Electronics for Diagnostic Ultrasound

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The Road to Miniature Ultrasound…

Expected World Ultrasound market in 2008: $5Billion

- InMedica

Expected Compact Ultrasound market in 2011: $1Billion

- Klein Biomed. Cons.

Console

Standard of care

Radiology/Hospital

> $125k

Portable

Convenience

Specialists

~$25k-$75K

Handheld

Ubiquitous Ultrasound

General Practice

< $10k

“Democratization” of imaging equipment
Moore’s Law affects everything but the probe

Where does Ultrasound fit…?

Imaging Type	Ionizing	IQ	2D/3D	Real-time	Portable	Cost	Molecular Imaging
MR	No	High	2D/3D	No	No	High	Yes
CT	Yes	High	2D/3D	No	No	High	Yes - PET/CT fusion
US	**No**	**Med./High**	**2D/3D**	**Yes**	**Yes**	**Low**	**Potentially - bubbles**
X-Ray	Yes	High	2D	Yes	No	Medium	No
PET/Nuclear	Yes	Low	2D	No	No	High/Med.	Yes

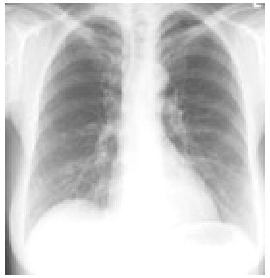
Magnetic Resonance

$1.5Million (+$250K infrastructure)

Computed Tomography/PET

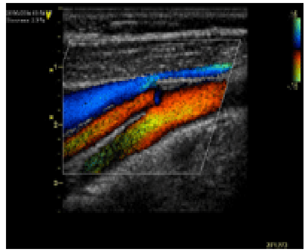
$1Million - $2.5Million

- MR, CT, XRAY all ***physics*** limited



X-Ray

$25K-$200K



Ultrasound

$25k-$75K

- Affordable, high quality real-time imaging
- ***Electronics*** limited

How is Ultrasound Used…?

Application	Steered	Probe	2D/3D	Depth	Resolution	Examples of Clinical Use
Cardiology	Yes	2D	2D/3D	2cm-16cm	2mm-3mm	Characterize heart function
OB/Gyn	No	Curved	2D/3D	2-20cm	2mm-3mm	Imaging fetus in 3D
IVUS	Yes	Linear	2D	<1cm	0.3mm	Asses severity of plaques
ICE	Yes	Linear	2D	1-5cm	0.5mm	Characterize heart function
General Imaging	Yes	Linear	2D	2-20cm	2-3mm	Locate cysts in liver/kidney
Vascular/ Small parts	No	Linear	2D/3D	1-5cm	0.3mm	Assess carotid plaques, breast tumors

OB/GYN

QuickTime™ and a Cinepak decompressor are needed to see this picture.

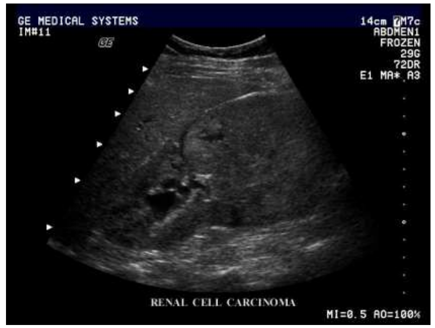
Cardiology

QuickTime™ and a Microsoft Video 1 decompressor are needed to see this picture.

Vascular

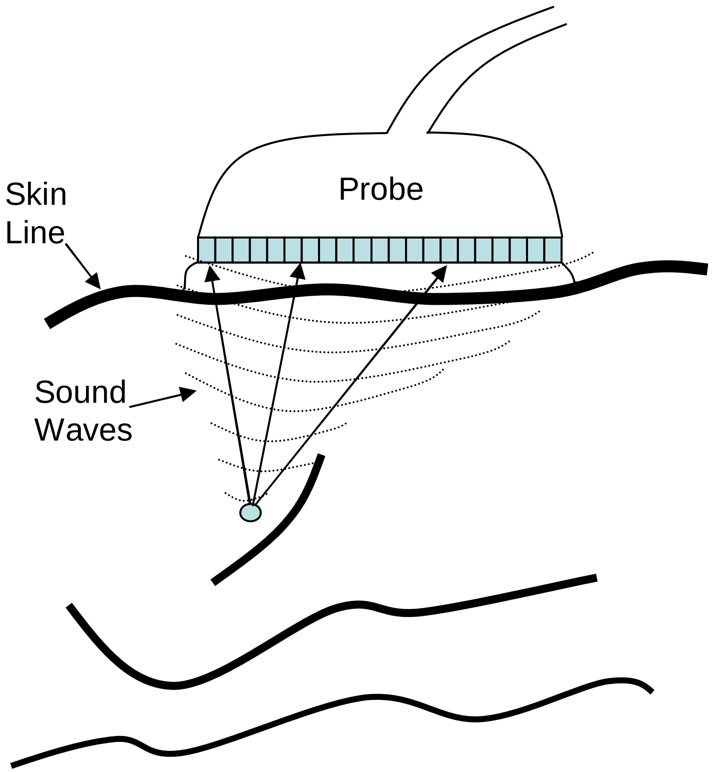
QuickTime™ and a YUV420 codec decompressor are needed to see this picture.

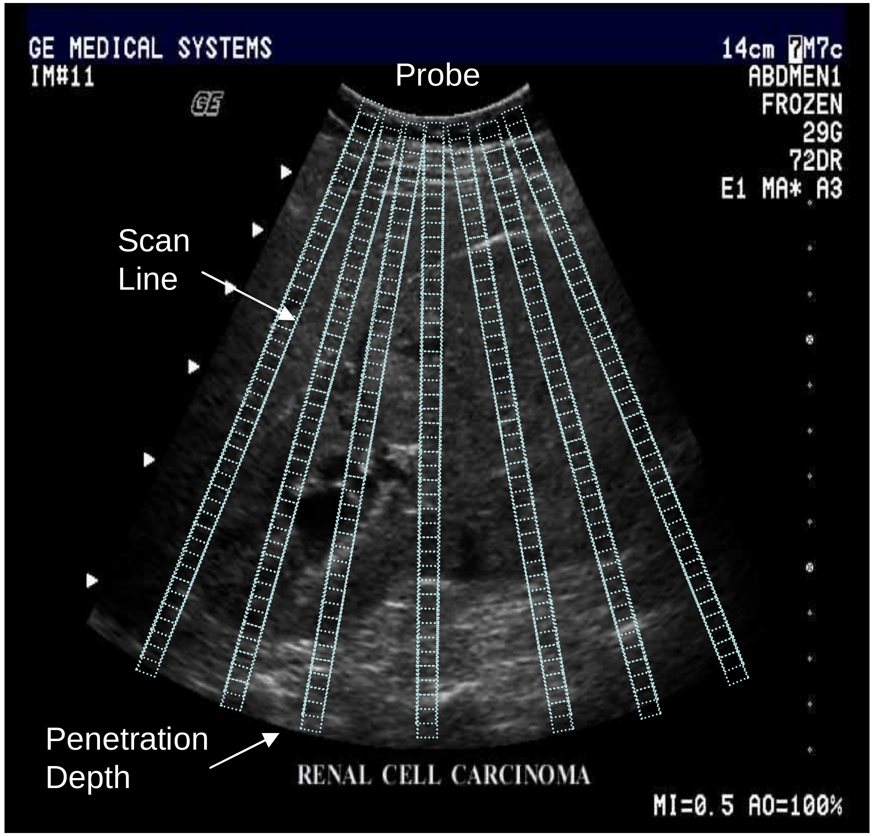
General Imaging



• Different clinical applications call for different probe designs

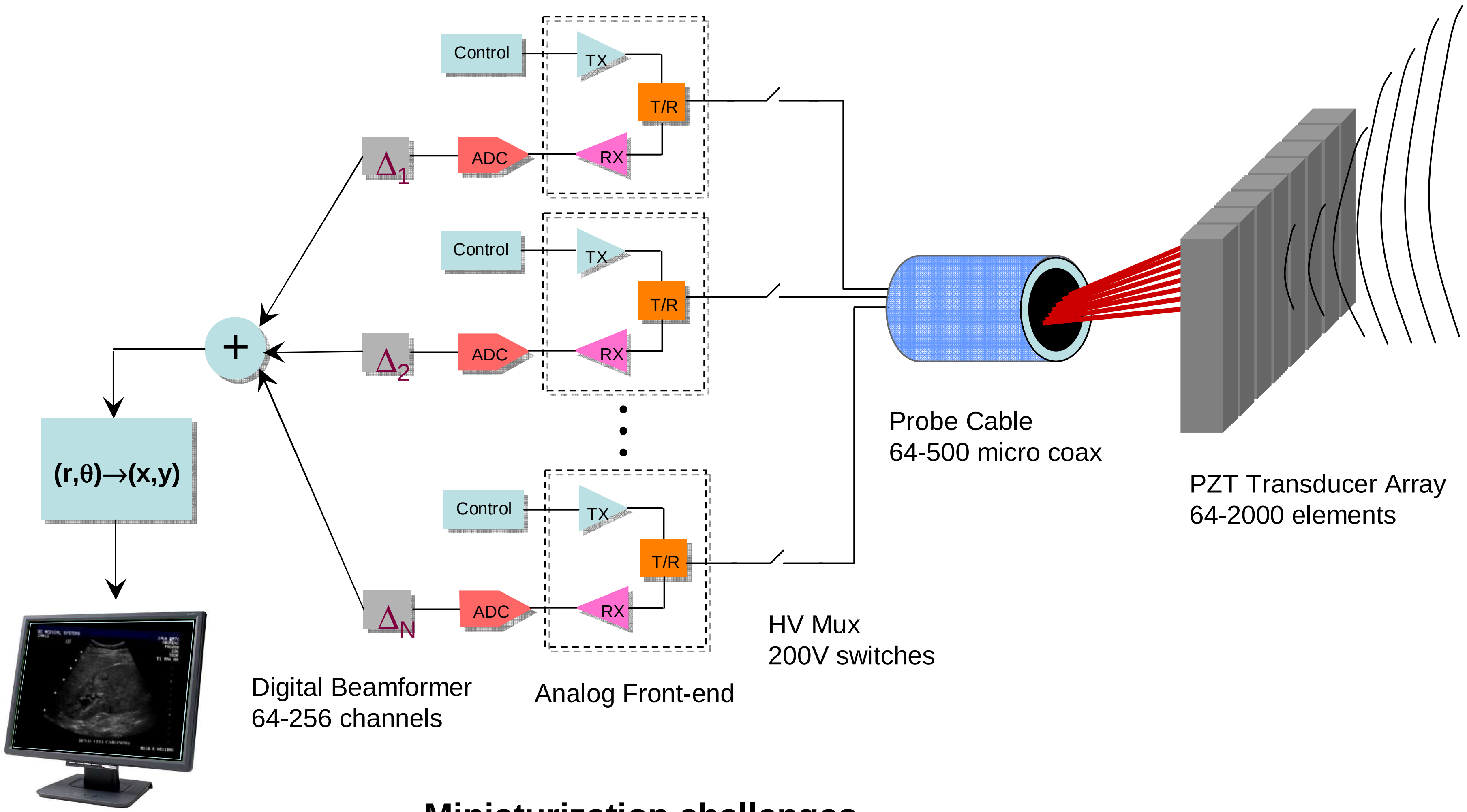
How do we image with Sound…?





- Ultrasound images by reflection from structures
- Build up 2D images using multiple scan lines
- Scanning/steering done electronically (mechanically in some systems)
- Strong reflections (e.g. bone) shadow deeper structures (issue in cardiology)
- Attenuation due to absorption (1dB/cm/MHz) → *120 dB Dynamic Range !*

Ultrasound System Diagram

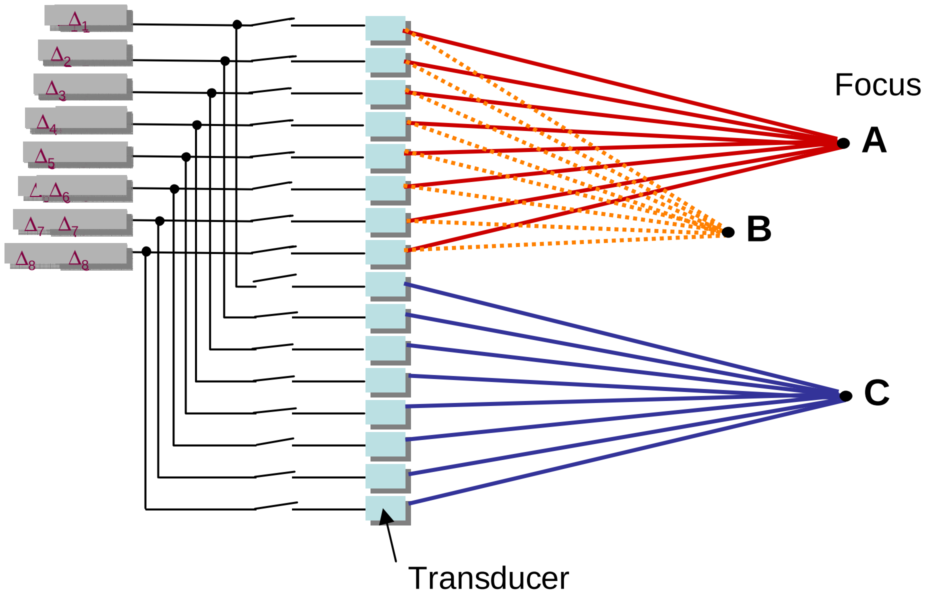


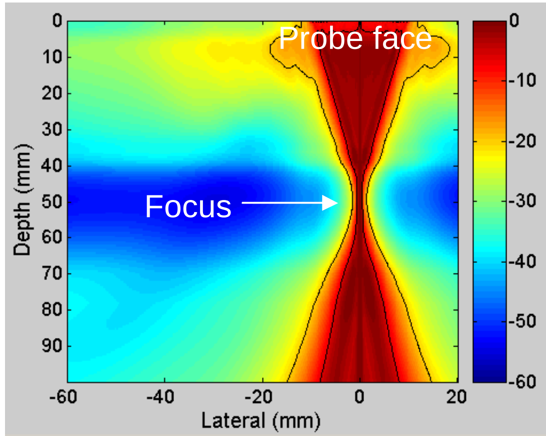
Miniaturization challenges

- Power (Tx and Rx)
- Large channel count
- Routing complexity
- Cable size (ergonomics)

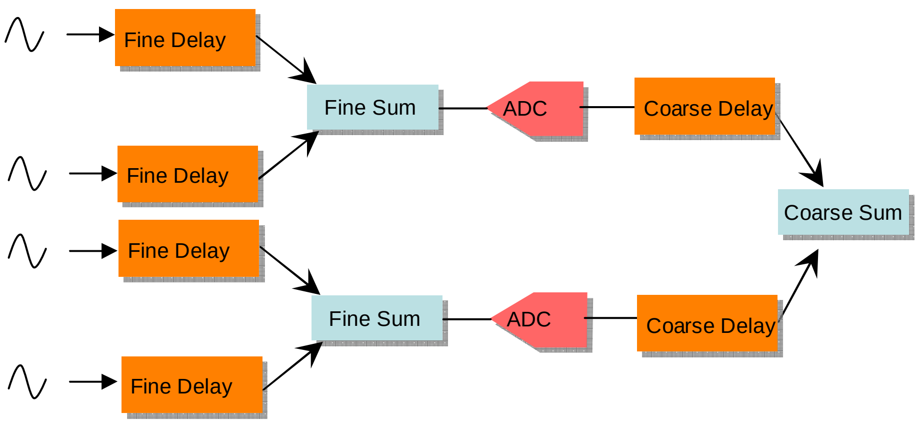
Movement of functionality into probe handle

Ultrasound Beamforming





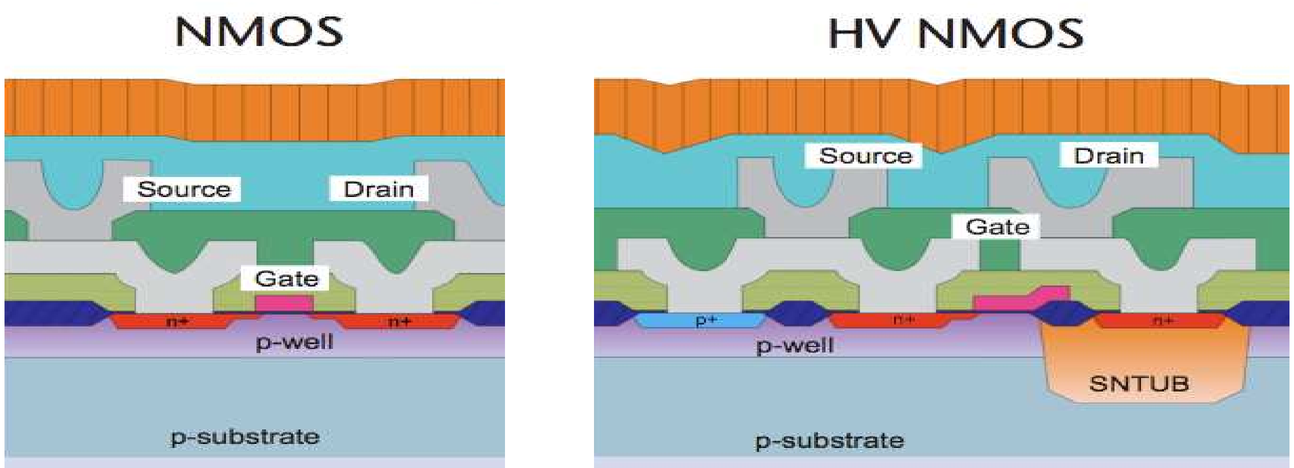
Adapted from R. Fisher, 2005, IEEE Ultra. Symp.



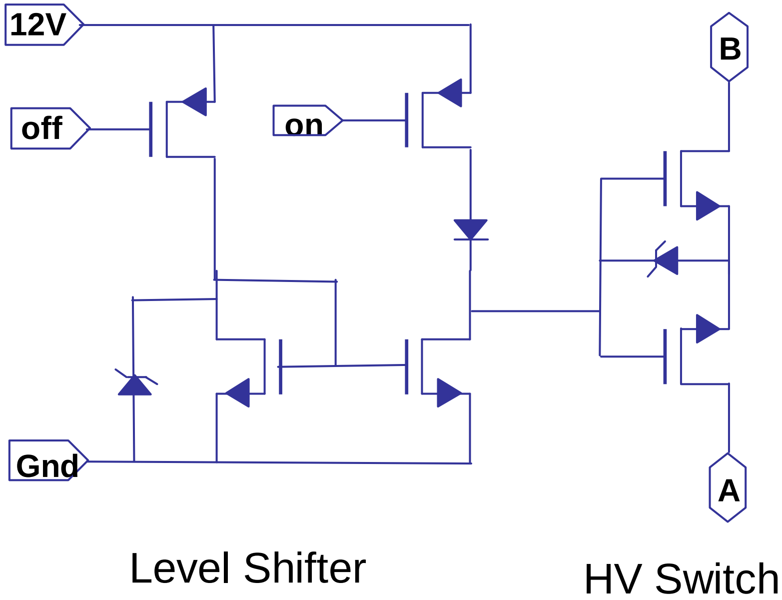
Adapted from Savord et al, 2003 IEEE Ultra. Symp.

- Analog Beamformer (prior to 1990’s)
  CCD’s, all-pass filters, Switched C&I
- Digital Beamformer (1990’s on)
  Proprietary ASIC’s
- “Hybrid” beamformer (2000 onward)
  Required for 3D imaging (2000 channels)
  Move beamforming to the probe to reduce
  micro-coax channel count (i.e. cable size)

High Voltage Transmit circuitry



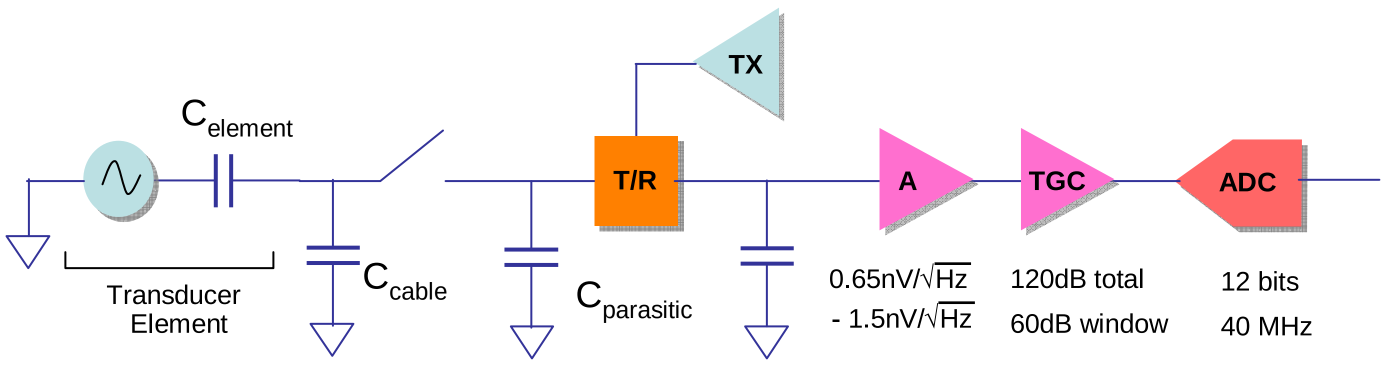
Adapted from XFAB CX08 50V 0.8um CMOS Process Datasheet (www.xfab.com)



Adapted from B. Dufort et al, 2002, IEEE Int. SOI Conf.

- Standard CMOS processes with HV extensions
  - ⇒ High density logic and good HV devices
- Manufacturers: AMS, AMIS, XFAB and others
- Applications: Automotive, display drivers, medical
- Floating gate problem
- HV muxes can be put in the probe to reduce micro-coax cable count

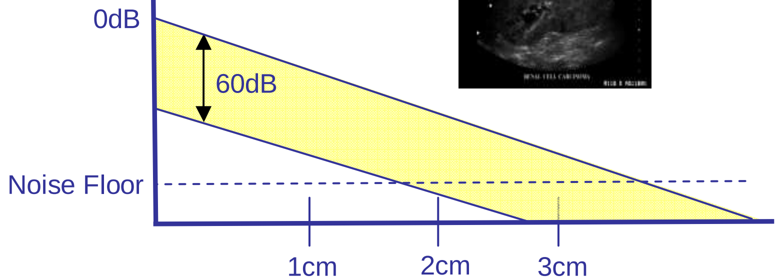
Receive circuitry

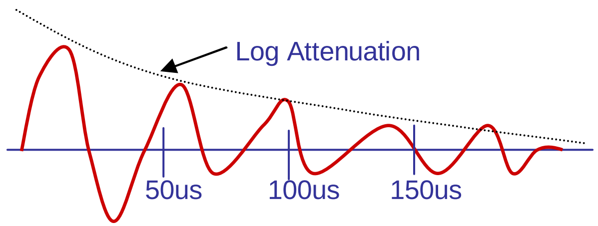


- Time Gain Control (TGC) Logarithmic Amplifier
- Attenuation on rx due to capacitive loading ($C_{element} << C_{cable}$ in 2D imaging probes)
- Preamps in probe improve SNR
- Integration of functionality (ADI 8 Ch. Front-end)
- Penetration limited by noise floor
- Dynamic range limited by max. Tx voltage and min. front end noise
- 1dB/cm/MHz attenuation

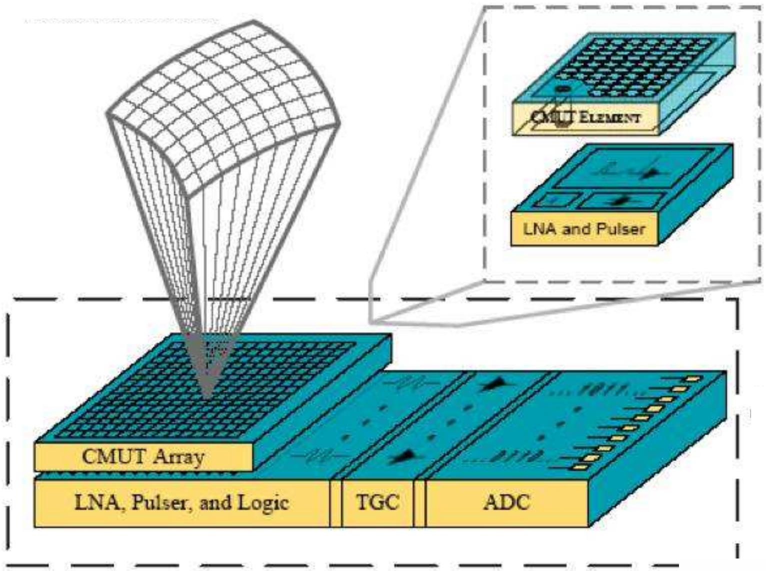
15dB/cm @ 100um resolution
3cm depth

45dB + 60dB
105dB total DR



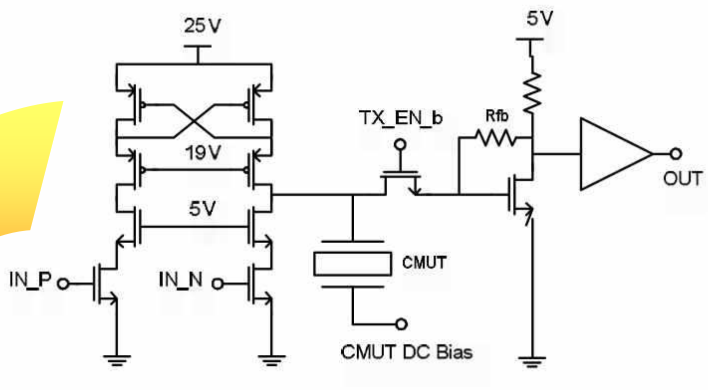


Highly Integrated Systems

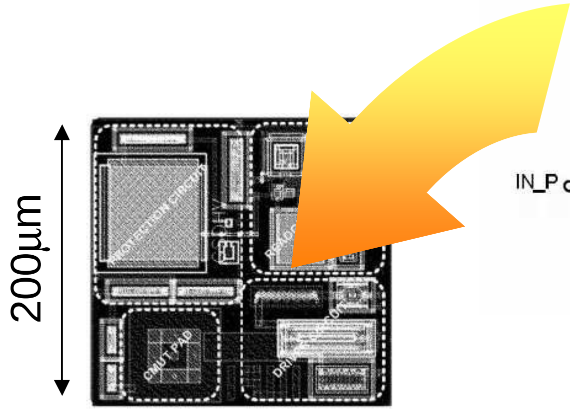


X. Zhuang et al, Proc. of SPIE Med. Imaging, 2005

- **Reduced Capacitance**
  - Less TX loading ➡ Lower power
  - Less RX loading ➡ More sensitive
- **Increased Channel Count**
  - Solves routing bottleneck
  - Enables high quality volumetric imaging
- **Reduced System Volume**
  - Miniaturizes routing assembly
  - Cable issue (Carpel tunnel syndrome)

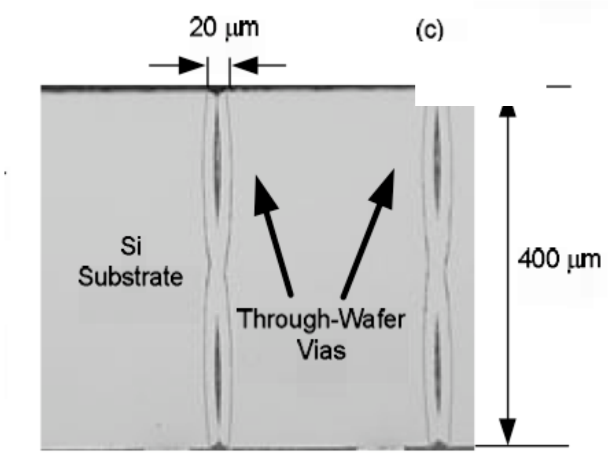


I.O. Wygant et al, Proc. of SPIE, Med. Imaging 2005

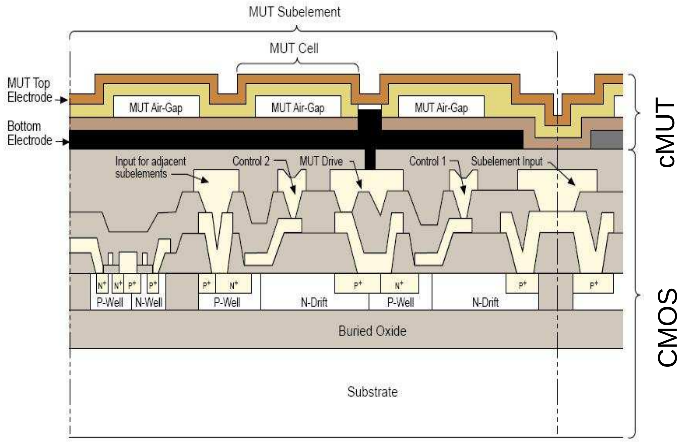


I. Cicek et al, IEEE UFFC

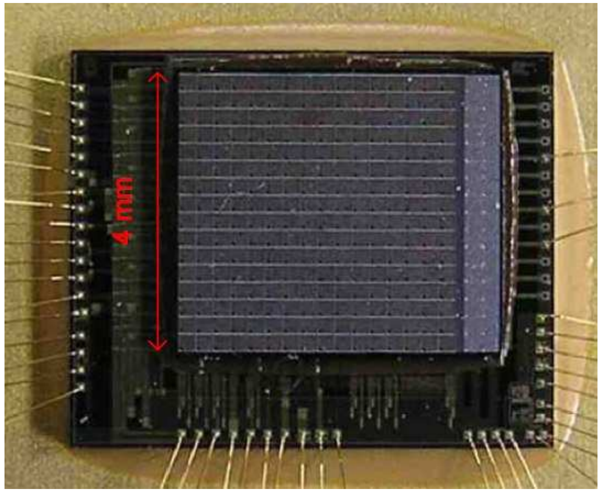
Transducer to Electronics Direct Integration



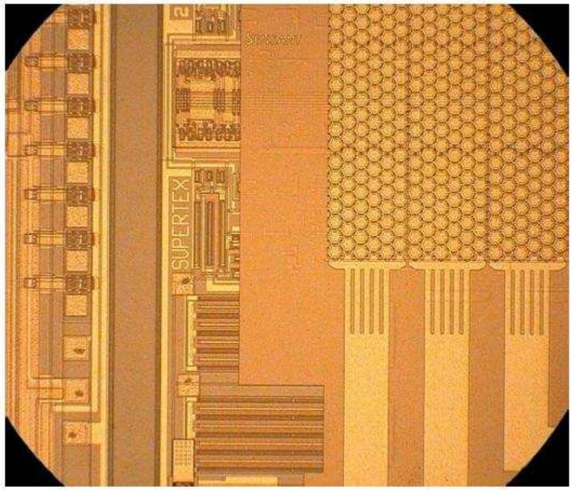
X. Zhuang et al, Proc. of SPIE Med. Imaging, 2005



Thomenius et al 2000



I.O. Wygant, Proc. of SPIE, Med. Imaging 2006



C. Daft et al, 2004 IEEE Ultr. Symp.

Chip to Chip Integration

High density Bump bonding

cMUT/CMOS co-processing

Run on same fab line

Ultrasound Stethoscope

Handheld = $1Billion market by 2010
-Frost & Sullivan

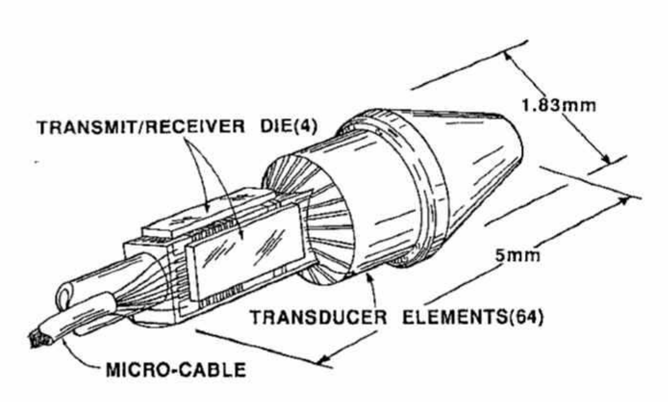
Challenges

- **Transmit Voltage**
  - > 100V, high power
  - HV CMOS processes
- **Beamformer Complexity**
  - > 2000 channels for 2D
  - SOC Integration
- **Power Dissipation**
  - Battery life
- **User Friendliness**
  - Inexperienced users
  - Improve image quality
- **Cost**
  - Very low
  - Commoditization of ultrasound

- Drivers: Moore's Law, Packaging, Novel system architectures imagination at work

Extra Slides

Applications of Miniaturization in Ultrasound

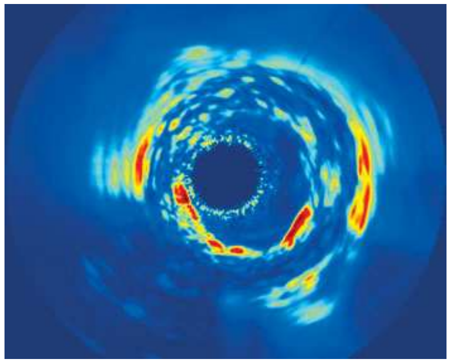


W.C. Black et al, IEEE JSSC 1994

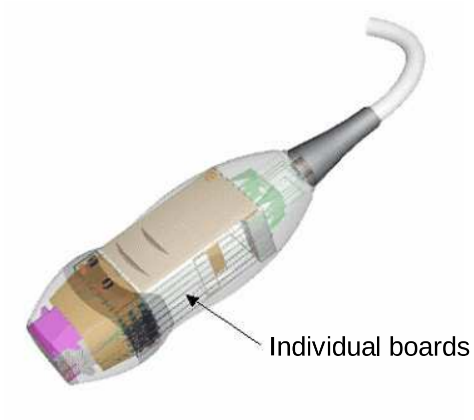
Intravascular Ultrasound (IVUS)

Tx/Rx electronics in catheter

Visualizing plaques



Kakadiarsis et al, University of Houston (www.cbl.uh.edu)

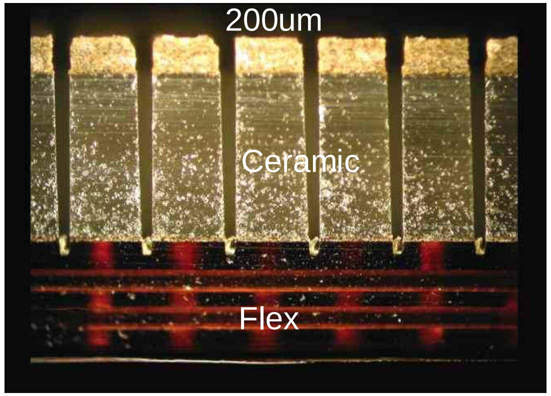


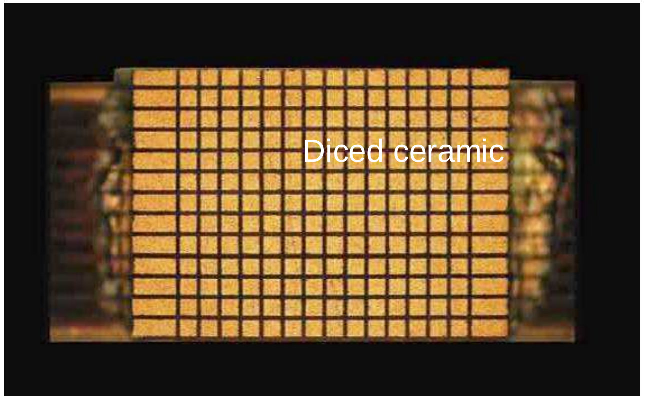
3D Volumetric Imaging

Highly integrated Analog beamformer

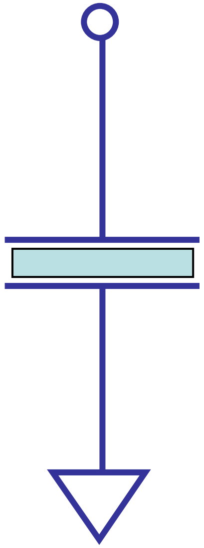
Real-time imaging of the heart

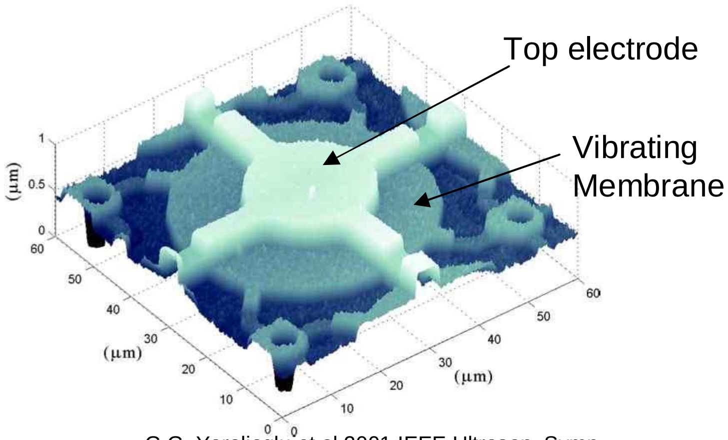
Ultrasound Transducer Technologies



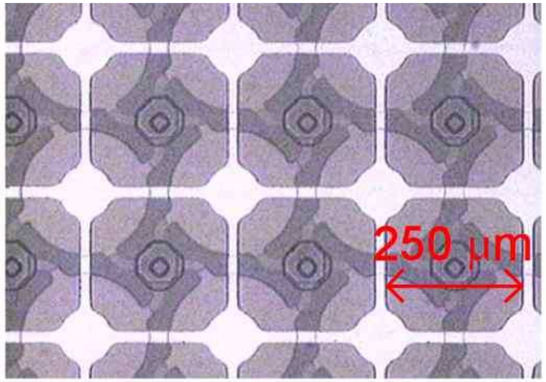


W. Lee et al IEEE UFFC, Oct. 2004





G.G. Yaralioglu et al 2001 IEEE Ultrason. Symp.



P. Khuri-Yakub et al

Piezoceramic Transducers

Lead Zirconate Titinate (PZT)

Well established technology (>50 years)

Gold standard in sensitivity

Limited bandwidth (<90%)

Micro-machined Transducers

capacitive Micro-machined Ultrasound Transducer (cMUT)

Semiconductor processing

Wide bandwidth - multiple applications (>110%)

Reduced sensitivity (-6dB over compared to PZT)