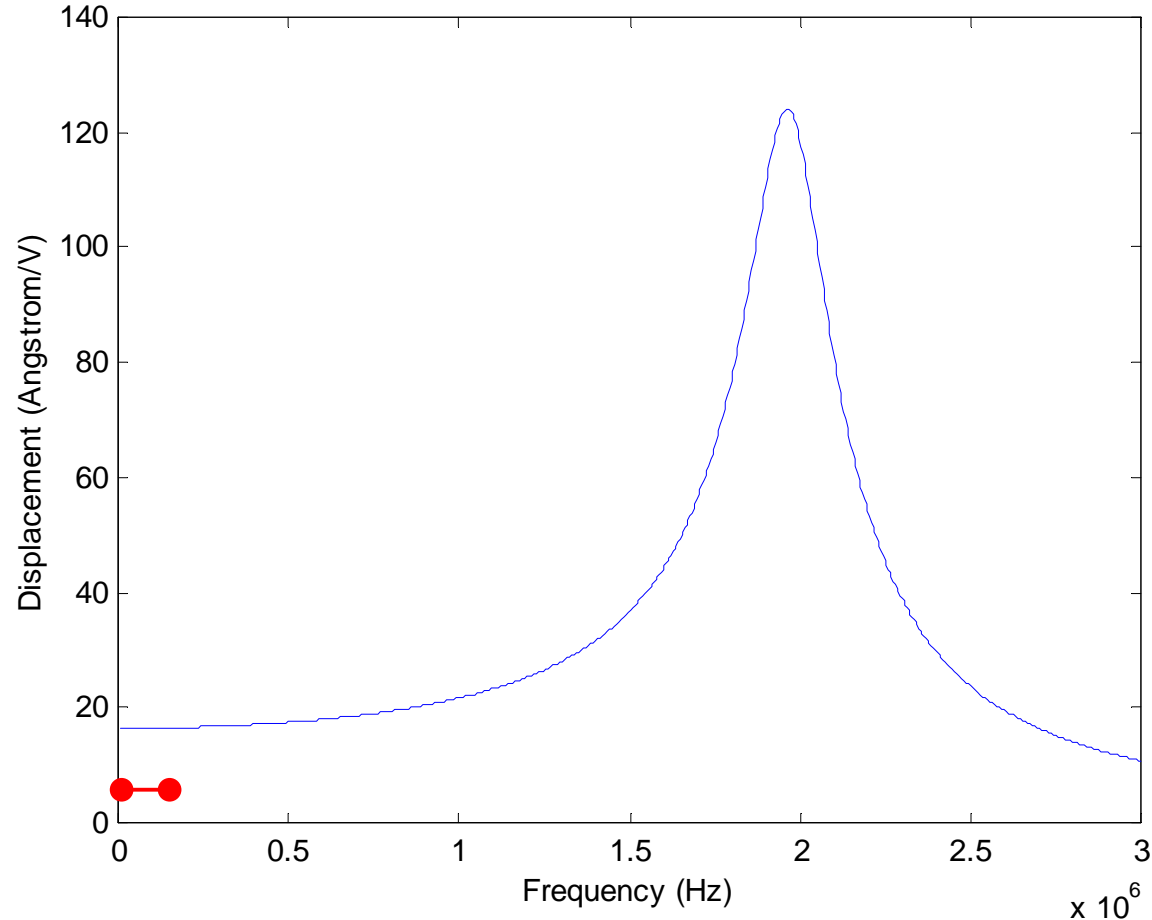
# Input Impedance of cMUT in Air



# Average Displacement of a Membrane



Displacement vs. Frequency  $V_{dc} = 213$  V,  $V_{collapse} = 213.3032$  V,  $C_{device} = 361.7644$  pF

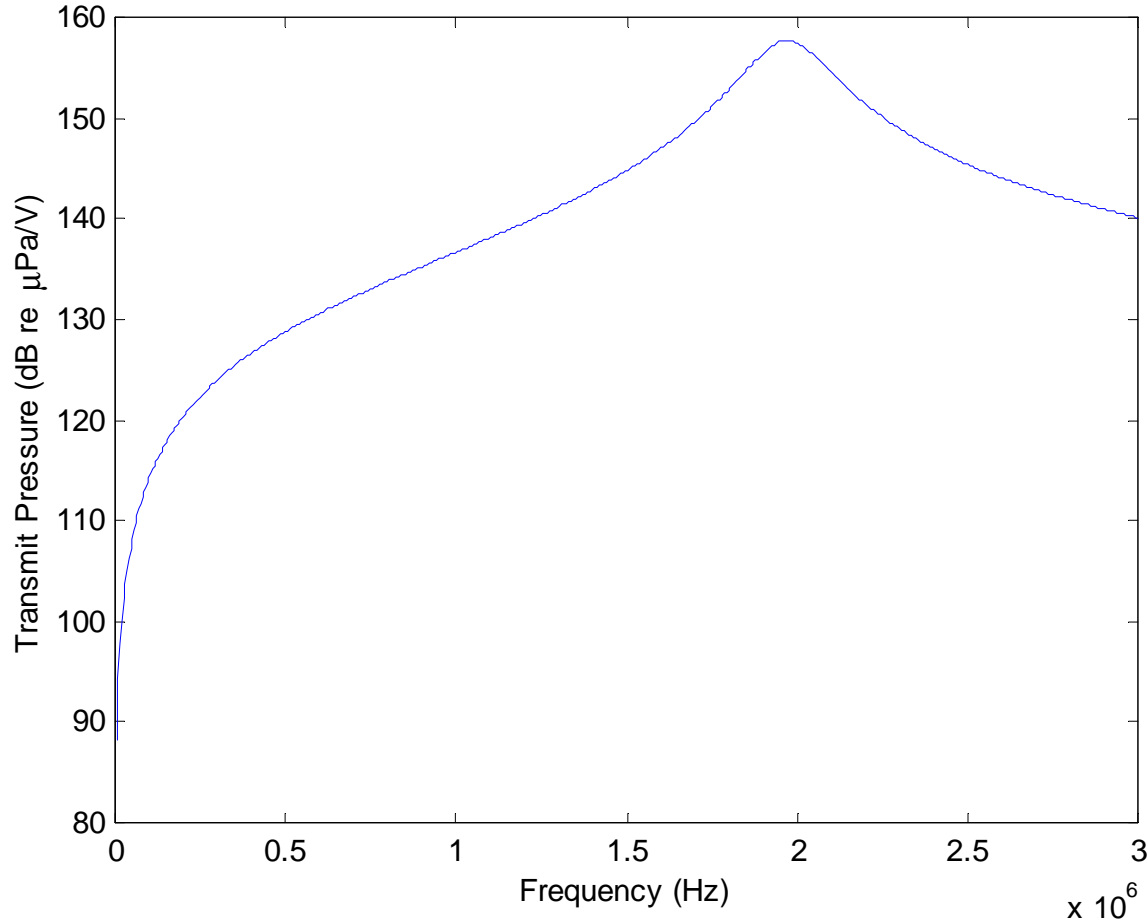


Broad band operation below resonance



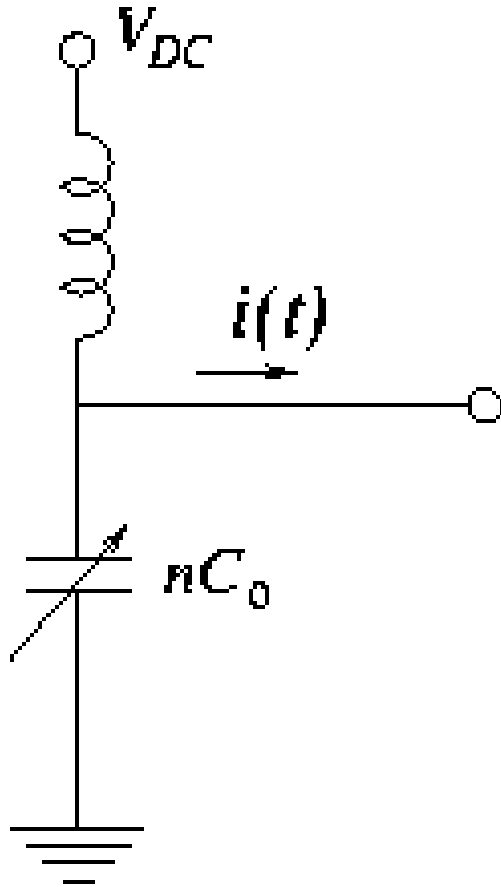
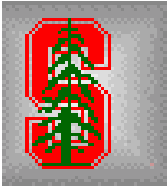
# Transmit Pressure of cMUT

Transmit Pressure vs. Frequency;  $V_{dc} = 213$  V,  $V_{collapse} = 213.3032$  V,  $C_{device} = 361.7644$  pF





# Conventional Detection



$$I_{out} = V_{DC} 2\pi f_1 n C_0 \frac{\Delta x}{x_0}$$

# Receive Output of Conventional Detection Method



1cm x 1cm X-ducer

Membrane:

50  $\mu$ m diameter

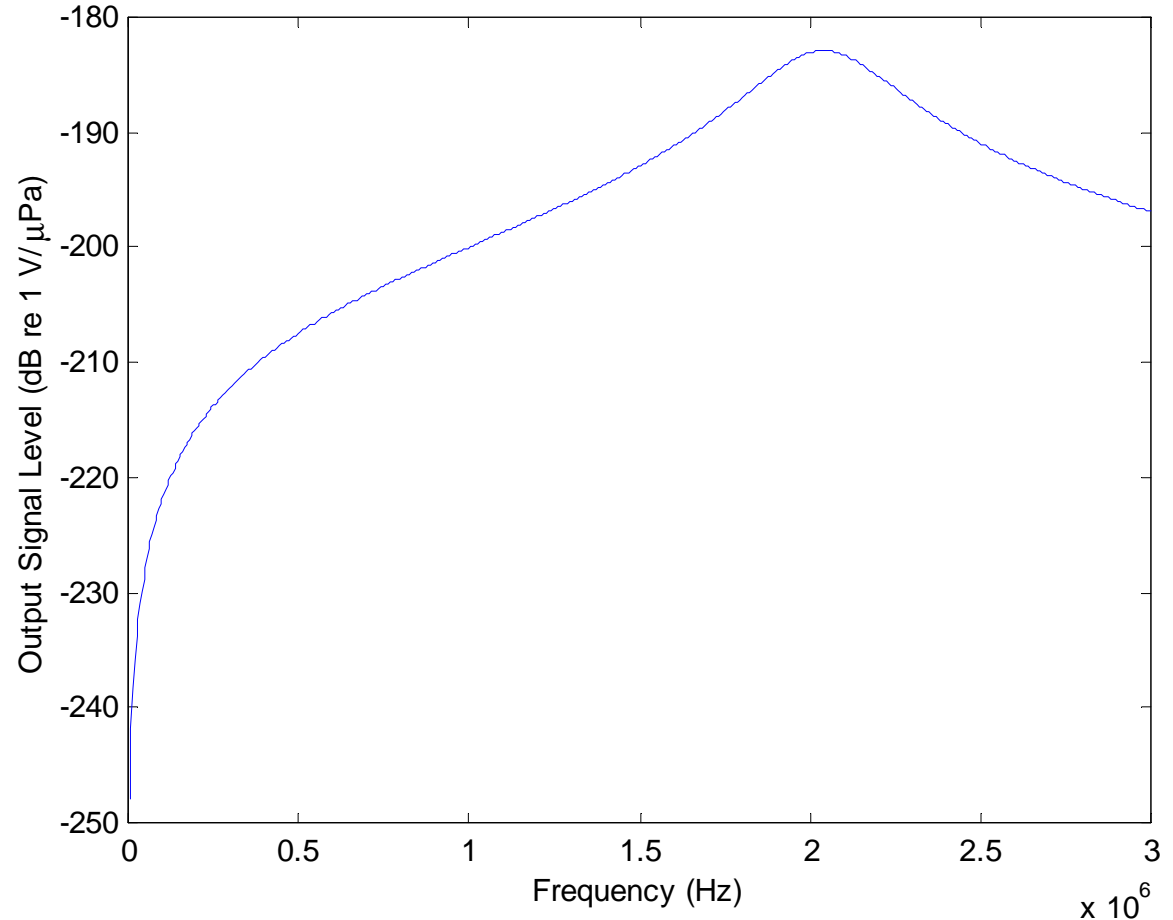
1  $\mu$ m gap

1  $\mu$ m thickness

Silicon Nitride

20% Parasitic C

Output Signal Level vs. Frequency  $V_{dc} = 213$  V,  $V_{collapse} = 213.3032$  V,  $C_{device} = 361.7644$  pF



# Signal to Noise Ratio of Receiver



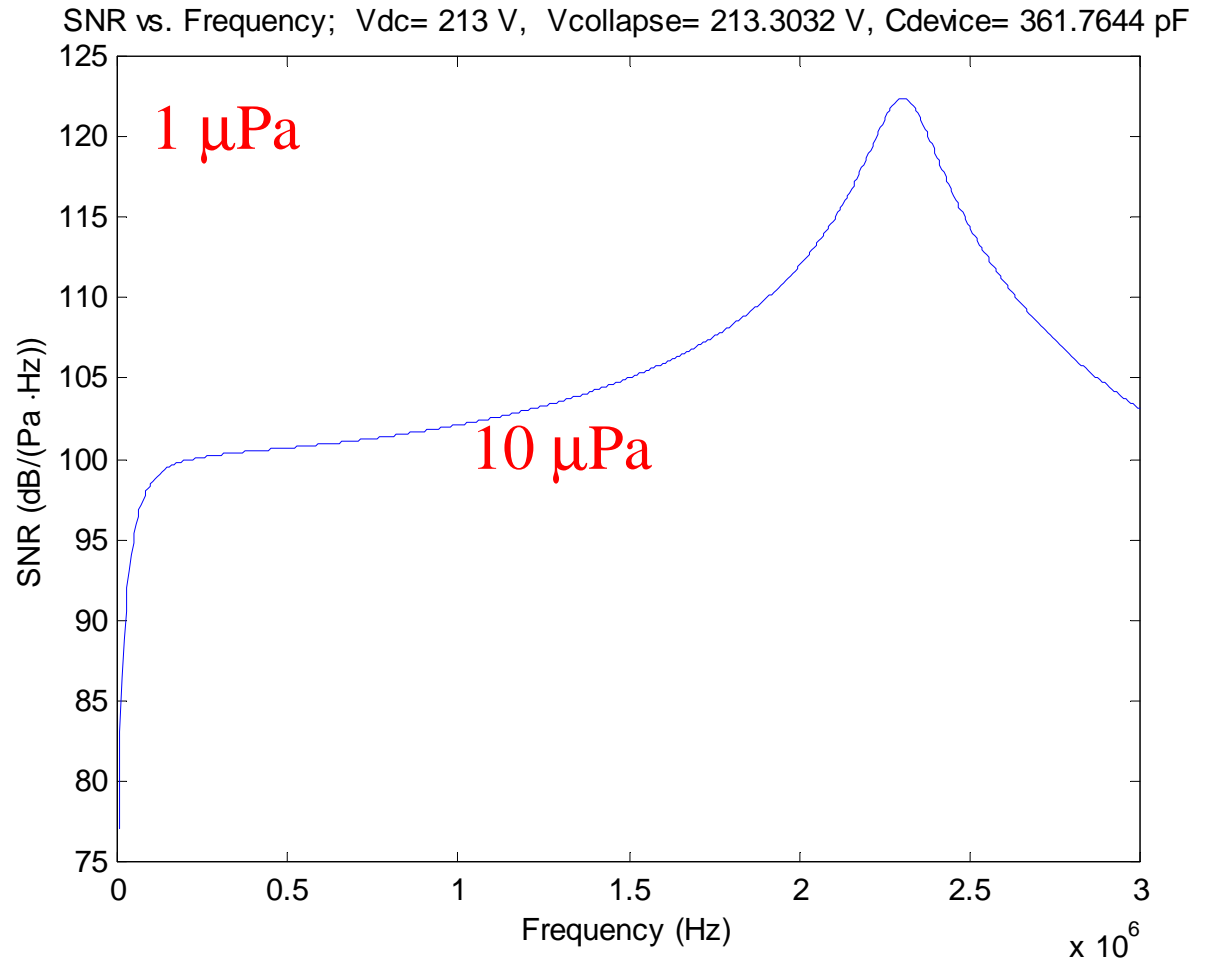
Amplifier:

$$R_{in} = 100 \text{ } \hat{\Omega}$$

$$C_{in} = 1 \text{ pF}$$

$$V_{na} = 1.4 \text{ nV}/\sqrt{\text{Hz}}$$

$$I_{na} = .01 \text{ pA}/\sqrt{\text{Hz}}$$

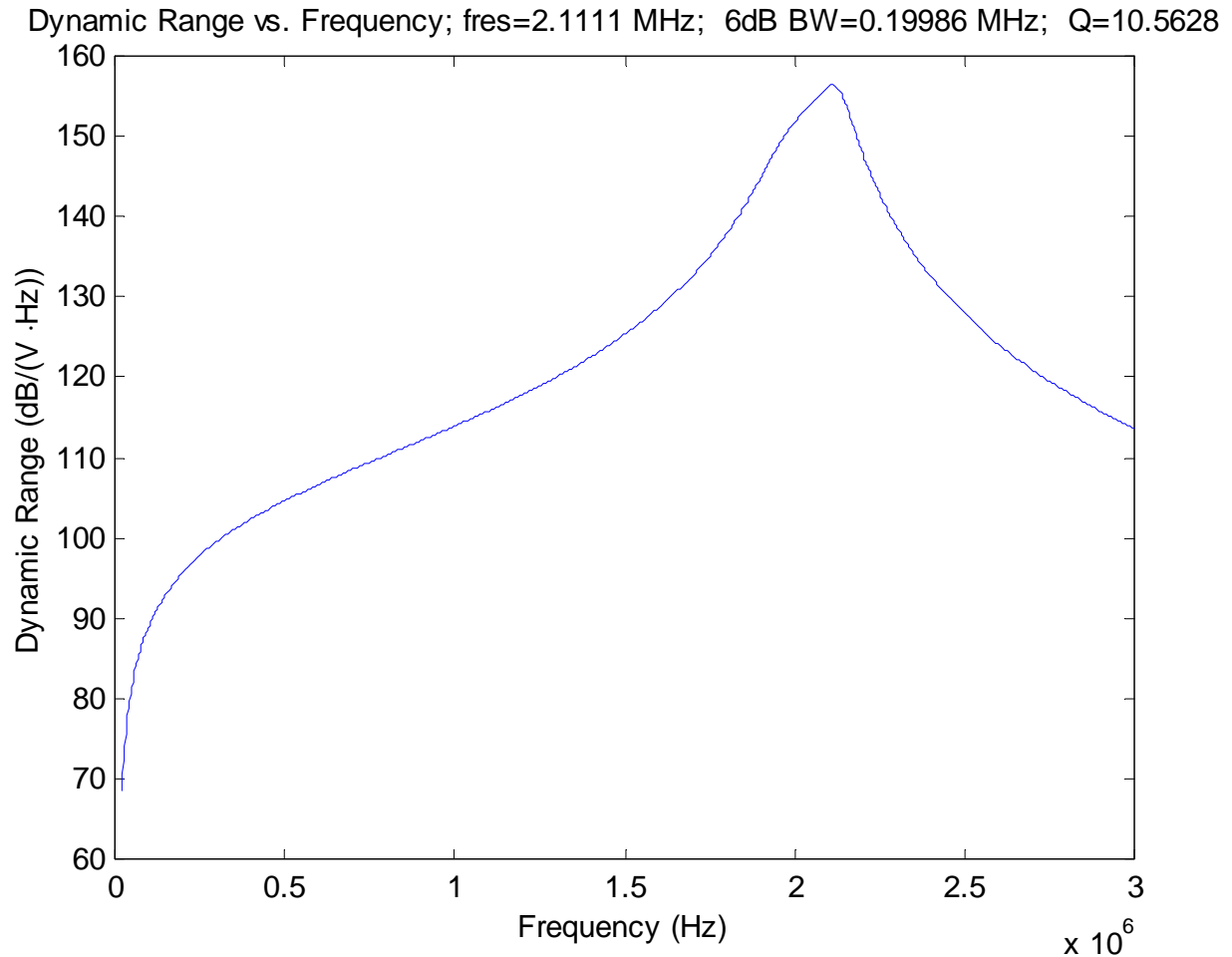


# Dynamic Range of cMUT Air Transducer System

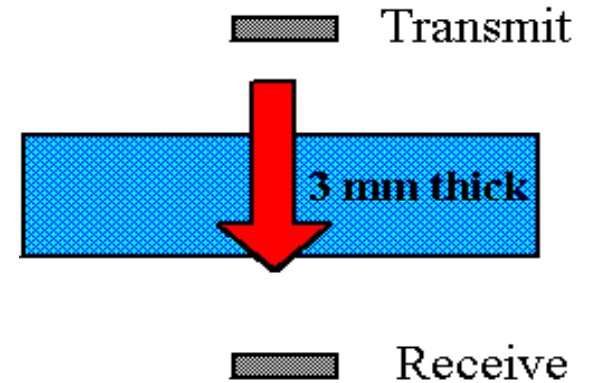
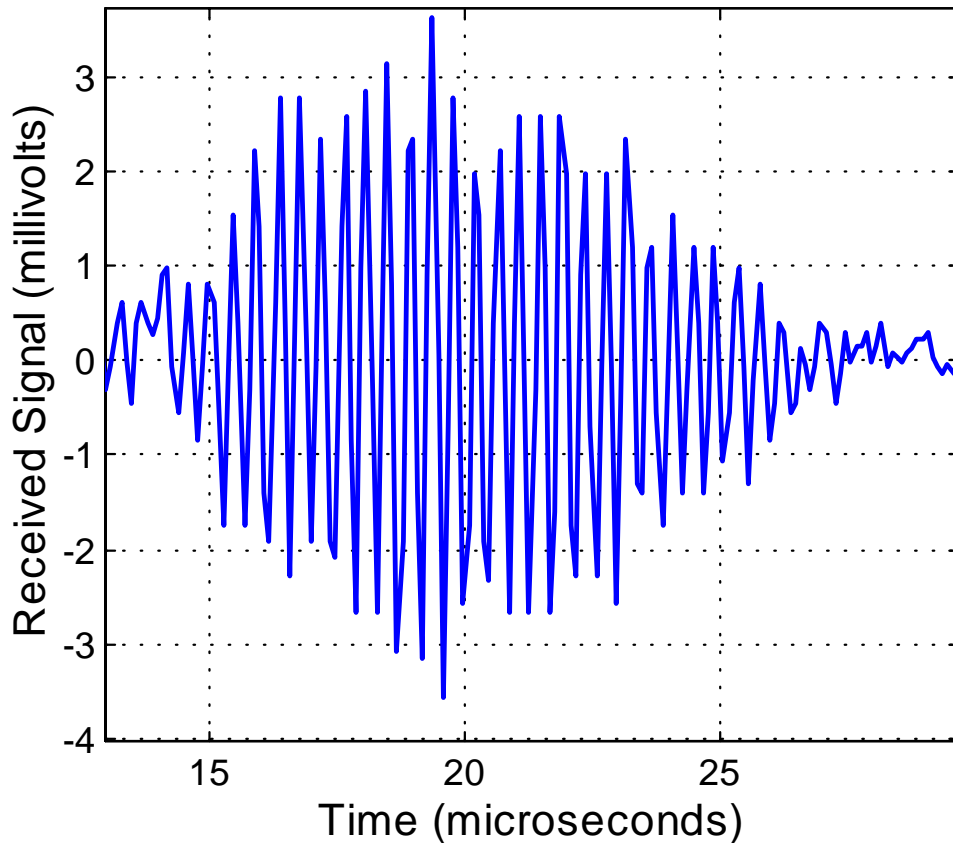
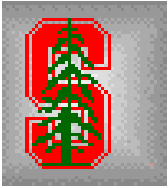


Transmitter:  
Source  $R = 50 \Omega$

Receiver:  
Previous slide

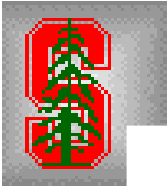


# Transmission Through Aluminum at 2.3 MHz

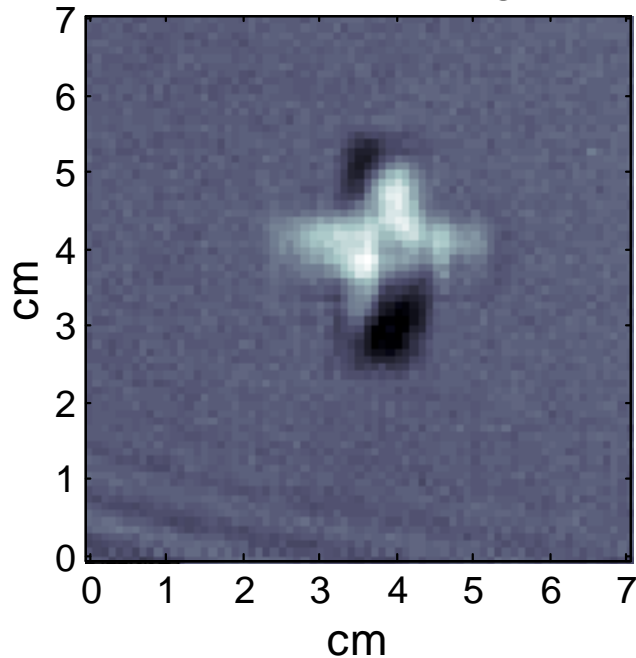


**82 dB loss in 3 mm Al**  
**16 dB SNR**  
**+ 5 dB loss in 0.6 cm air**  
**103 dB System**  
**Dynamic Range**

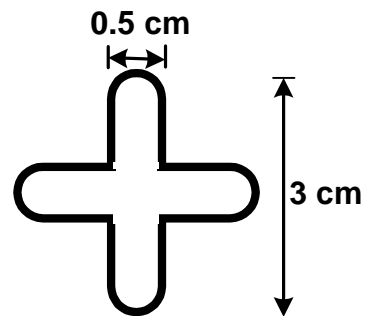
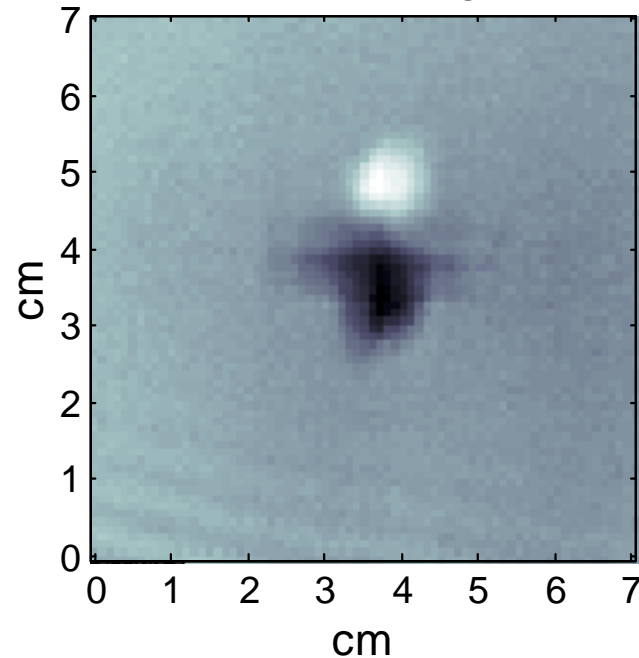
# Transmission Image of Aluminum



Amplitude image



Phase image

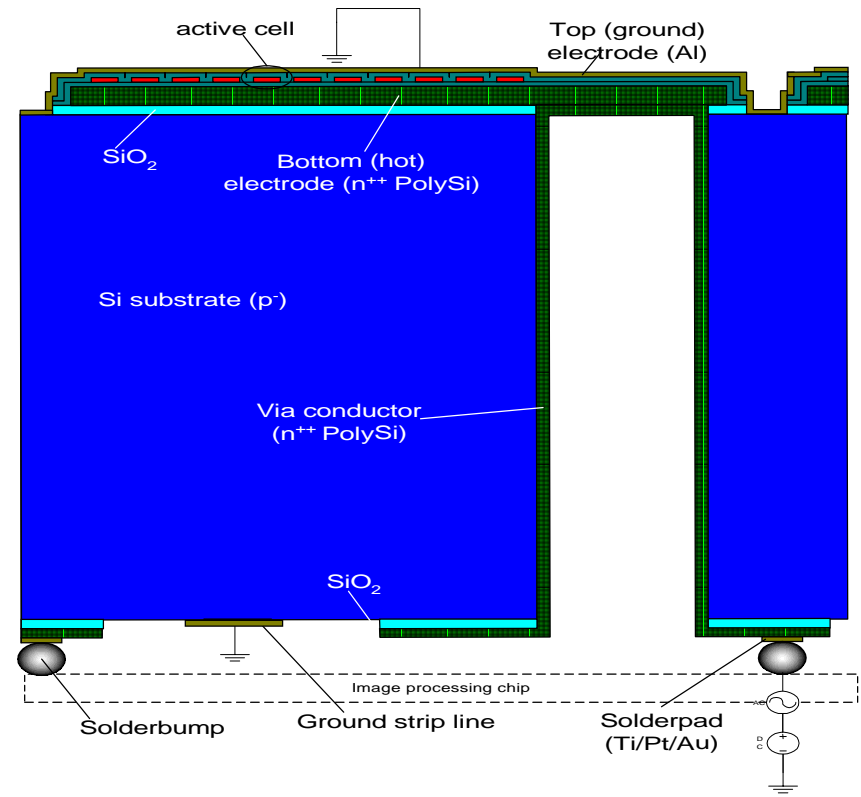
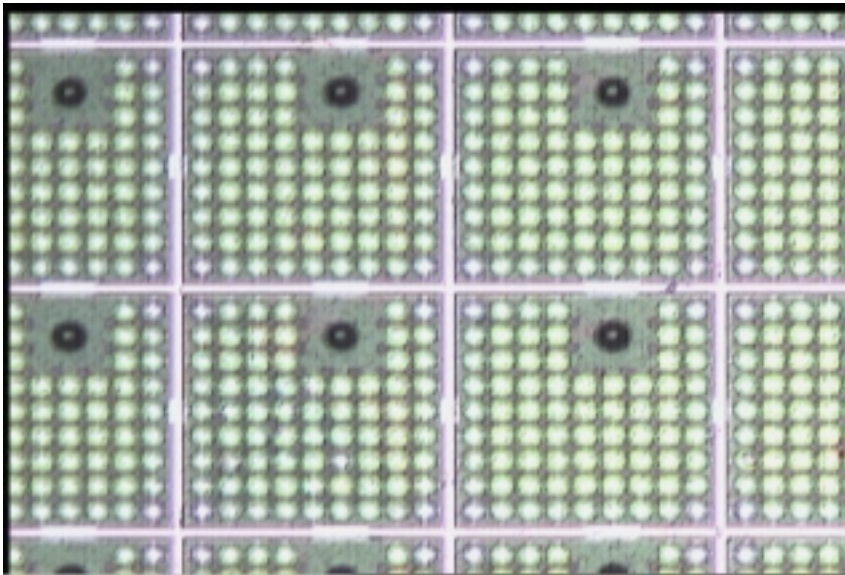


0.5 mm deep milled pattern  
on underside of 3 mm thick  
aluminum

# Accomplishments of Present Technology



- Large dynamic range systems from **800 kHz - 11 MHz**
- Single element, 1-D and 2-D arrays
- Through wafer contact vias
- Flip-chip bonding to integrate ultrasonics and electronics

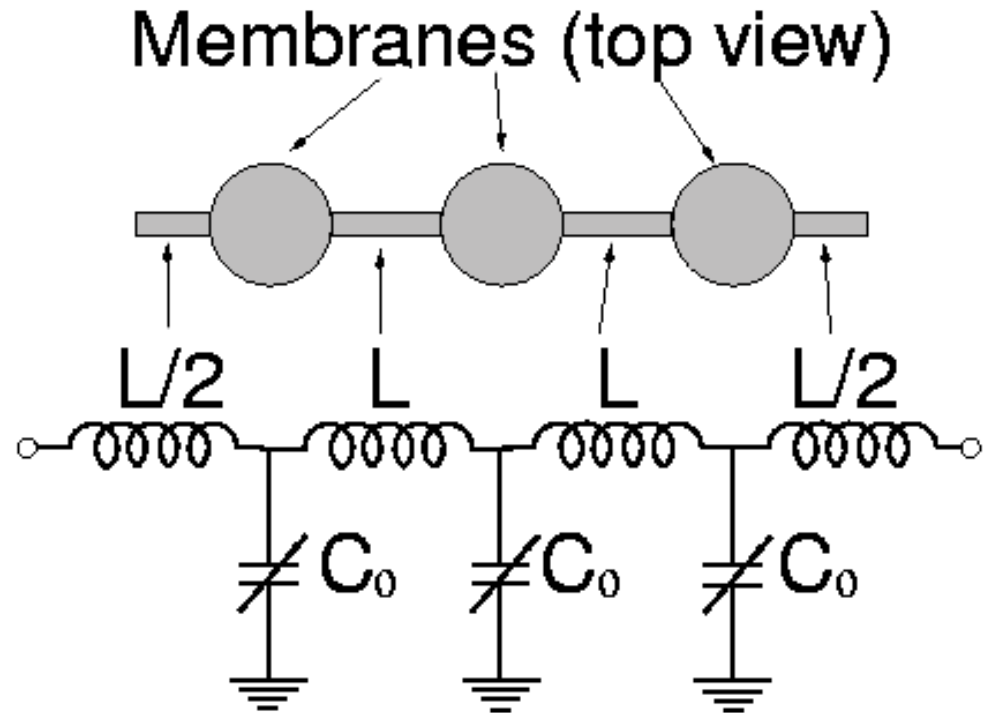


# Broadband Detection: cMUTs as Elements of a Transmission Line



$$Z_a = \sqrt{\frac{L}{C_0}}$$

$$\beta = 2\pi f_0 \sqrt{LC_0}$$



Incident sound wave modulates the phase of an HF signal applied to the transmission line.



# Comparison of Conventional and Broadband Detection Schemes



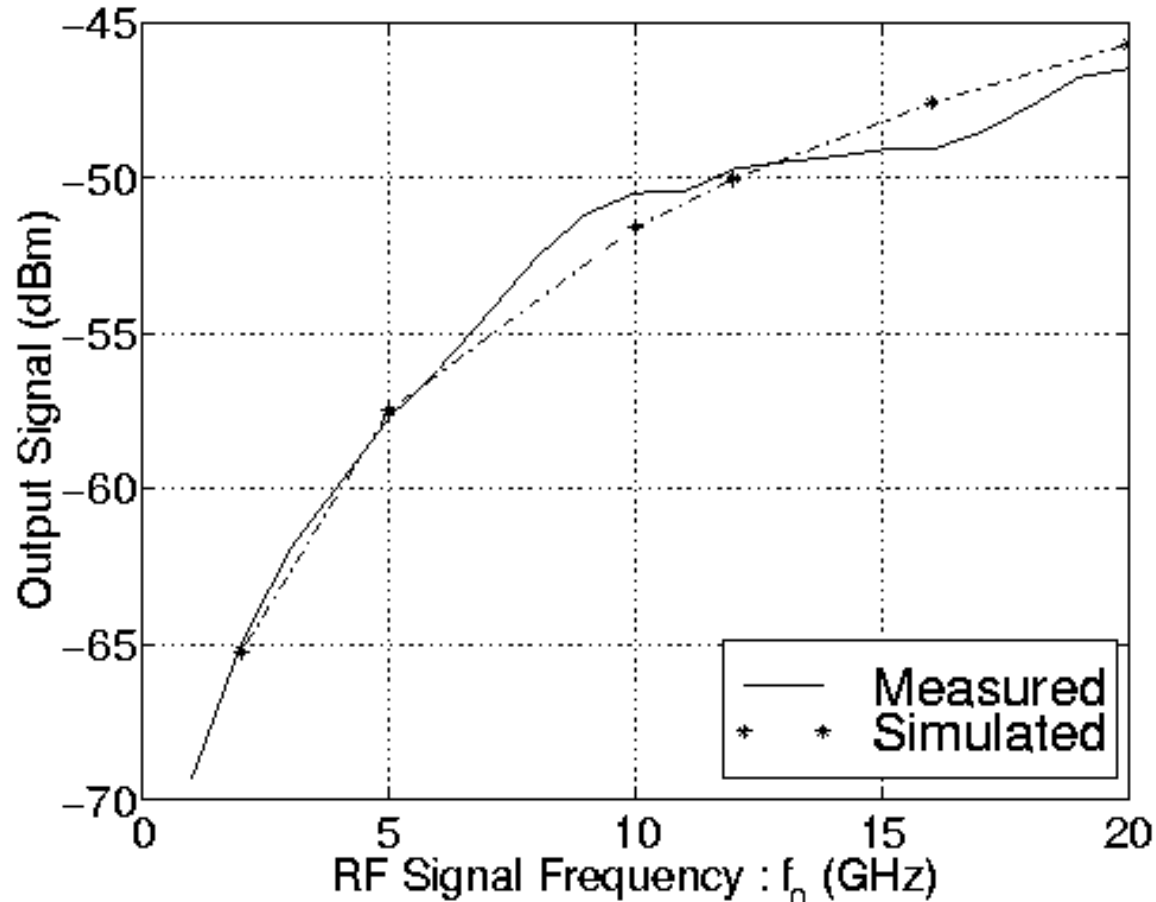
$$I_{out} = V_{DC} 2\pi f_1 n C_0 \frac{\Delta x}{x_0}$$

$$I_{out} = \frac{V_{RF}}{4} 2\pi f_0 n C_0 \frac{\Delta x}{x_0}$$

- Higher Sensitivity
- Broadband
- No dc necessary
- The lower the frequency, the better the sensitivity

Variable	Typical
$V_{RF}$	2 V
$V_{DC}$	100 V
$f_0$	10 GHz
$f_1$	0.1 MHz
Ratio	500

# Broadband Detection: Experimental Results



Courtesy of Ergun and Atlalar (Bilkent University)

# Conclusions

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- Surface micromachining can achieve low frequency (20-200 kHz) receivers.
- A broadband detection scheme allows operation over dc-GHz range.
- 1-D and 2-D arrays enable direction sensing.
- Through wafer vias enable integration to electronics via flip-chip bonding.