Introduction to Medical Imaging

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Texas Instruments
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Texas Instruments

Agenda

- TI in Medical Market
- Ultrasound Imaging
  - Principles
  - System Considerations
- Other Imaging Modalities
  - X-ray Imaging
  - CT Imaging
- Medical Image Safety

TI in Medical Market

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TI Commitment to Medical

Committed for the long term

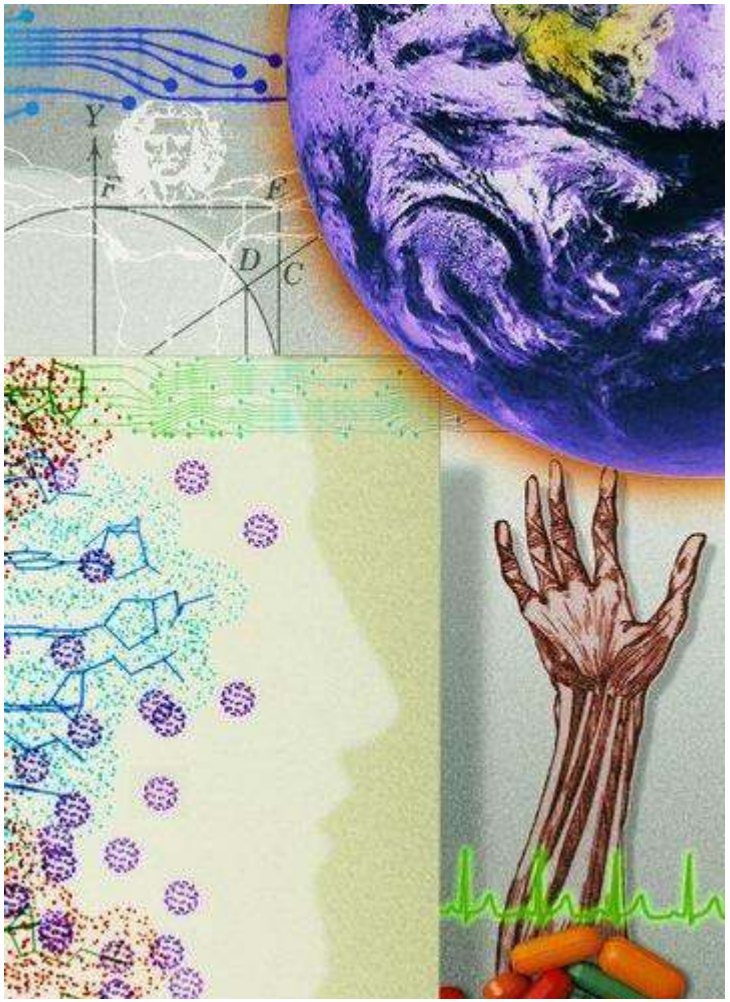
- Dedicated Medical Business Unit (MBU) Organization combines expertise from **Military/Automotive** to support Medical customers with for enhanced products, quality and services.

Investing in Innovation

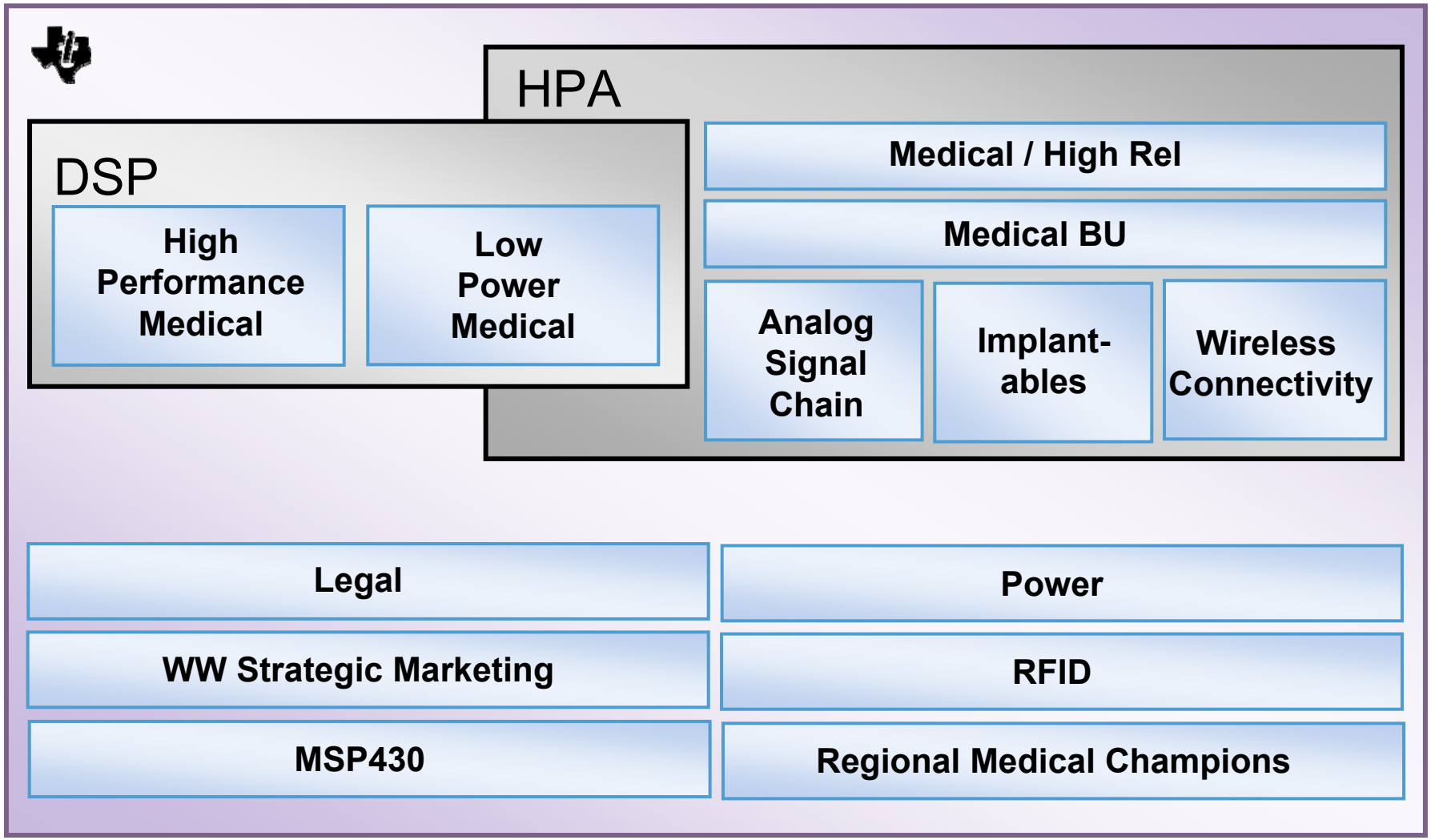
- R&D
- Venturing (funded)
- Partnering (co-marketing, design, etc)
- University Programs -$15M

Driving standards

- Continua Health Alliance (interoperable telehealth)
- IEEE-11073 (medical communication)
- iNEMI MCRS (medical component reliability)



TI Medical Organization

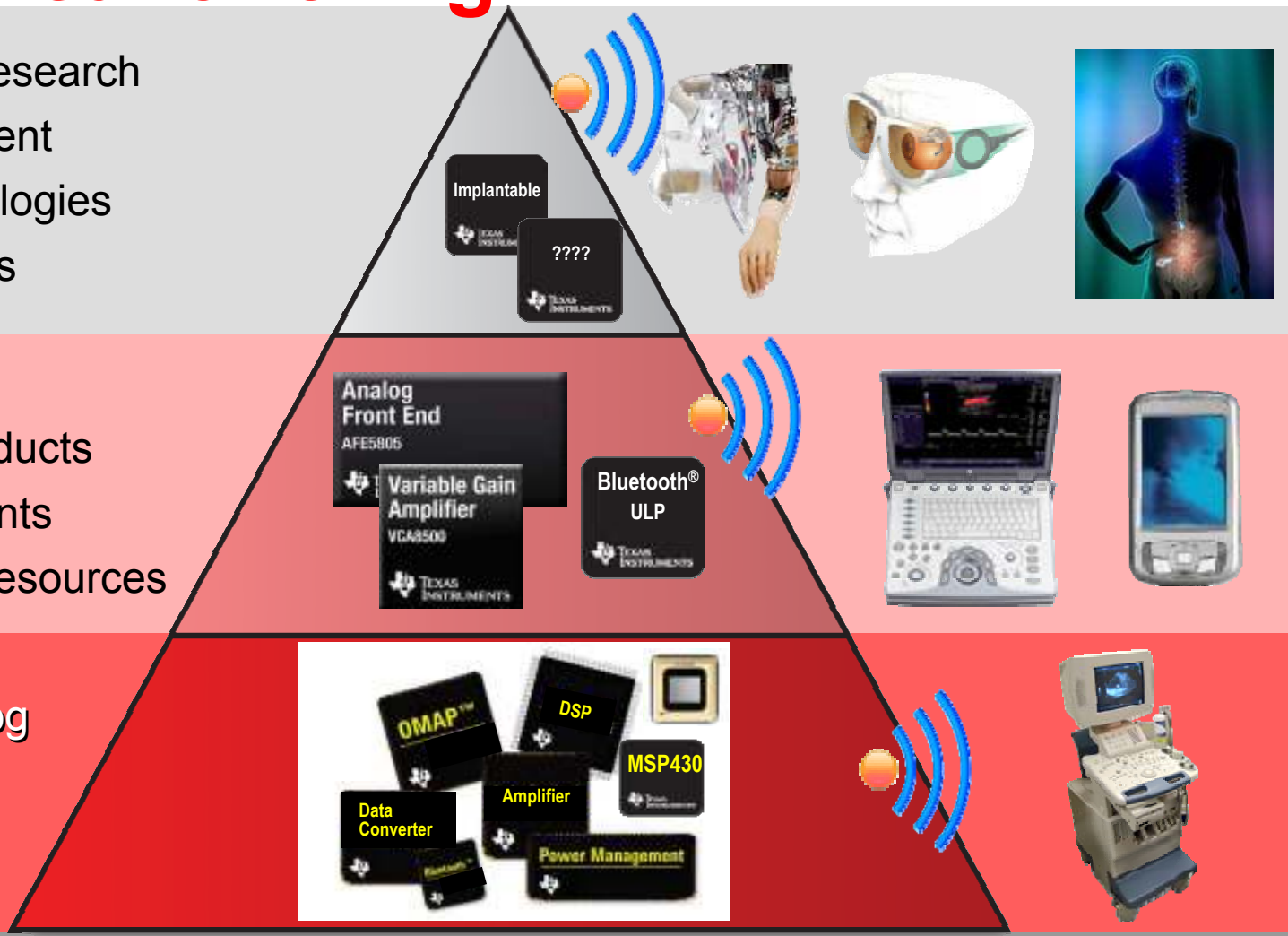


TI Medical offering

- University research
- VC investment
- New technologies
- Implantables

- Application-specific products
- TI investments
- Dedicated resources

- Broad analog and digital catalog portfolio



Quality & reliability | **Process technology** | **Sales & applications support**

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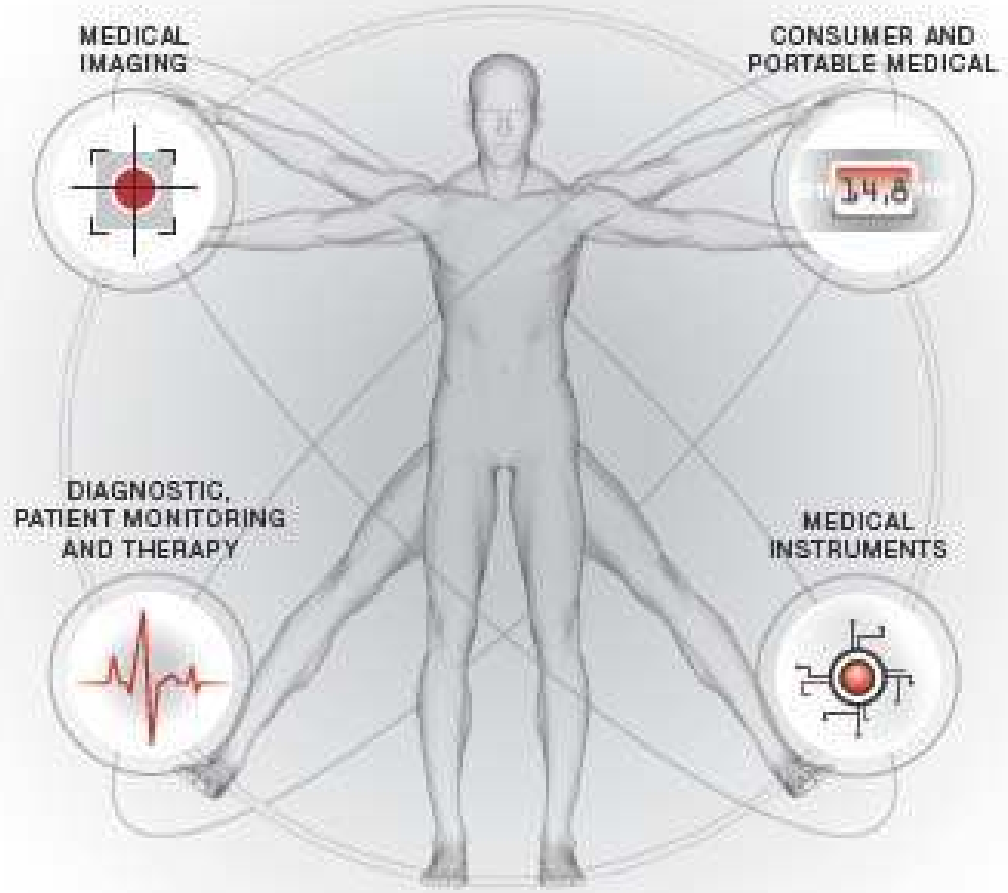
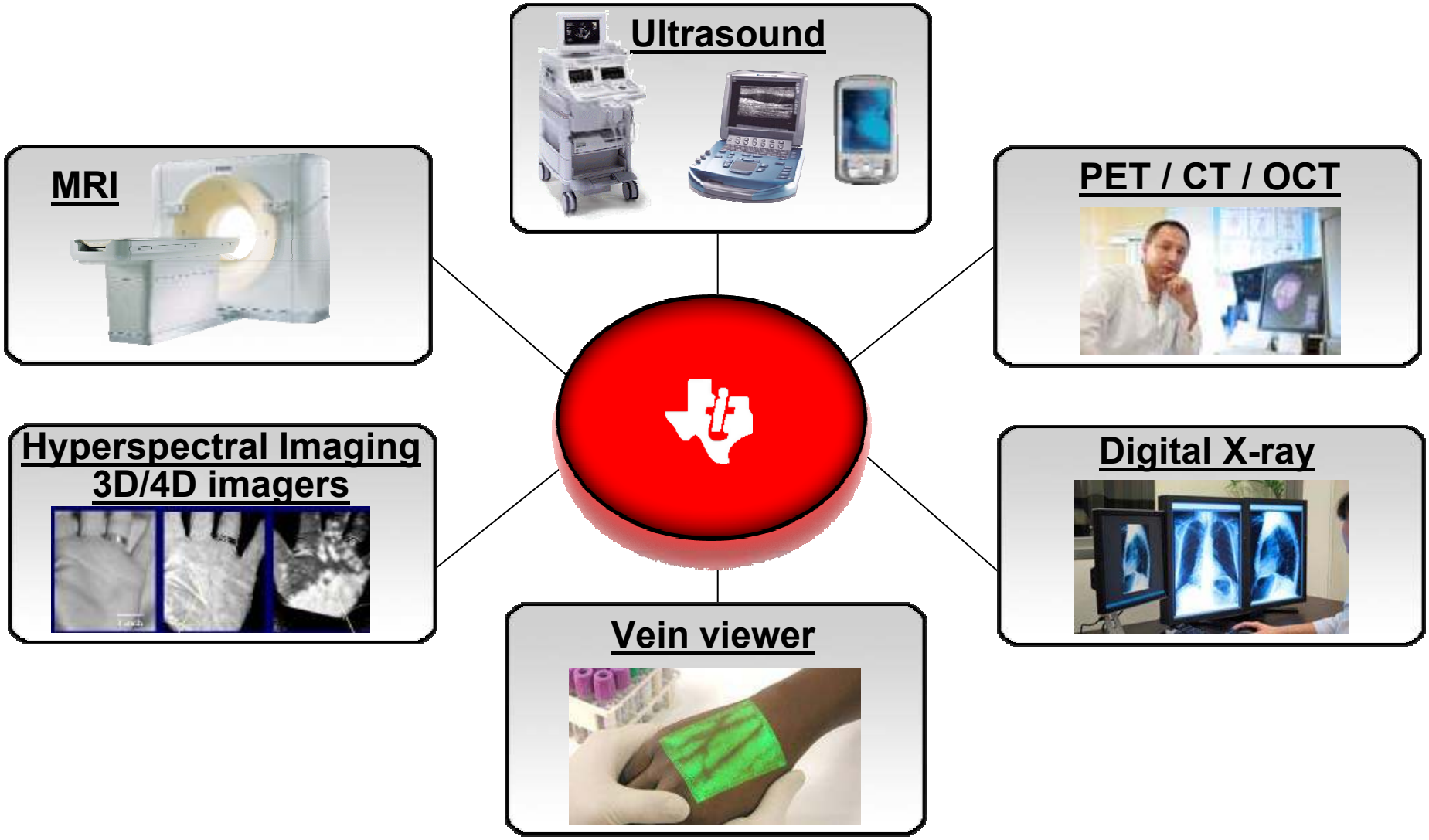
Medical overview

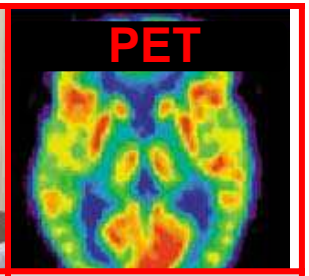


Broadest portfolio of analog and embedded processing solutions in the market

Medical imaging modalities



Complete IC portfolio for medical imaging

	CT	Ultrasound	MRI	X-ray	PET
					
Embedded processors	• High-performance DSPs* • Digital signal controllers	• High-performance DSPs • DaVinci™-based SoCs • Low power OMAP35x application processors	• High-performance DSPs • Digital signal controllers	• High-performance DSPs • Digital signal controllers	• High-performance DSPs • Digital signal controllers
Application-specific Analog products	• Analog front ends • Data converters	• Analog front ends • Pulsers and switches	• Data converters	• Analog front ends	• Amplifiers
Catalog Analog	Power management, data converters, amplifiers, clocks, interfaces, switches				

*high-performance DSPs include multi-core, single-core and floating point

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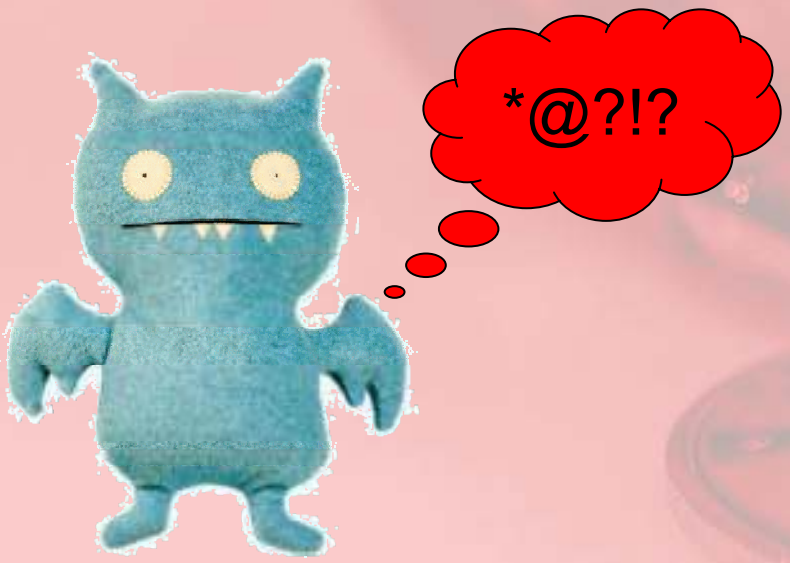
Ultrasound



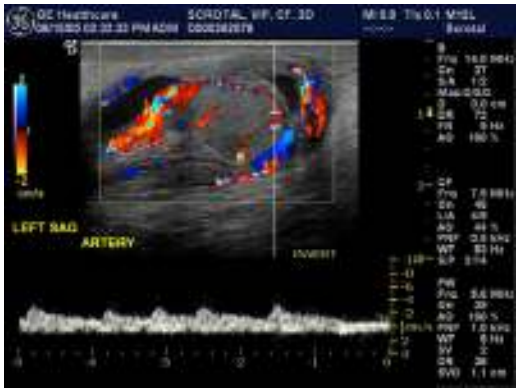
Overview of Ultrasound

- Ultrasound Basics
  - Advantages
    - Real-time & Non-invasive
    - Inexpensive
    - Multi-channel in a single system
    - Growing market of >4 billion worldwide

  - Operation Principles
    - Sound vs Ultrasound ~ 20Hz-20KHz vs 2-20MHz
    - Transducer ~ Loudspeaker & Microphone
    - US AFE ~ Power Amplifier & Signal Amplifier
    - US System ~ Radar System

Ultrasound Basics

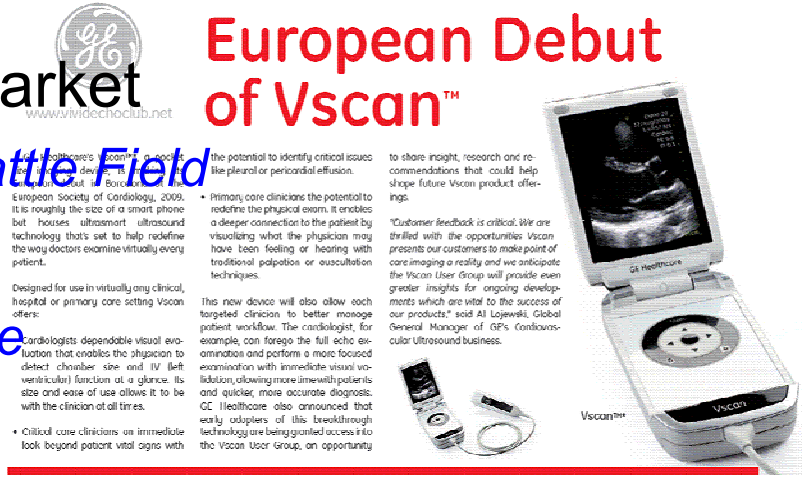
- Ultrasound Basics
  - Imaging Modes
    - Brightness Mode (B-mode) *64-256 channels*
    - Doppler Mode (D-mode) *1-64 channels*
    - Color Doppler mode (2-D Doppler) *64-256 channels*
    - 3D & 4D Ultrasound *1024-4096 channels*

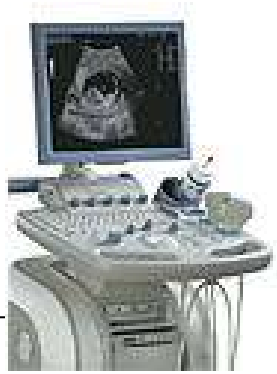


Courtesy of GE

Ultrasound Basics

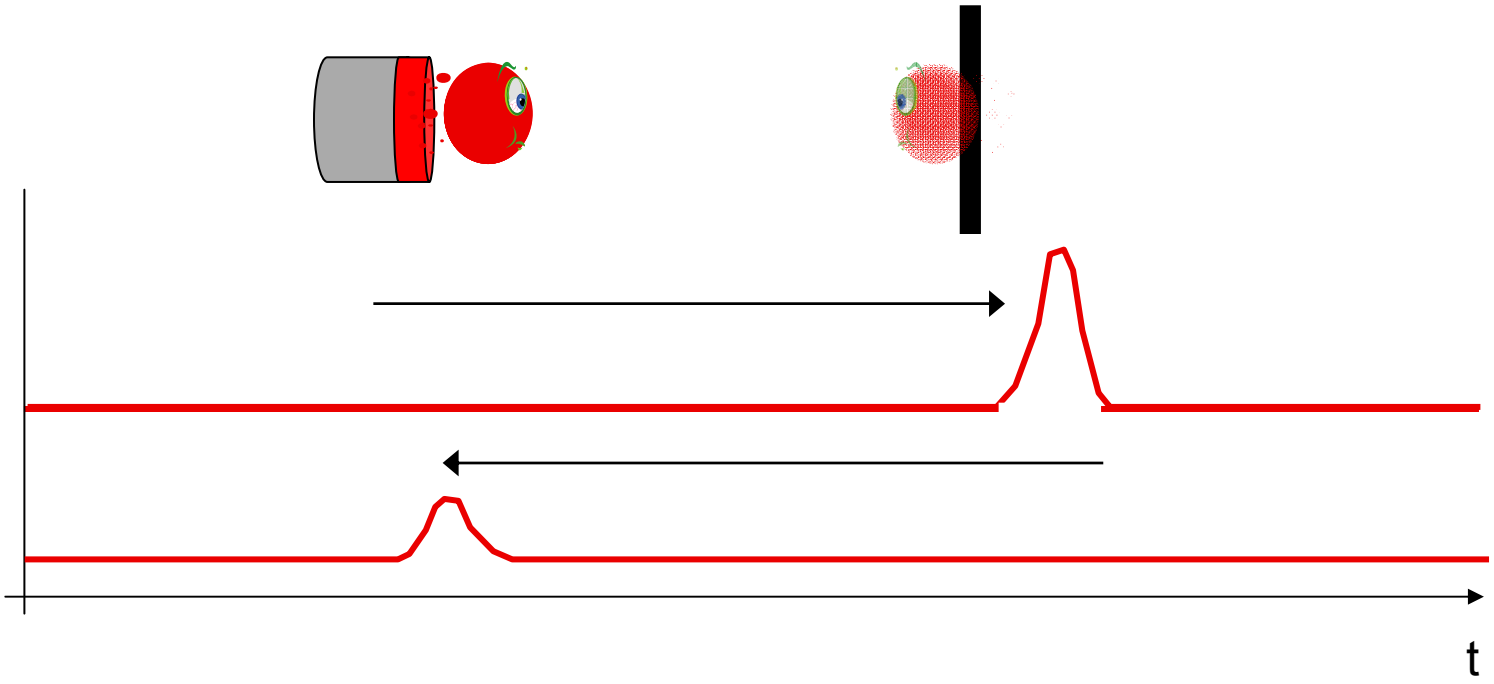
- Ultrasound Basics
  - Growing Portable Ultrasound Market
    - *Ambulance, Emergency Room, Battle Field*
  - Demand of Advanced ICs
    - *Compact, Low Power, & Low Noise*
  - More Channels per System
  - More Systems per Year
  - Much More Opportunities for ICs



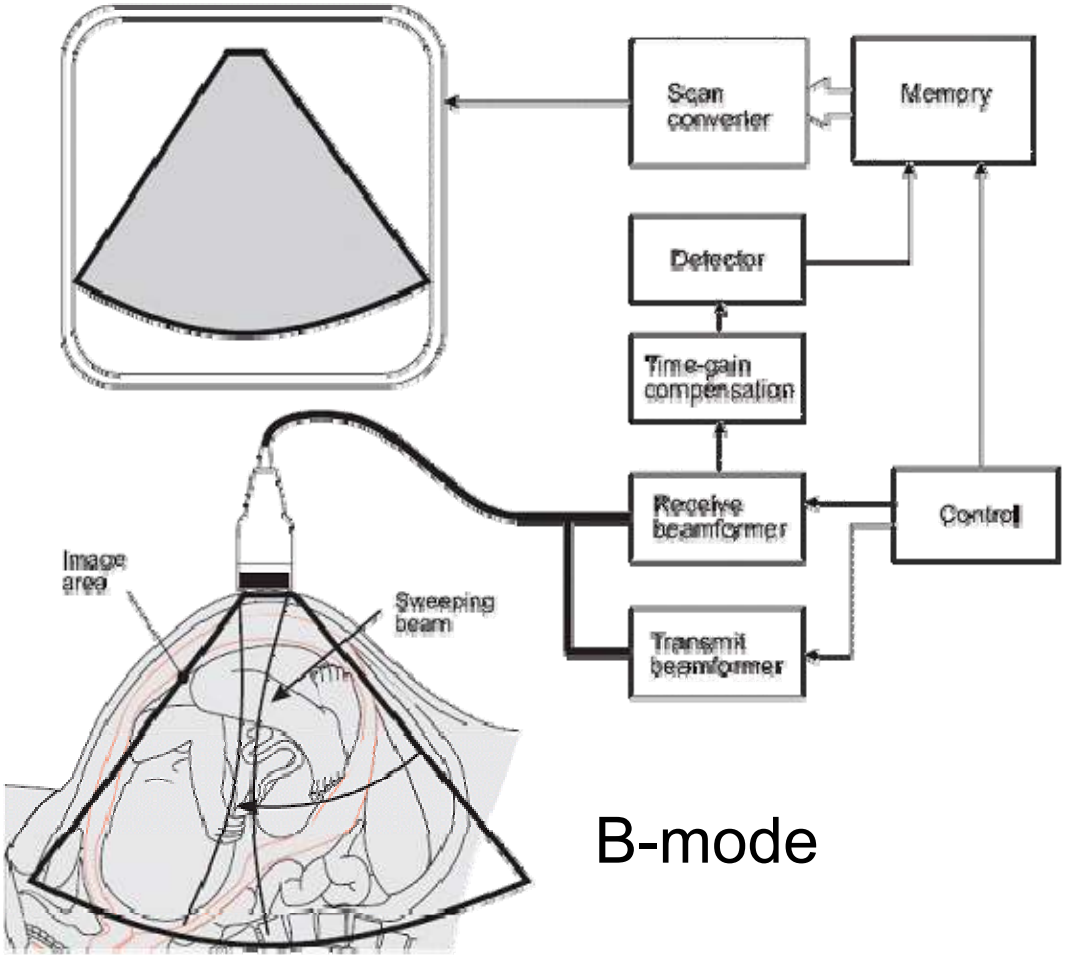


Courtesy of GE

Principle



The machine – Top level



B-mode

Physics (I)

Substance	c [m/s]	ρ [g/cm^3]	Z = ρc [10^5 Rayl]	**Attenuation [dB/MHz.cm]**
Fat	1470	0.97	1.42	**0.5**
Muscle	1568	1.04	1.63	**2**
Compact bone	3600	1.7	6.12	**4-10**
Air	331	0.0013	43.10^{-5}	

Position
Frame rate

Reflections
Strong or weak

Depth

Physics (II)

c = 1560m/s

$$R_{Axial} = \frac{\lambda}{2.FBW} = \frac{c}{2}\tau_{-6dB} \propto \frac{c}{2f}$$

Frequency [MHz]	Wavelength [mm]	Penetration depth [cm]	Lateral resolution [mm]	Axial resolution [mm]
2	0.78	25	3	0.8
5	0.31	10	1.2	0.35
10	0.16	5	0.6	0.2
15	0.1	3.3	0.4	0.15

f.2.x.α = 100dB

α = 1dB/(MHz.cm)

$$R_{Lateral} = \frac{c}{f}\frac{2r}{w.\cos\theta}$$

Imaging Systems for Medical Diagnostics - Siemens

Frame rate

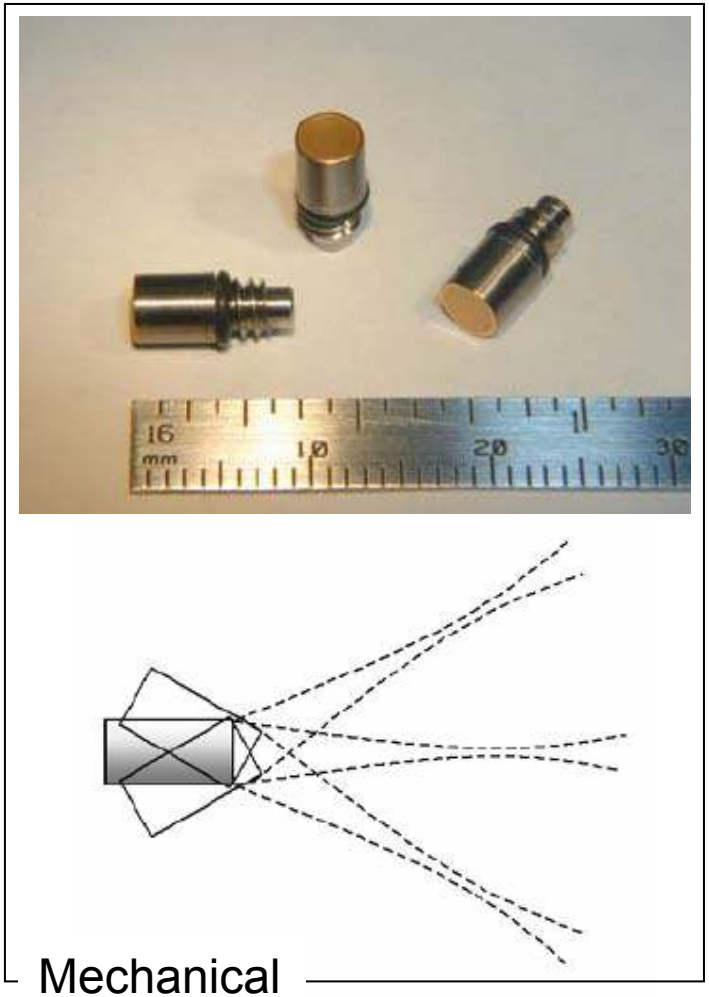
Example:

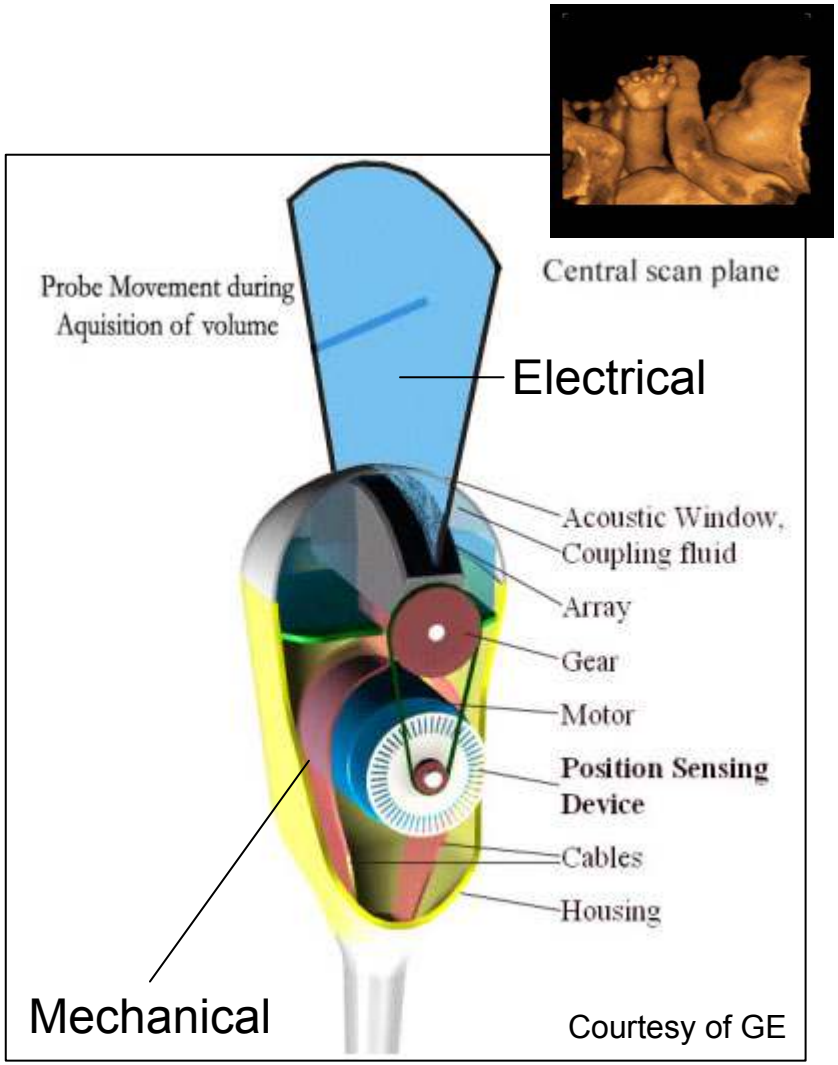
c = 1540m/s
60^{o} sector
0.5^{o} beam spacing
25cm depth

120 beams
25cm x 2 / 1540m/s =320us / beam

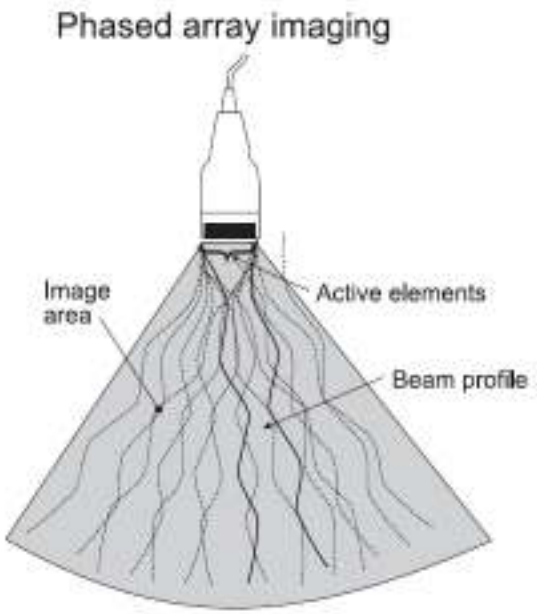
26 frames/s

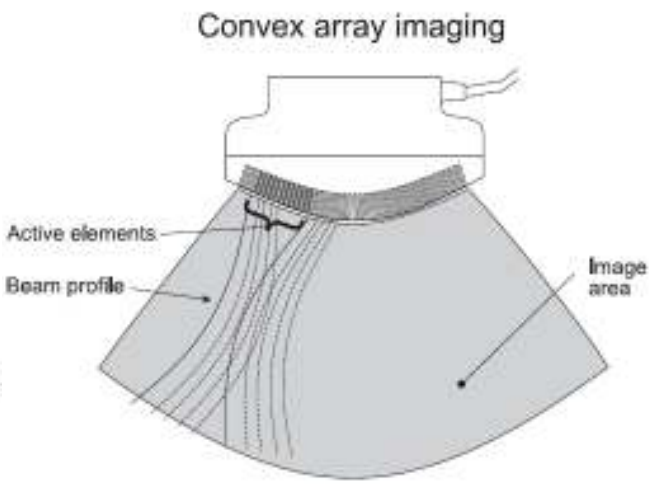
Mechanical Scan

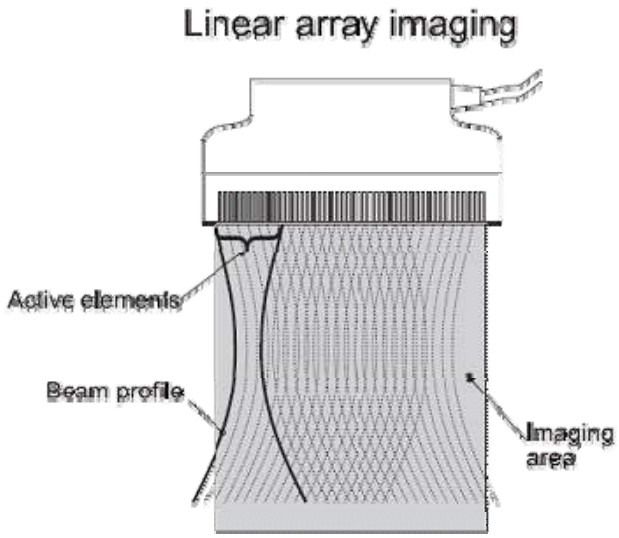




Electronic scan







- Fast frame rate
- Low noise
- More patient friendly

http://www.es.oersted.dtu.dk/staff/jaj/field/index.html

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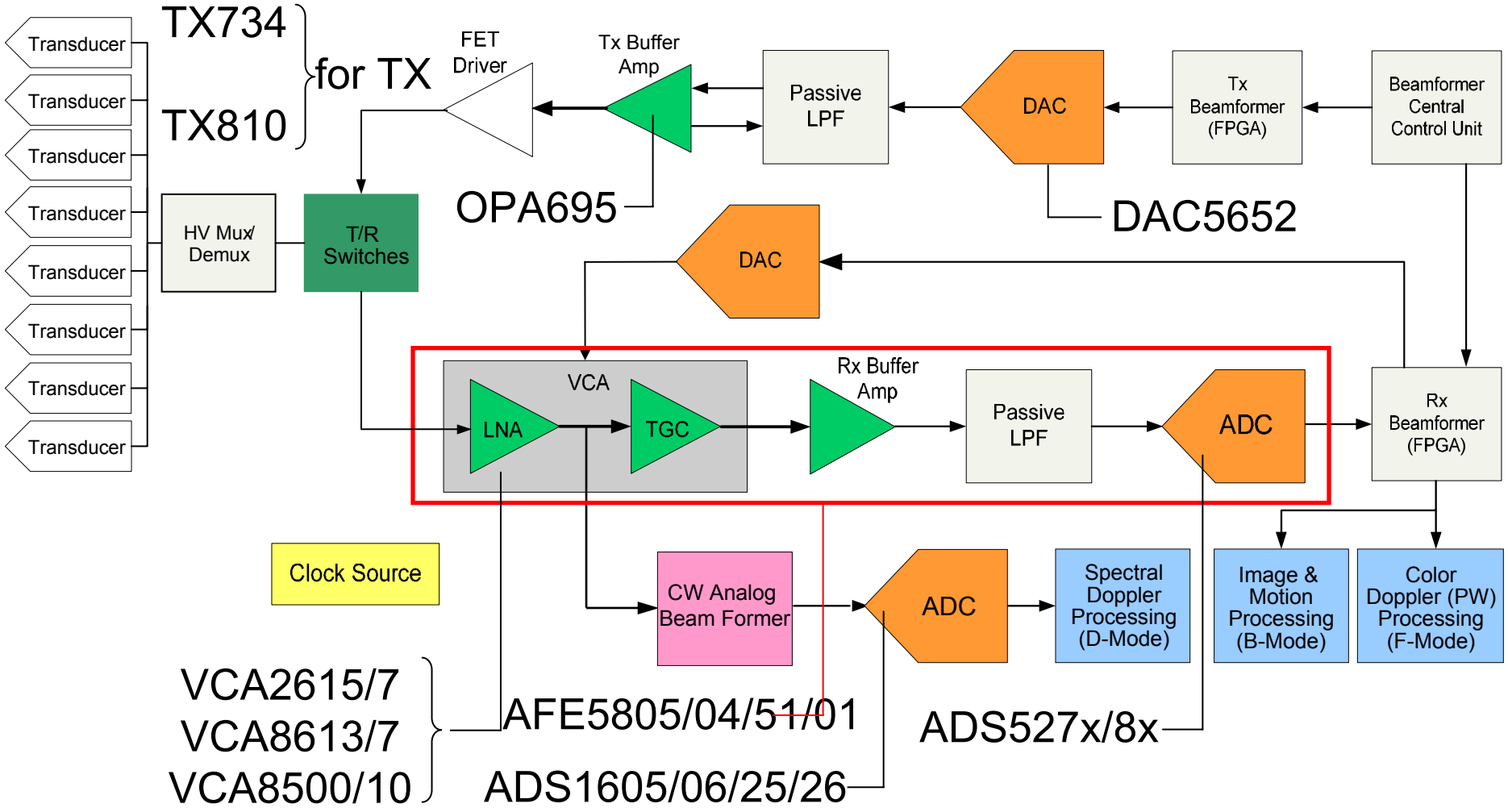
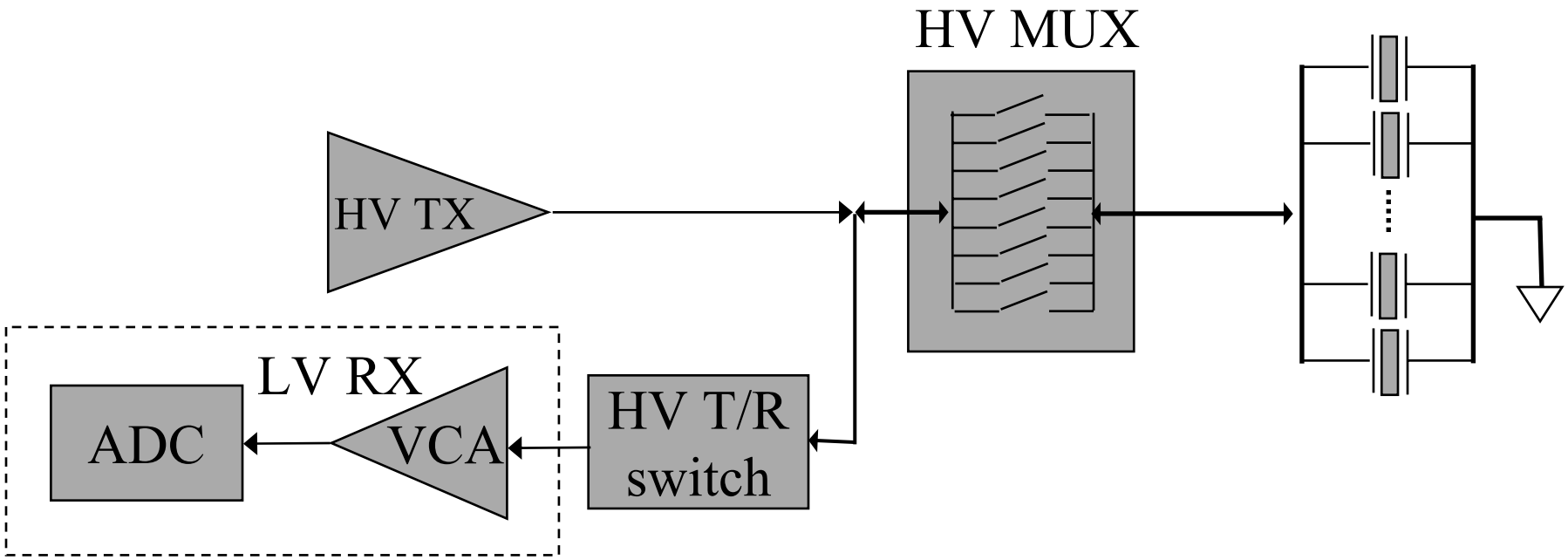
Ultrasound System

TI Goal: *More Colorful Diagram, ease of US design*



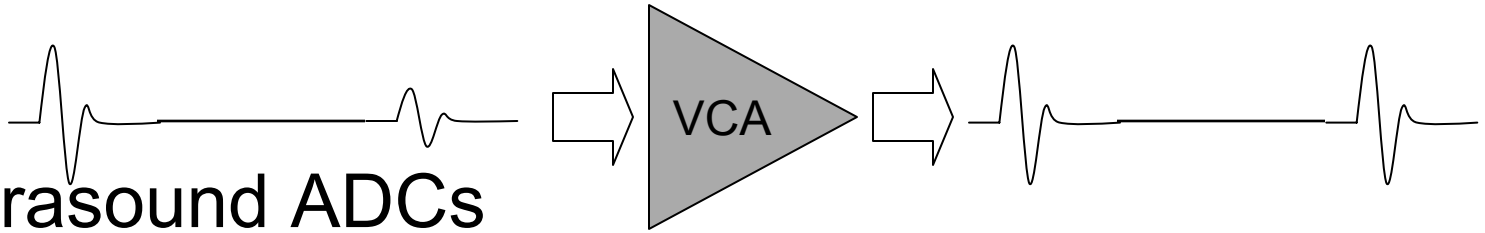
Main Components in Ultrasound TX

- Ultrasound Transmitter: Signal Generator
- Ultrasound T/R Switch: Protect LV RX
- Ultrasound Multiplexer: Reduce TX/RX CH#

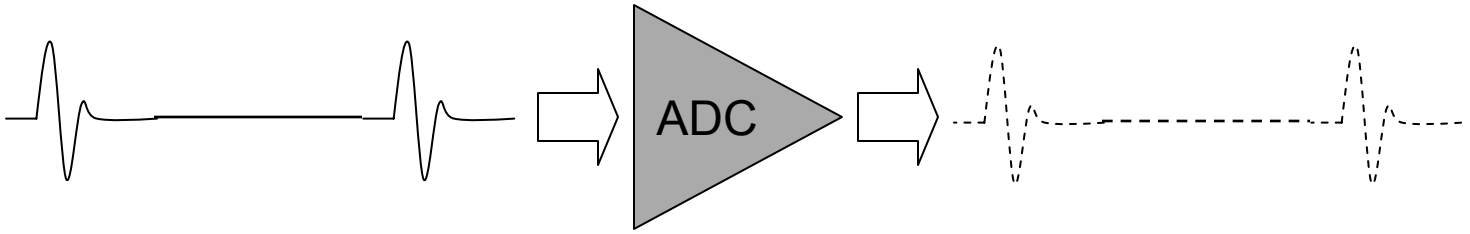


Main Components in Ultrasound RX

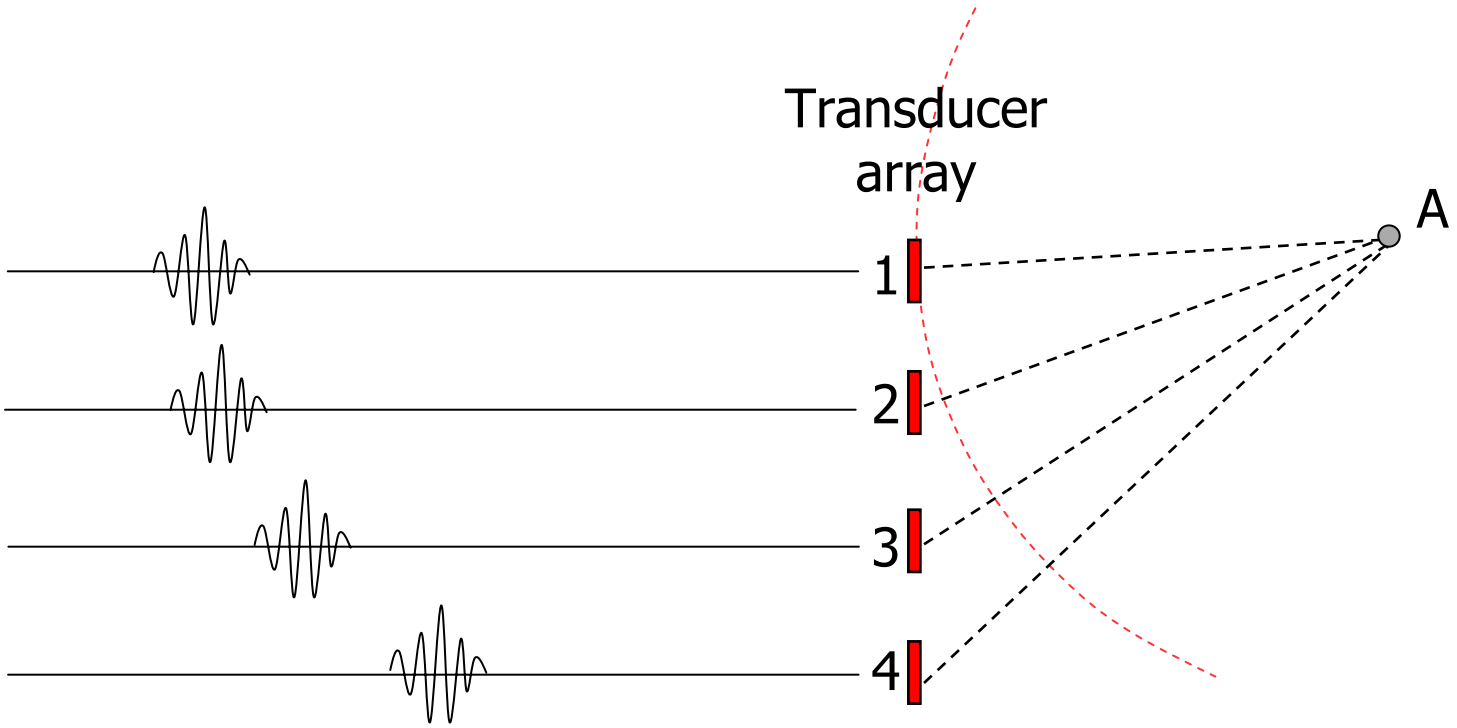
- Ultrasound VCAs
  - Amplify signals from 10uV~1V i.e.100dB
  - Compensate attenuation in tissues



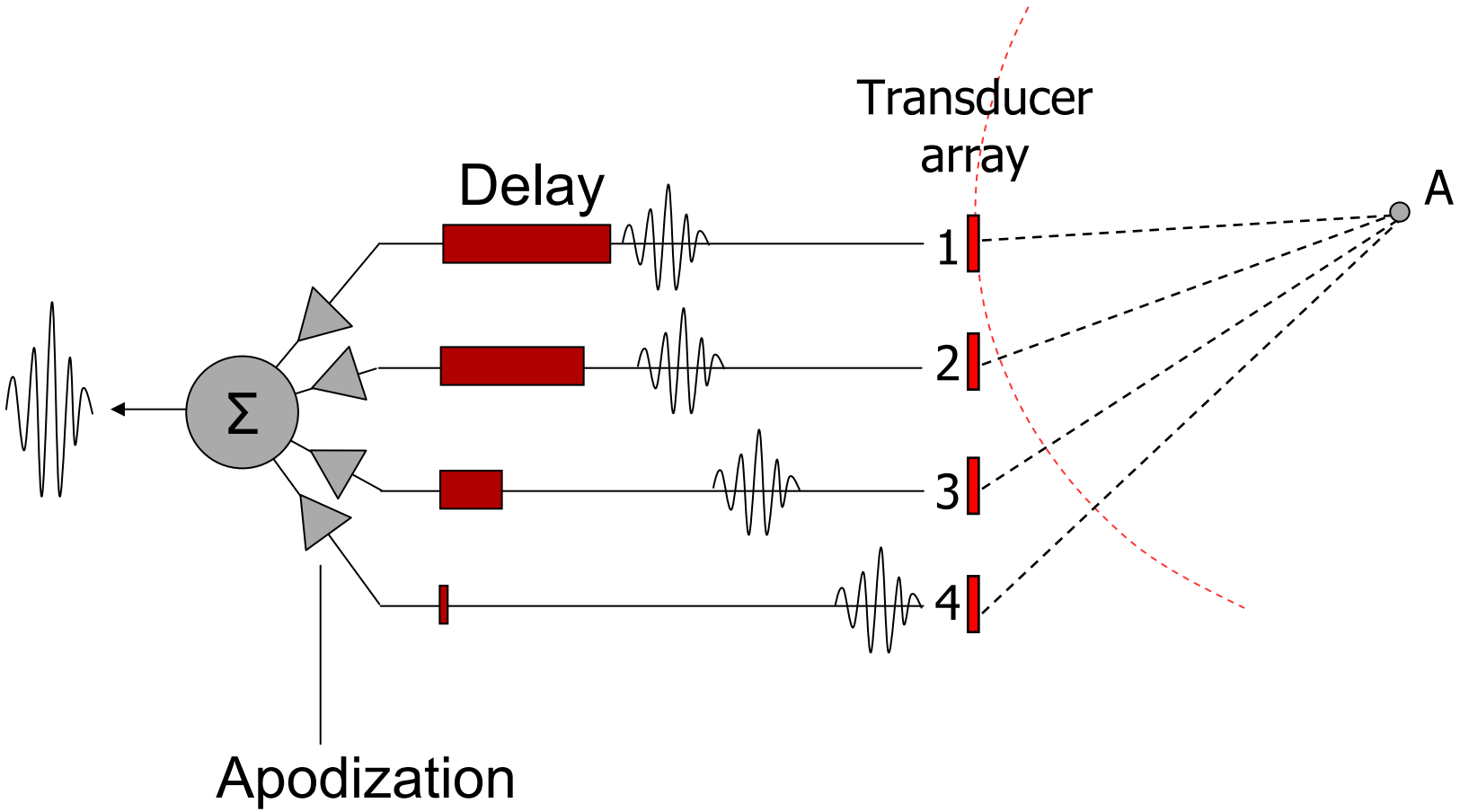
- Ultrasound ADCs
  - Digitize conditioned signals



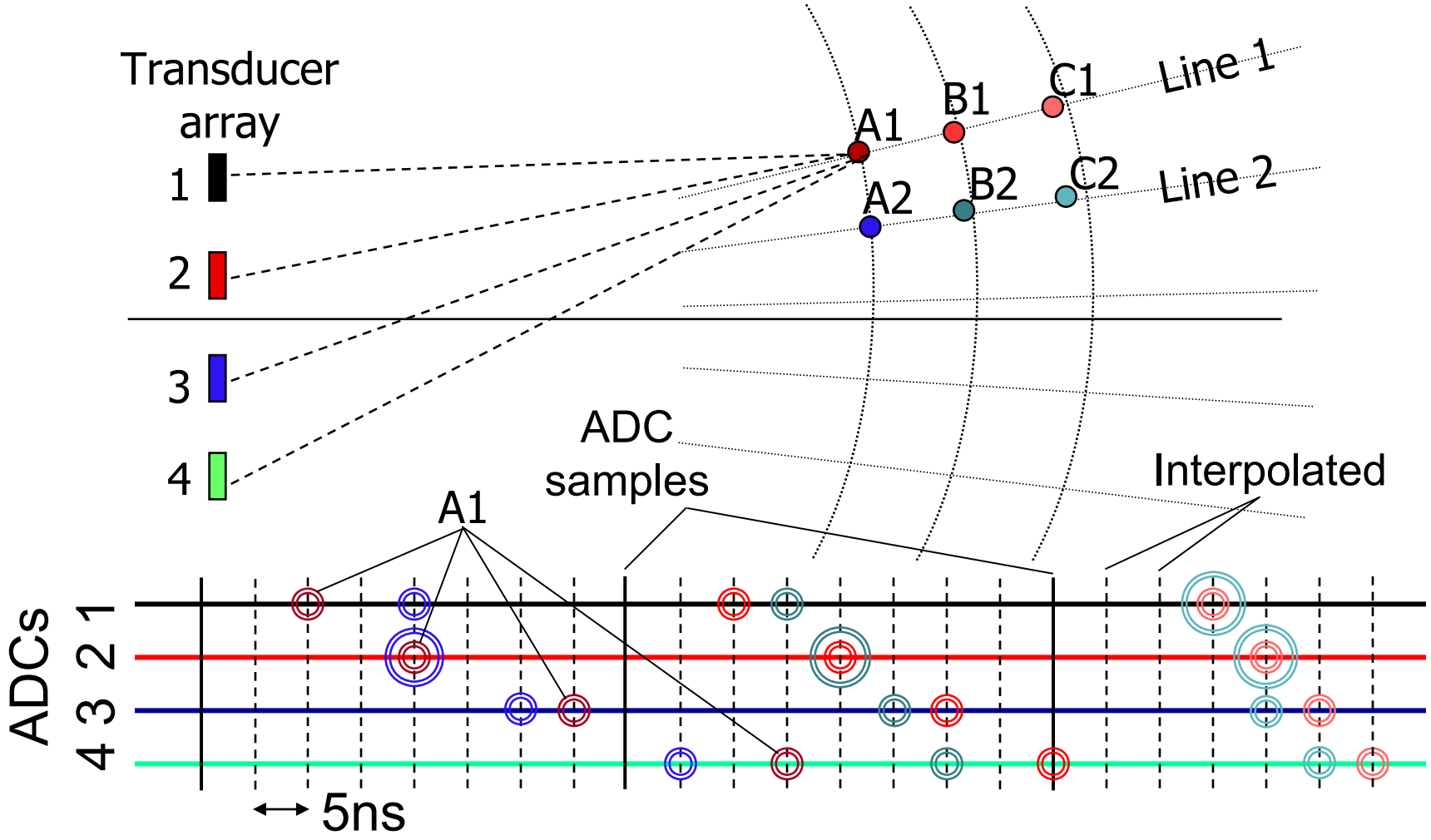
Tx beamformer



Rx beamformer



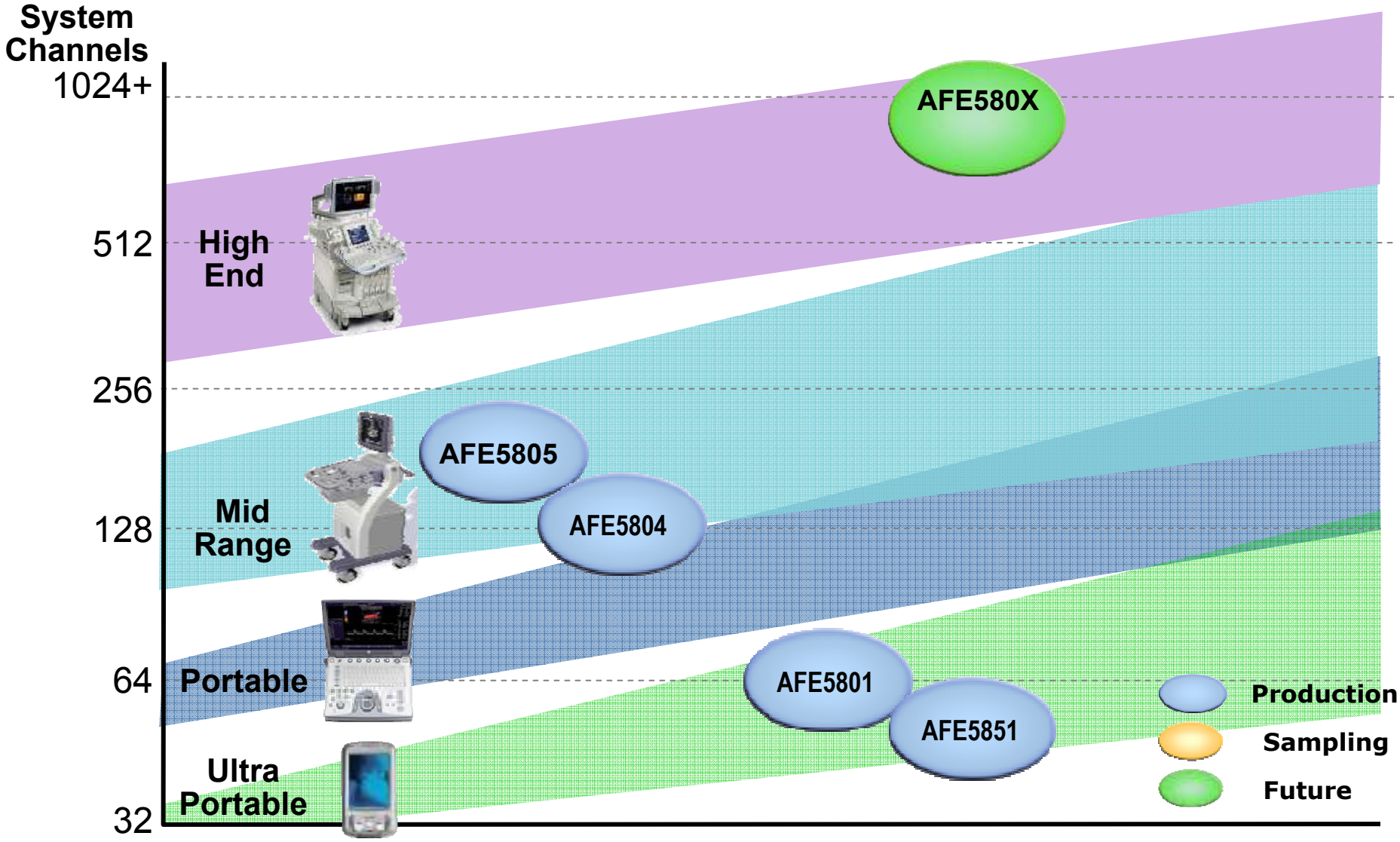
Receive Beamforming



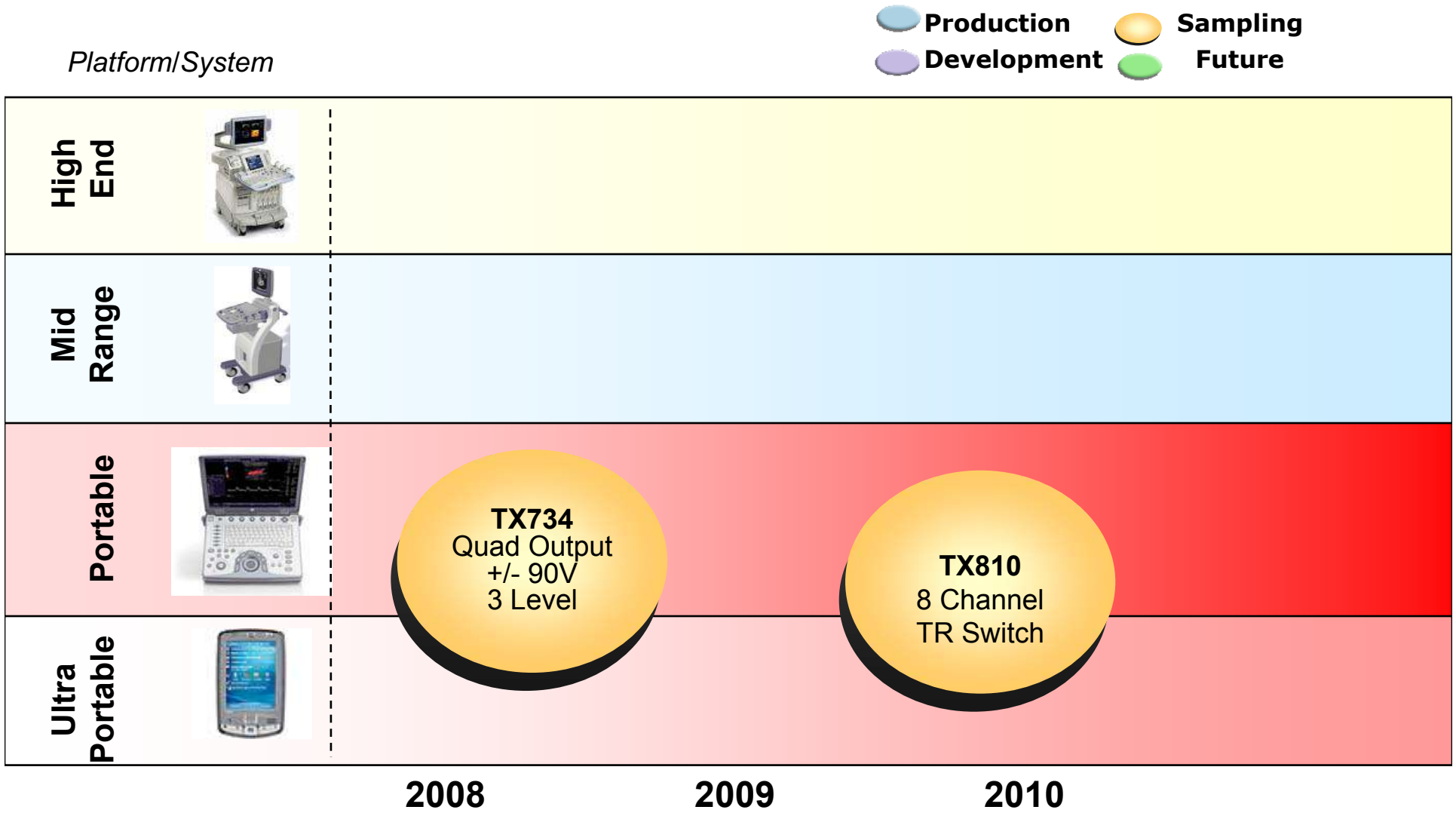
ADC Sample Rate: 40MSPS→25ns interval

BF Resolution: <λ/16: 10MHz→>160MSPS→<5ns

Receiver Solutions for Ultrasound



Transmit Solutions for Ultrasound



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Valuable Specs in Ultrasound

- Power/Noise
- Overload Recovery
  - Recovery time & recovery consistence.
  - Consistent recovery char leads to less color noise.
  - Overload recovery reports for AFE580x are available.
- Power up/down speed
  - Related to VCA shut down duration
  - Better power saving and more flexibilities for users
- Input Termination vs system performance
  - Active termination vs Passive termination
  - No external resistor needed for active termination

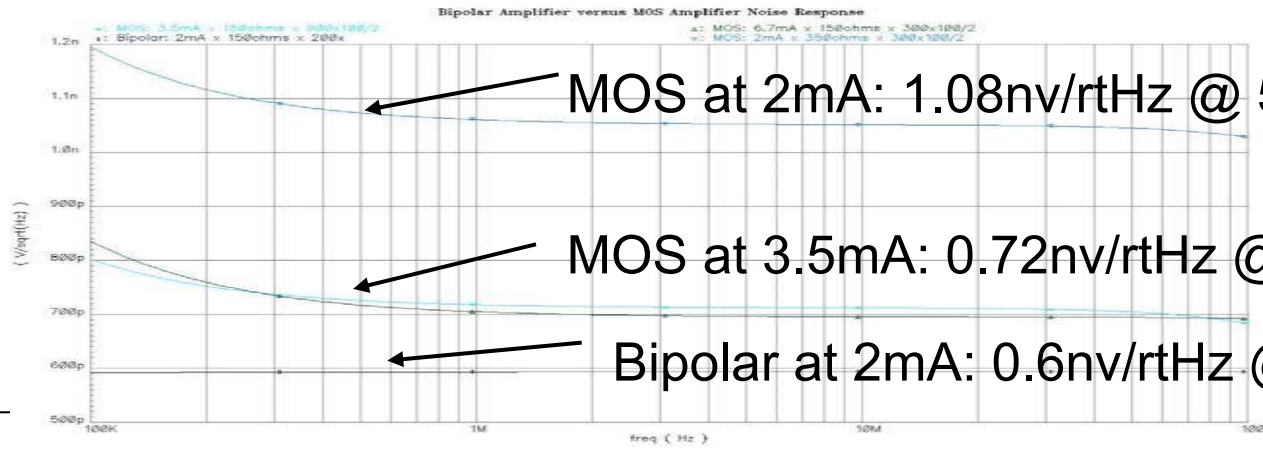
Valuable Specs in Ultrasound

- Matching among channels and chips
  - Considered probe sensitivity variation
  - Chip matching is a guaranteed number at ATE.
- Harmonic Distortion(HD2 and HD3)
  - Harmonic Imaging (HD2)
  - CW demodulation (HD3)
- Jitter vs Color Noise
- CW IQ Matching
  - Affect the forward and backward flow detection
- SNR at low gain i.e. SNR at near and mid range
  - Related to VCA IRN and PGA gain specs

Detail information can be obtained from TI MBU

Low Power/Low Noise for both ADC/AMP

Bipolar Technology	CMOS Technology
LOW NOISE	*LOWEST POWER LOGIC*
WIDE DYNAMIC RANGE	*HIGHEST LEVEL INTEGRATION*
WIDE BANDWIDTH	*SWITCHES, MUX'S and SAMPLE/HOLD's*

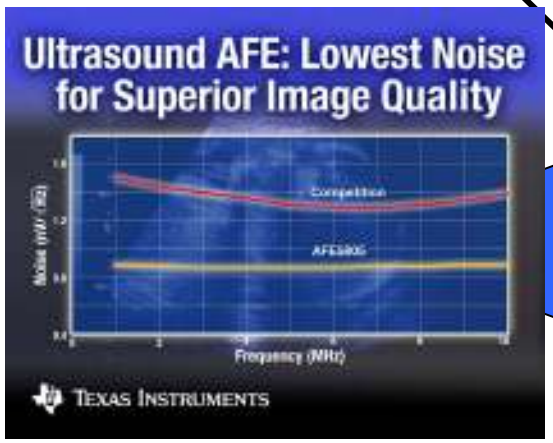


Low Power/Low Noise for both ADC/AMP

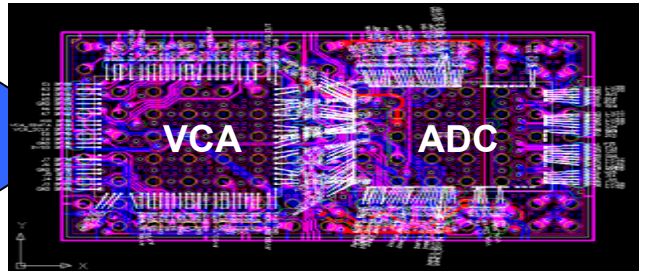
ADS528x- C05
0.18um CMOS
Low Power ADC
High Digital Intensity

VCA85xx –BiCom3X
0.35um BiCOMS
Lowest Power 60mW/Ch
Highly Integrated (8 Ch)
Voltage-Controlled AMP

BiCOM3x or Future BiCom Process

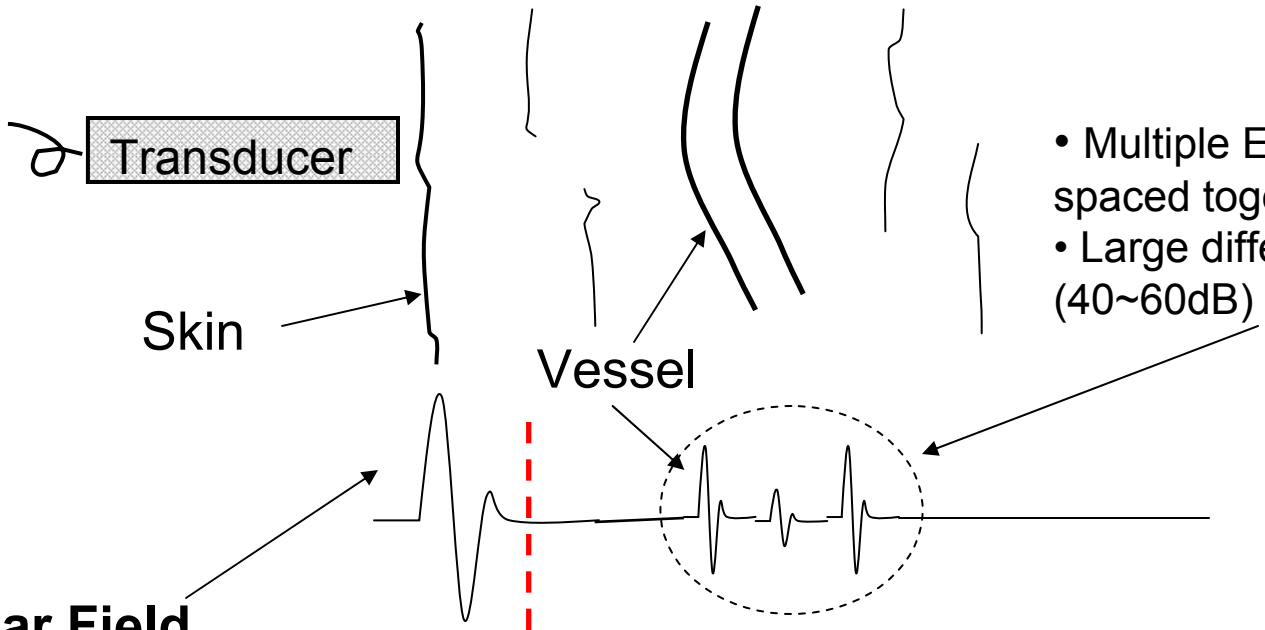


Low Power Low Noise AFEs



Overload Recovery

- Signal Path & VCA Requirements



Near Field

- Low TGC Gain setting
- Large echo likely to overload LNA

Need: Fast overload Recovery of LNA

Mid-far Field

- Increasing/High TGC Gain setting
- Potential overload of LNA and PGA

Need: Fast and Repeatable overload recovery characteristics

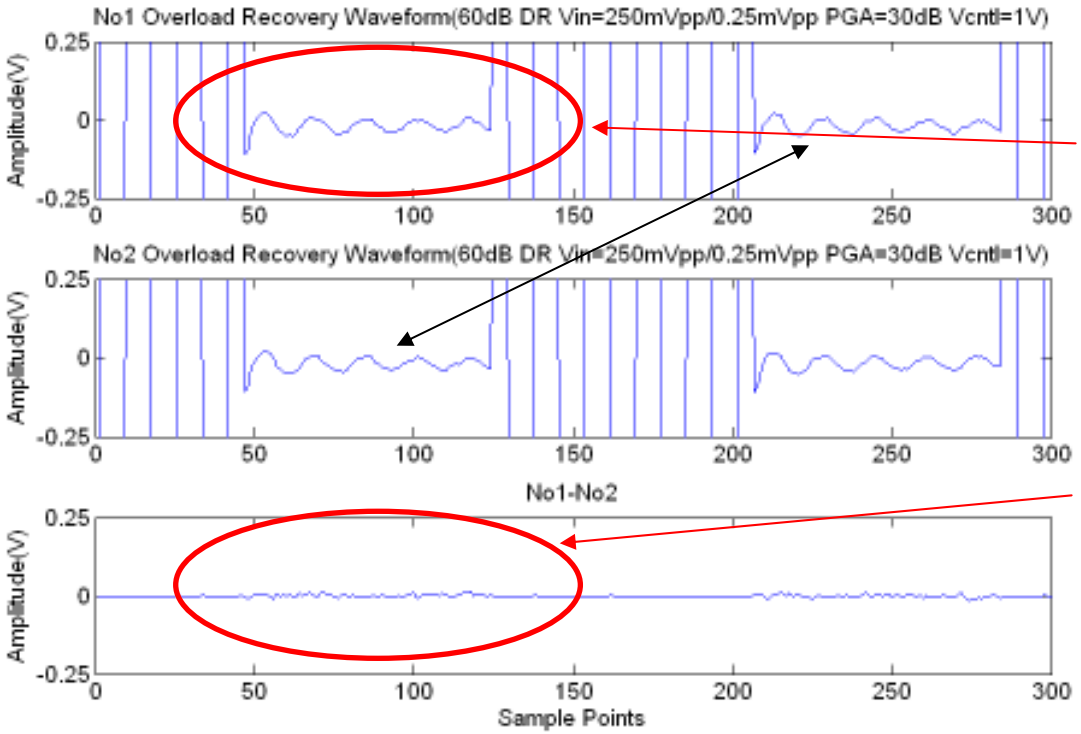
Overload Recovery

- **AFE5805: Proof of zero phase shift**
  - PGA=30dB, Vcntl=1V, No Clamp, 15M LPF,Gain~45dB
  - Signals: 250mVpp/**0.25mVpp**

No1

No2

No1-No2



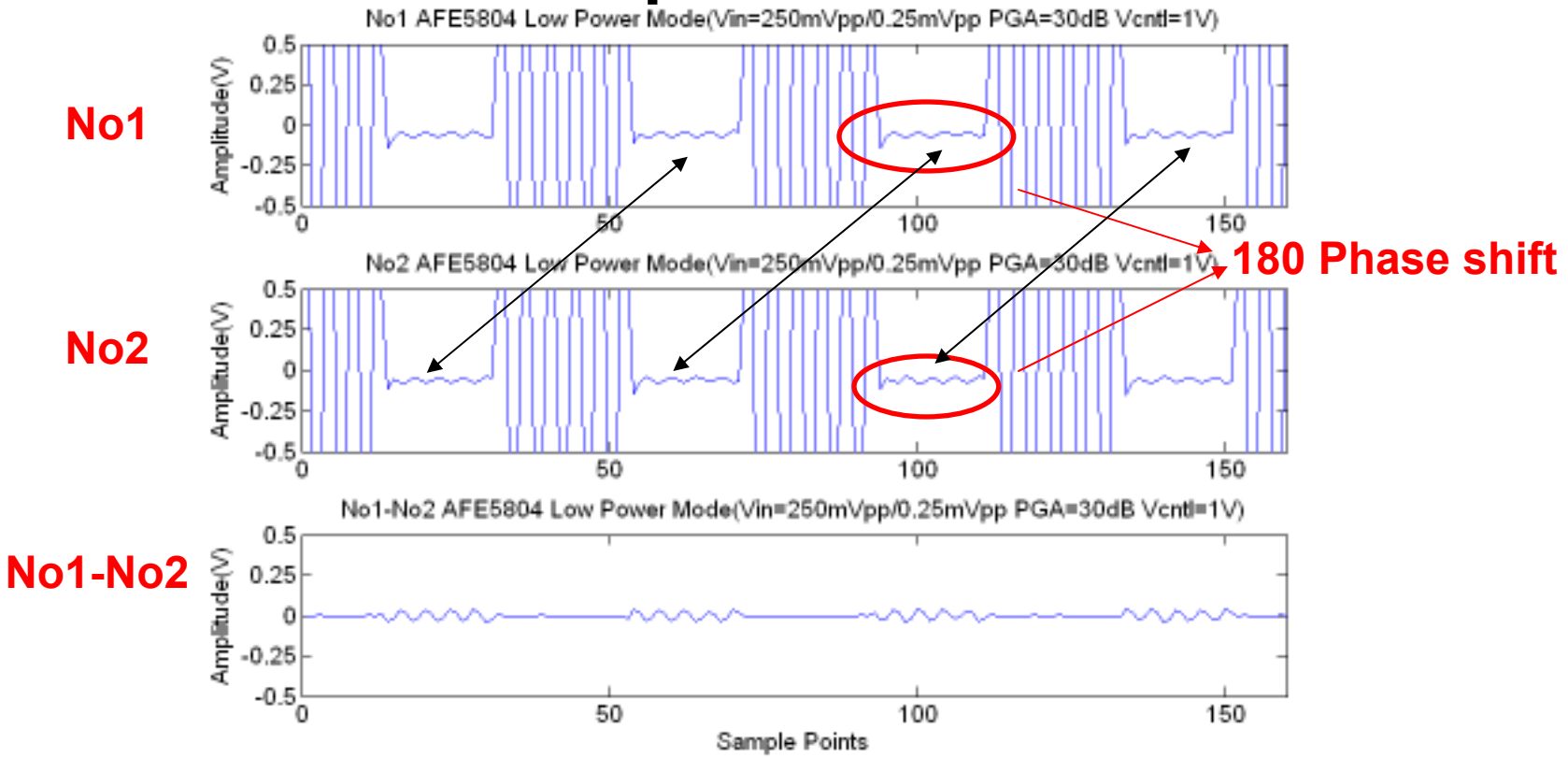
Can detect small signals

Consistent overload recovery characteristics; No phase shift

1. AFE5805 can detect signals with DR>60dB.

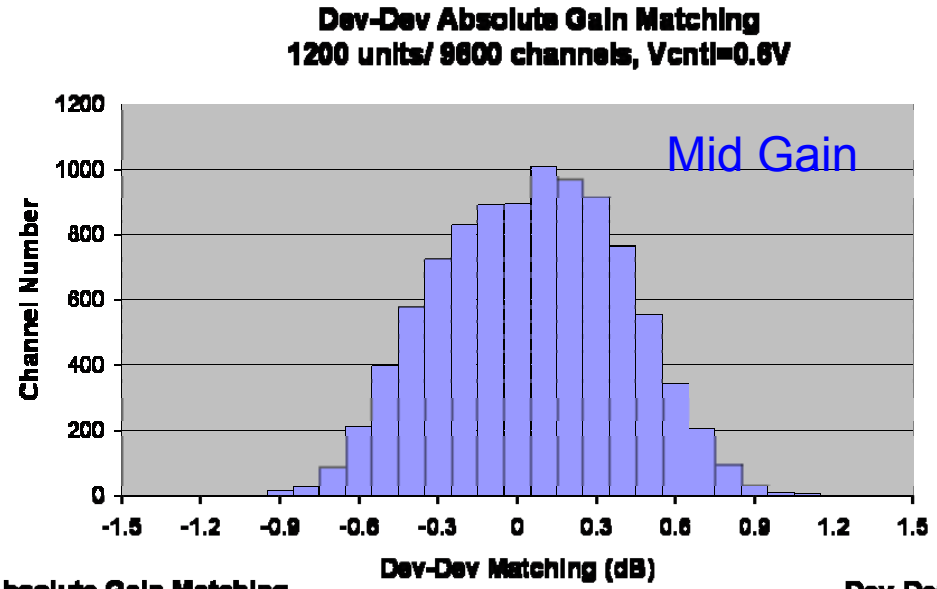
Overload Recovery

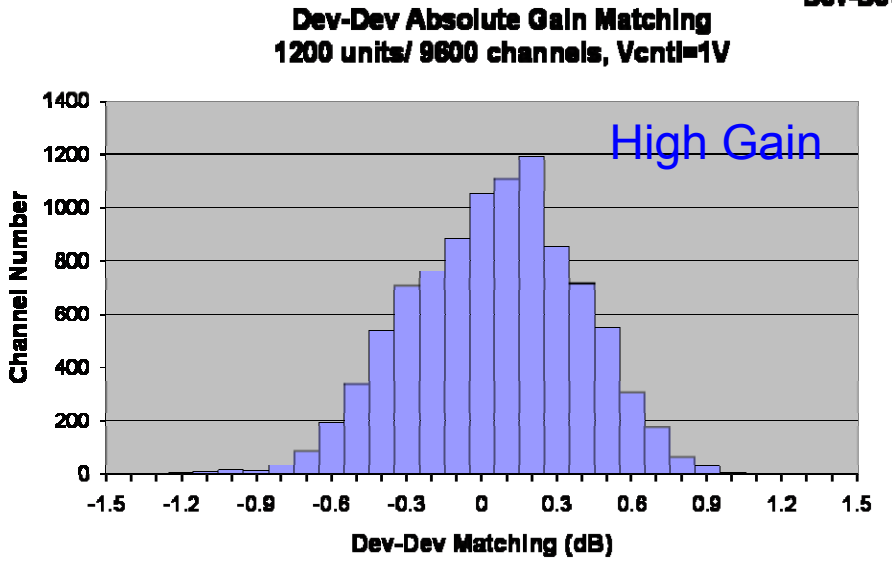
- **AFE5804: Proof of phase detection**

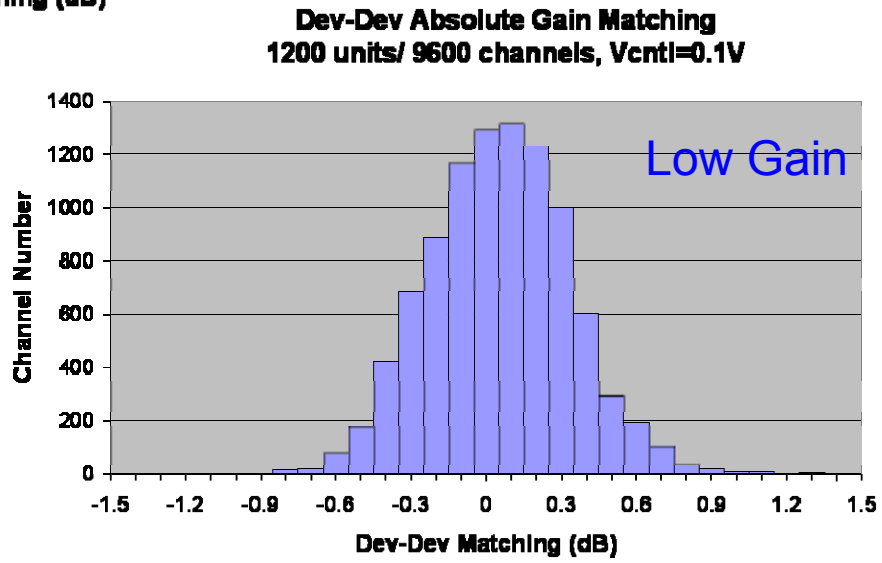


1. The small signal amplitude in No1-No2 is doubled.
2. 180 phase detection can be proved by amplitude doubling.
3. AFE5804 achieves excellent performance even at low power mode.

Gain Matching & Range

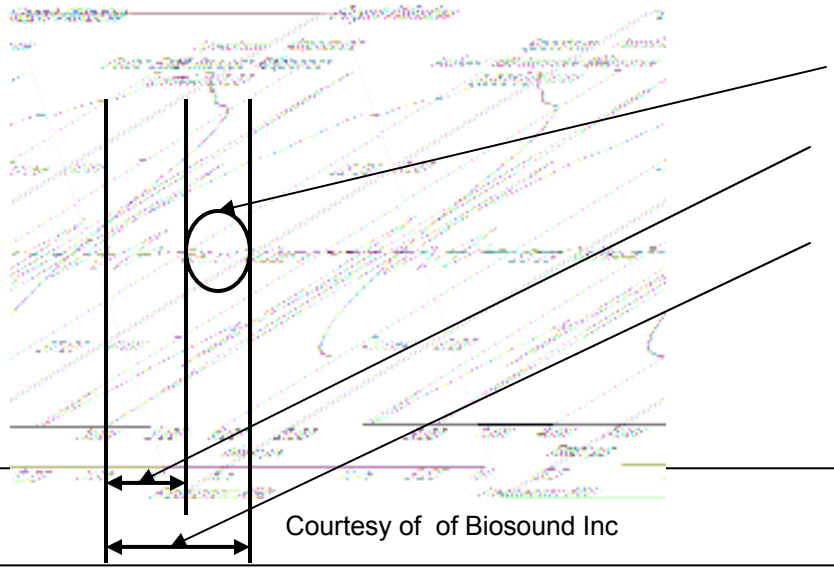






Termination for Ultrasound

- Termination Purpose
  - Ultrasound signal is a wide band signal→ Short pulse
  - Resolution is depending on pulse length
  - Reflection can affect system resolution
  - Xducer/cable: 100ohm; Rin of AFE: 10K→Mismatching →Reflection
  - Termination→Reduce reflection→ Improve Resolution



Reflection from mismatching

Ideal 0dB axial resolution

Degraded 0dB axial resolution due to mismatching

Courtesy of of Biosound Inc

Termination for Ultrasound

- Termination Resistor is NOT noiseless
- Thermal Noise is Added
- Low Impedance termination→ High Noise Figure
- Termination vs Noise Figure
  - No Termination: Lowest NF
  - Active Termination: Medium NF
  - Passive Termination: Highest NF
- Active termination is common on new AFEs

Future Ultrasound Solution

- Lower Power
- Higher Integration
- Ultra-Portable system
- Ultrasound Systems in Walmart

www.vividechoclub.net

European Debut of Vscan™

GE Healthcare's Vscan™, a pocket size imaging device, is making its European debut in Barcelona at the European Society of Cardiology, 2008. It is roughly the size of a smart phone but houses ultrasmart ultrasound technology that's set to help redefine the way doctors examine virtually every patient.

Designed for use in virtually any clinical, hospital or primary care setting Vscan offers:

- Cardiologists dependable visual evaluation that enables the physician to detect chamber size and LV (left ventricular) function at a glance. Its size and ease of use allows it to be with the clinician at all times.
- Critical care clinicians an immediate look beyond patient vital signs with the potential to identify critical issues like pleural or pericardial effusion.
- Primary care clinicians the potential to redefine the physical exam. It enables a deeper connection to the patient by visualizing what the physician may have been feeling or hearing with traditional palpation or auscultation techniques.

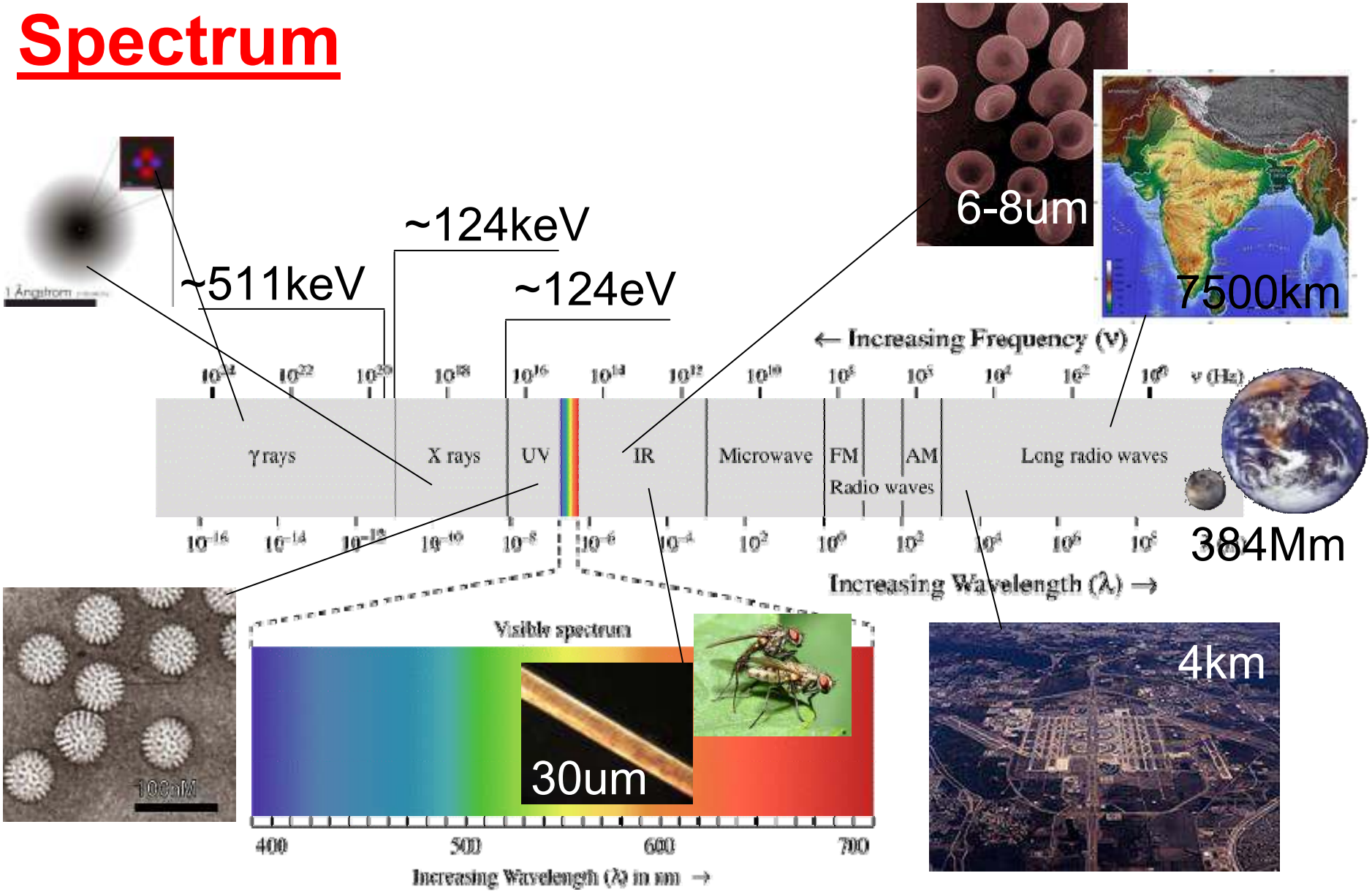
This new device will also allow each targeted clinician to better manage patient workflow. The cardiologist, for example, can forego the full echo examination and perform a more focused examination with immediate visual validation, allowing more time with patients and quicker, more accurate diagnosis. GE Healthcare also announced that early adopters of this breakthrough technology are being granted access into the Vscan User Group, an opportunity to share insight, research and recommendations that could help shape future Vscan product offerings.

"Customer feedback is critical. We are thrilled with the opportunities Vscan presents our customers to make point of care imaging a reality and we anticipate the Vscan User Group will provide even greater insights for ongoing developments which are vital to the success of our products," said Al Lojewski, Global General Manager of GE's Cardiovascular Ultrasound business.

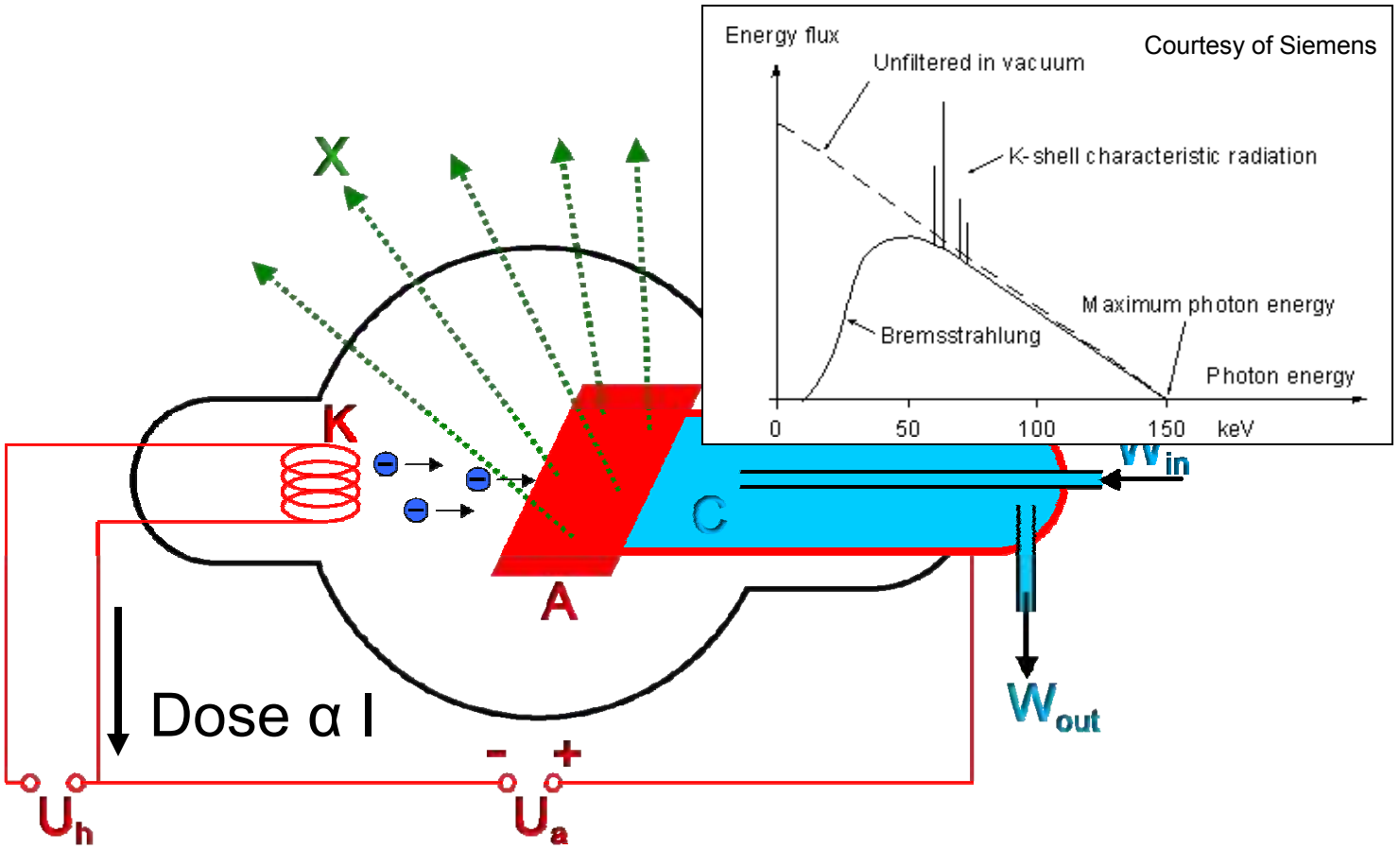
Vscan™

Digital X-rays

Spectrum

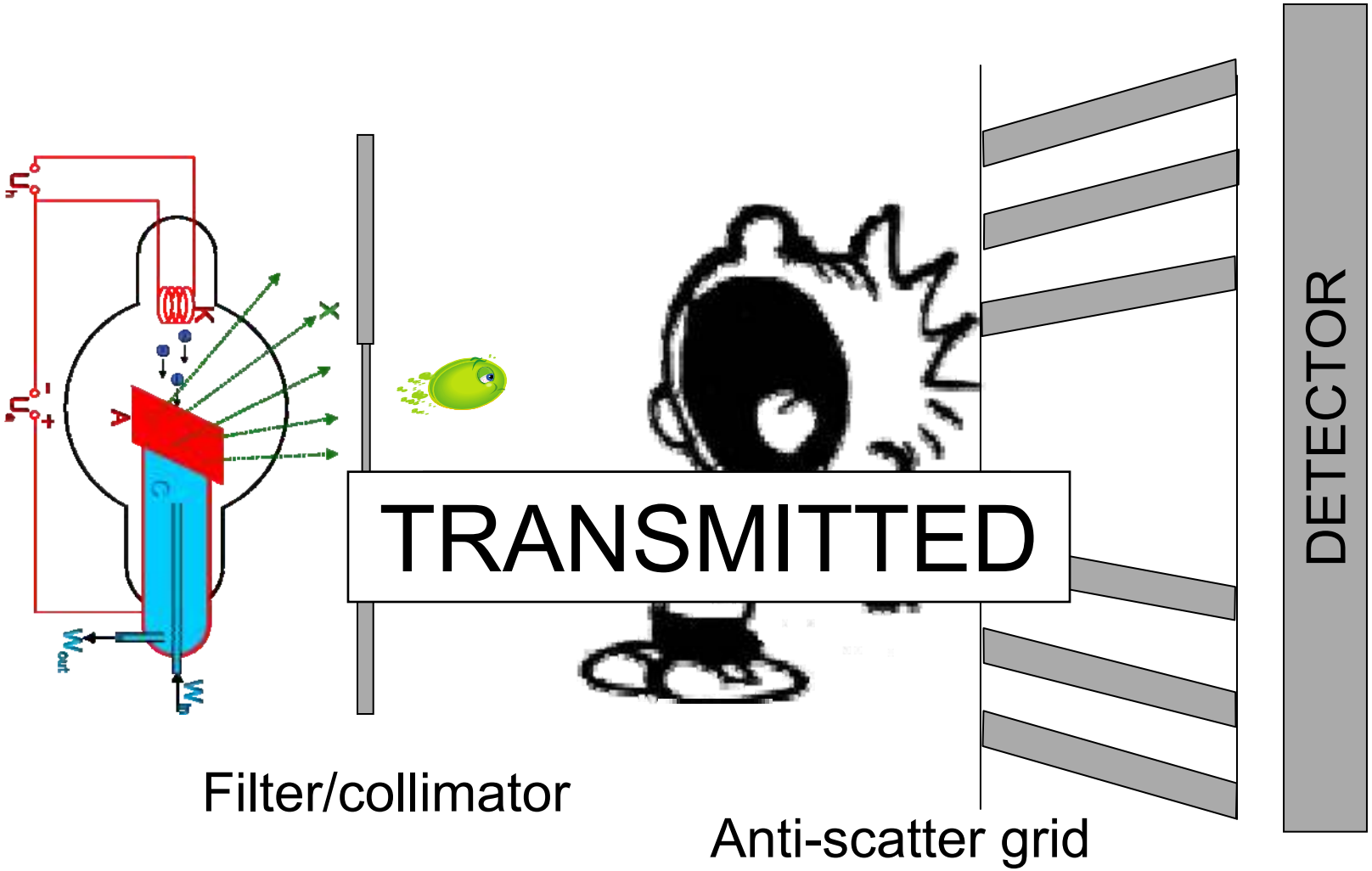

~511keV
~124keV
~124eV
6-8um
7500km
← Increasing Frequency (ν)
γ rays
X rays
UV
IR
Microwave
FM
AM
Radio waves
Long radio waves
ν (Hz)
384Mm
Increasing Wavelength (λ) →
Visible spectrum
30um
4km
400
500
600
700
Increasing Wavelength (λ) in nm →

X-ray – Generation

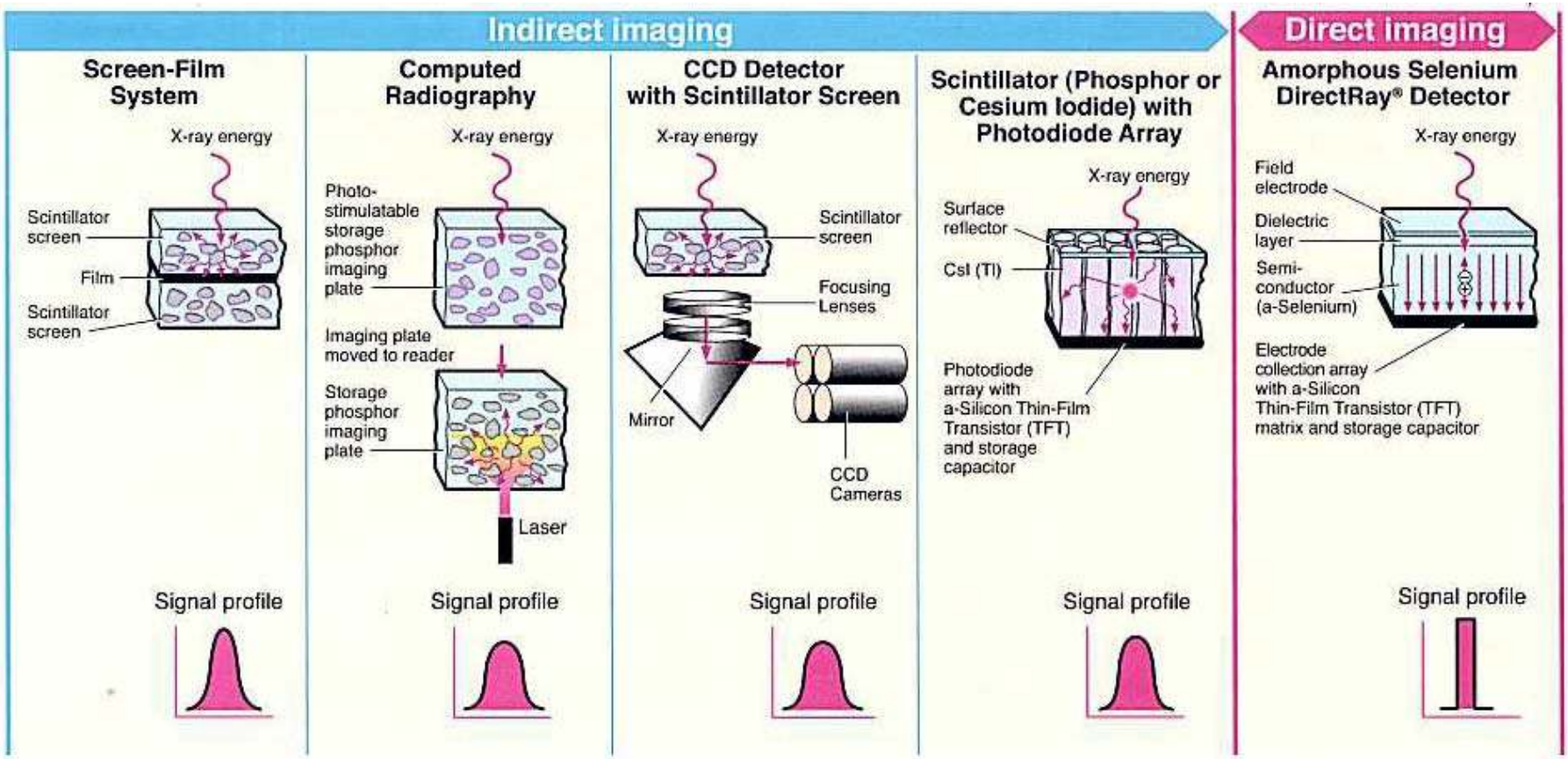


Energy α Voltage

X-ray Machine



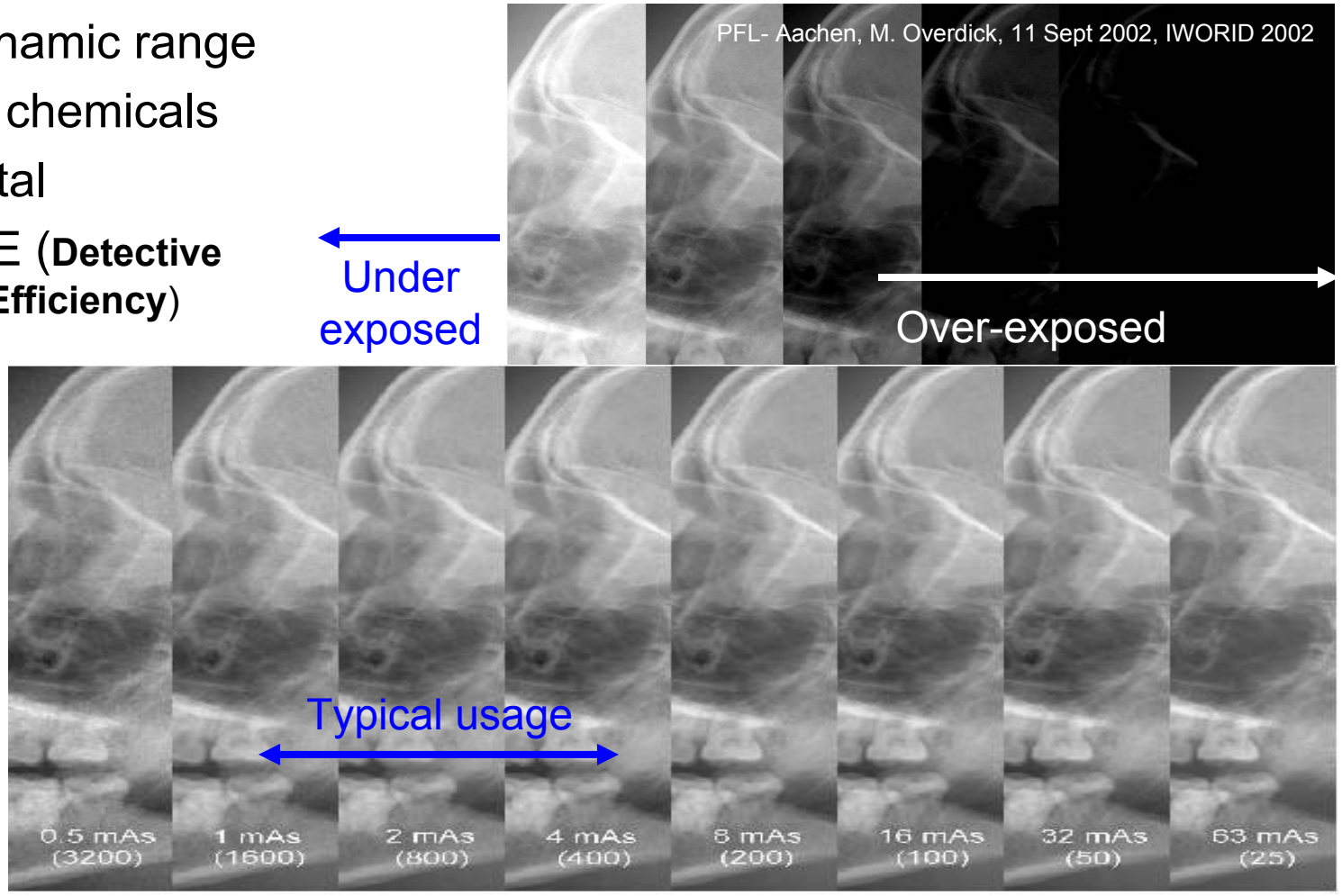
X-ray imagers overview



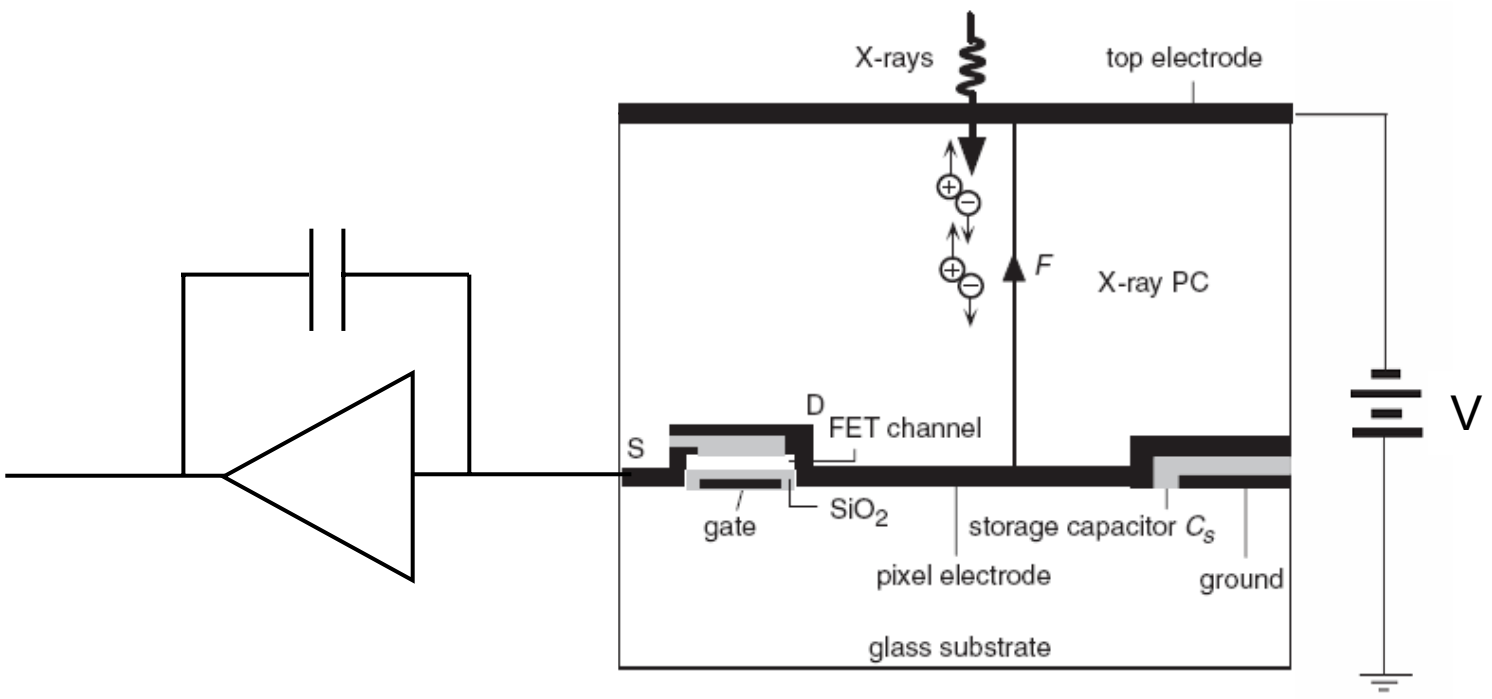
Courtesy of Hologic

Digital advantages vs. Screen/Film

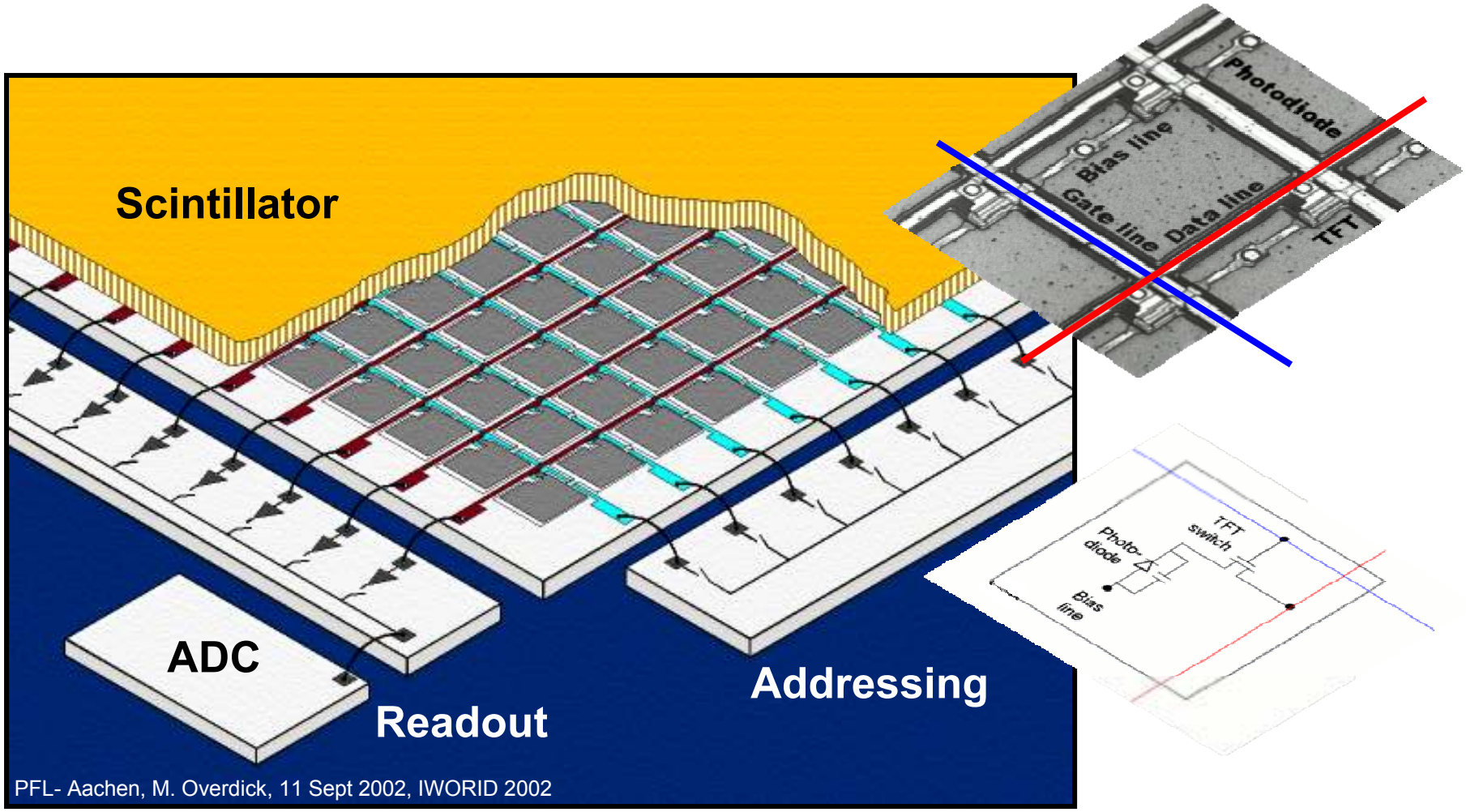
- Large dynamic range
- No films, chemicals
- Fully digital
- High DQE (**Detective Quantum Efficiency**)



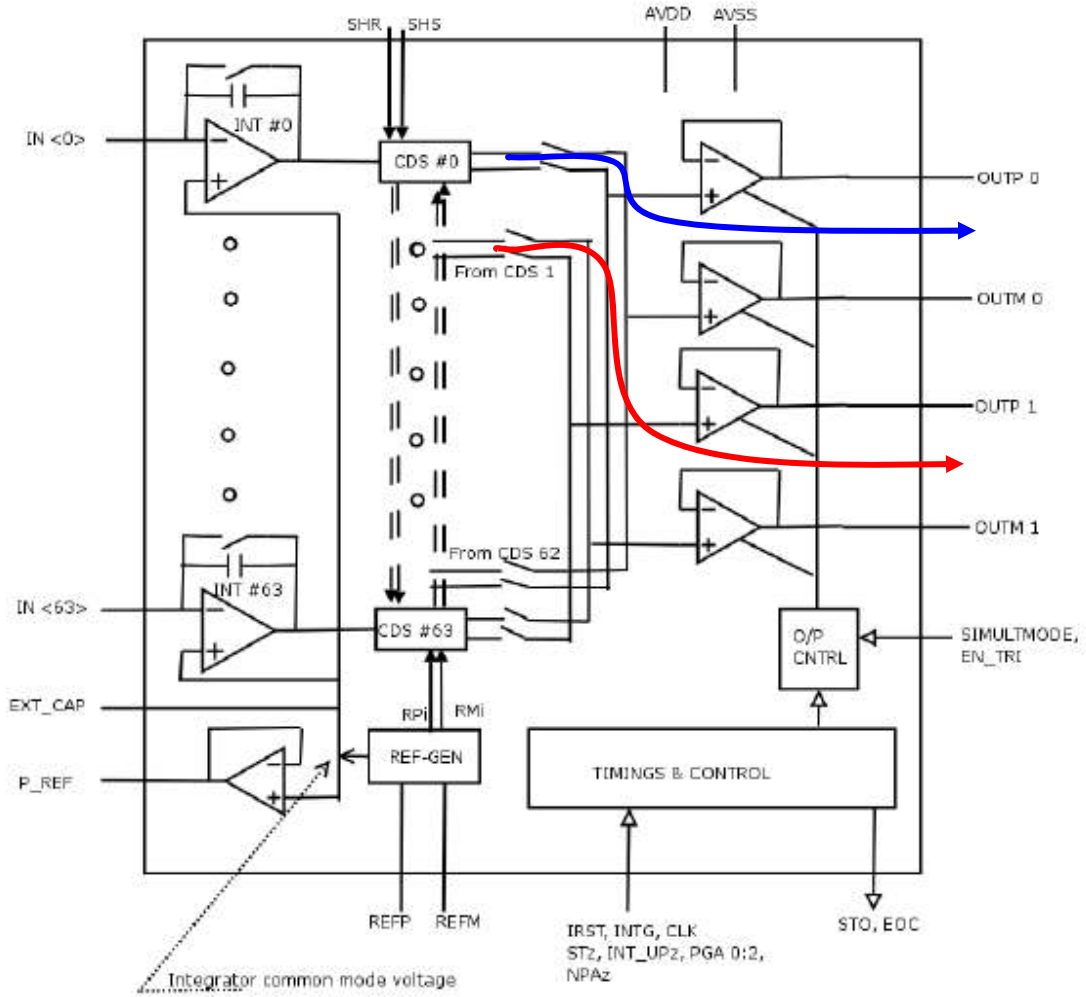
Direct


X-rays
top electrode
F
X-ray PC
D
FET channel
S
gate
SiO_2
storage capacitor C_s
pixel electrode
ground
glass substrate
V

Indirect

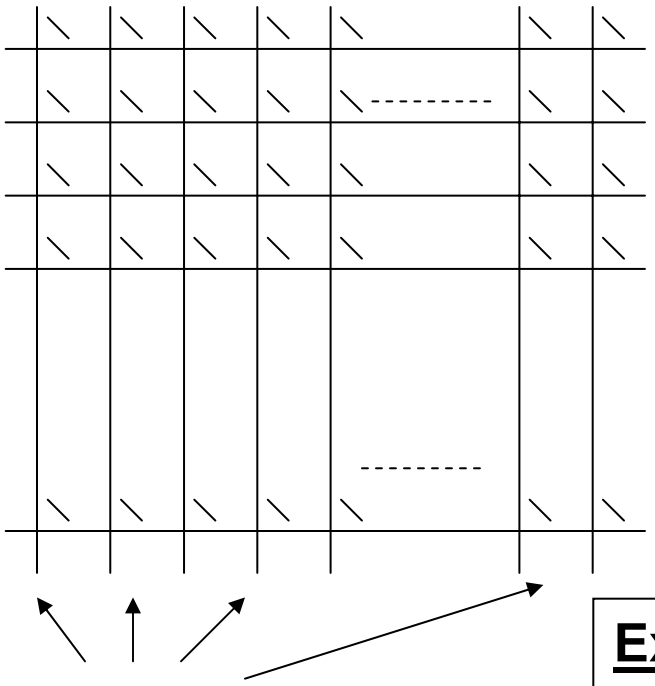

Scintillator
ADC
Readout
Addressing
Photodiode
Bias line
Gate line
Data line
TFT
TFT switch
Photo-diode
Bias line
PFL- Aachen, M. Overdick, 11 Sept 2002, IWORID 2002

AFE-XR0064 operation



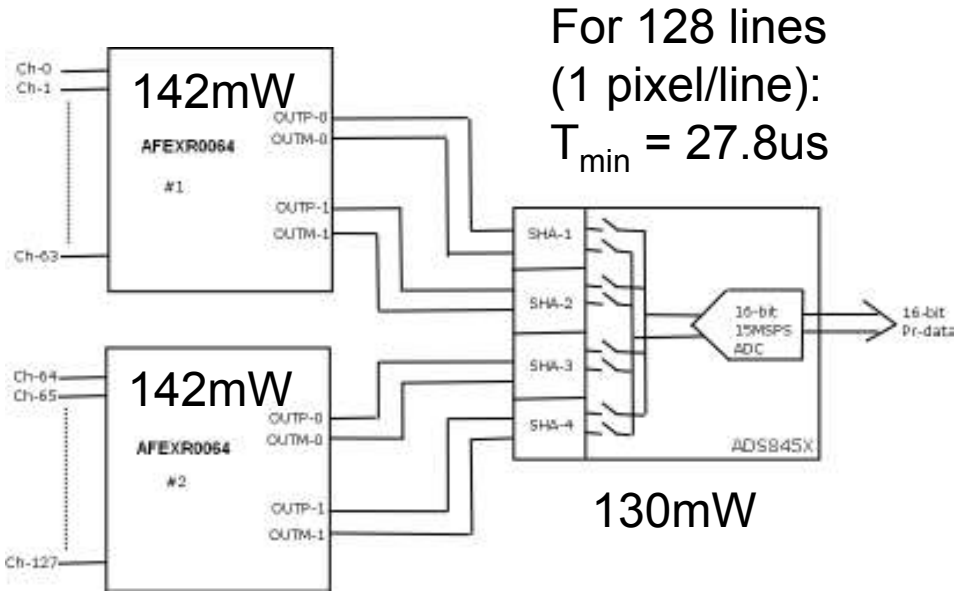
1. CDS samples offset.
2. The panel control turns on the TFTs of a new column of pixels.
3. The charge is integrated (needs about 14us).
4. The CDS takes the integrated values and subtracts the offsets.
5. We can now RST the integrators. CDS still holds the analog values.
6. Analog values are muxed to the ADC inputs.

Readout time



Scan lines controlling gates of TFT:

- Ron ≅ 1-2MΩ
- C_{pixel} ≅ 1-2pF



For 128 lines (1 pixel/line):
T_{min} = 27.8us

130mW

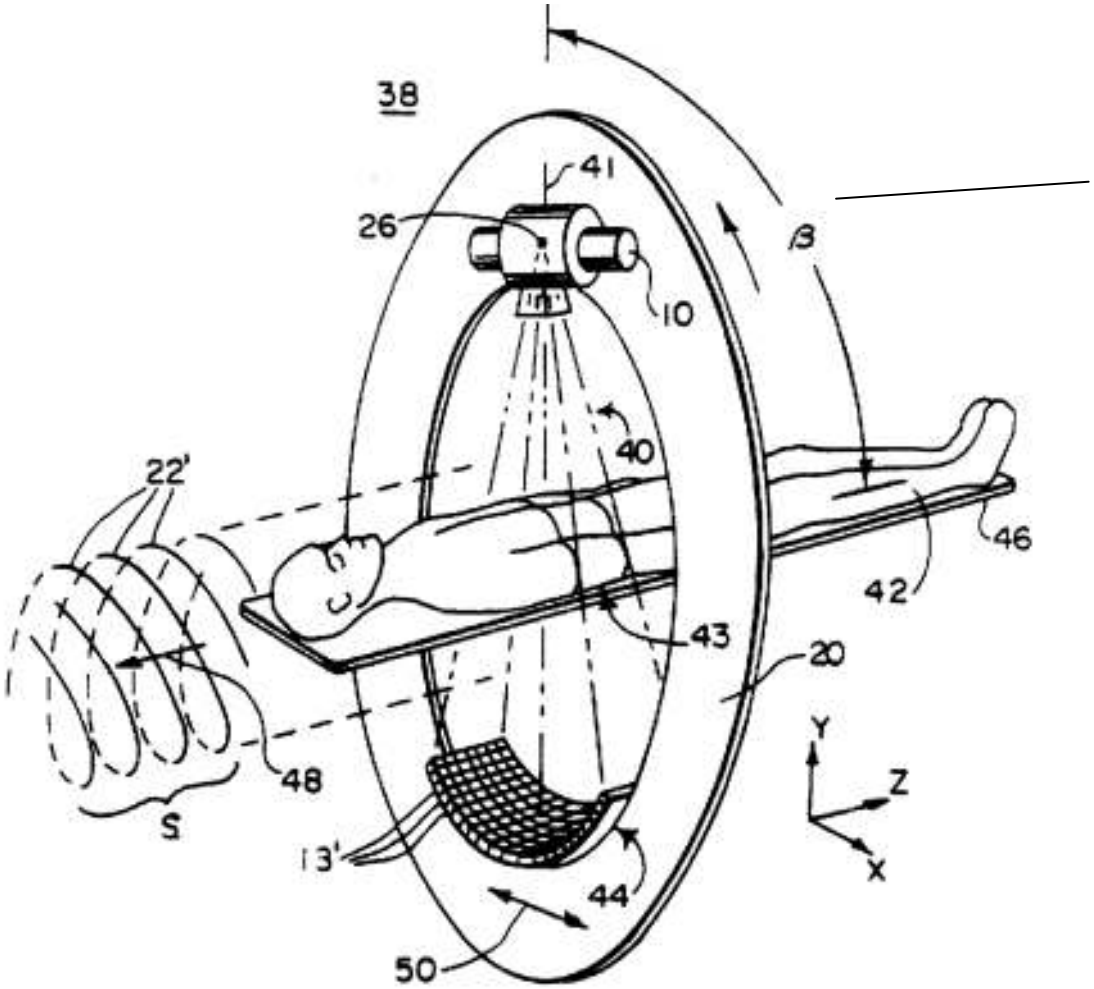
Example: 1536 * 1536 panel

Divide panel on 2 blocks of 768 columns, each with 24 AFEXR0064:

768*27.8us = 21.35ms → FR >30fps

Computer Tomography (CT)

The machine



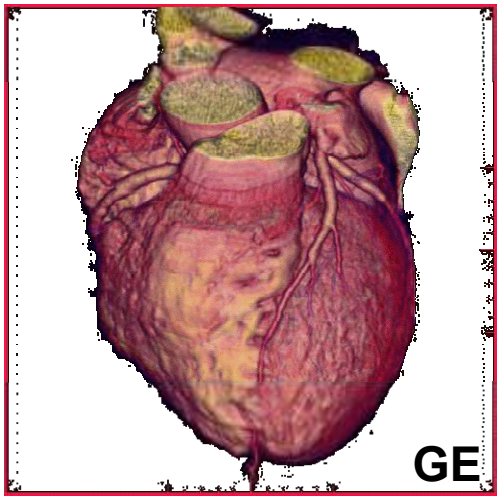
3 revolutions per second

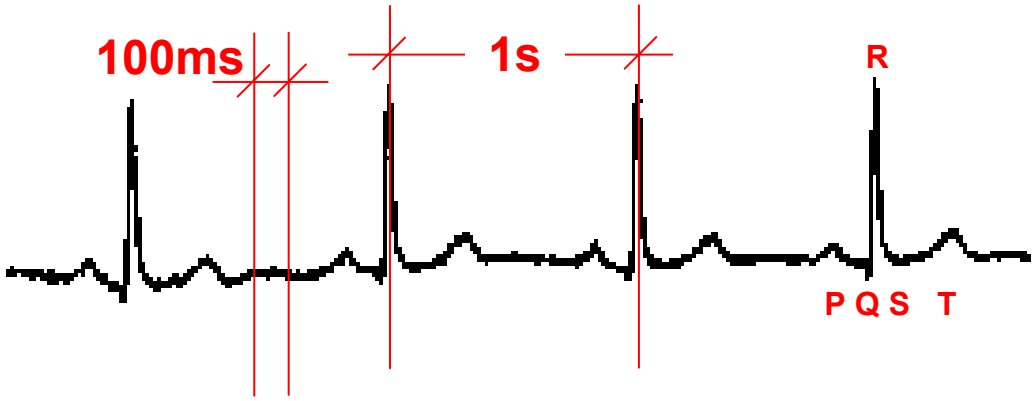
1000 profiles per revolution

3KSPS/pixel

Imaging the heart - Challenges

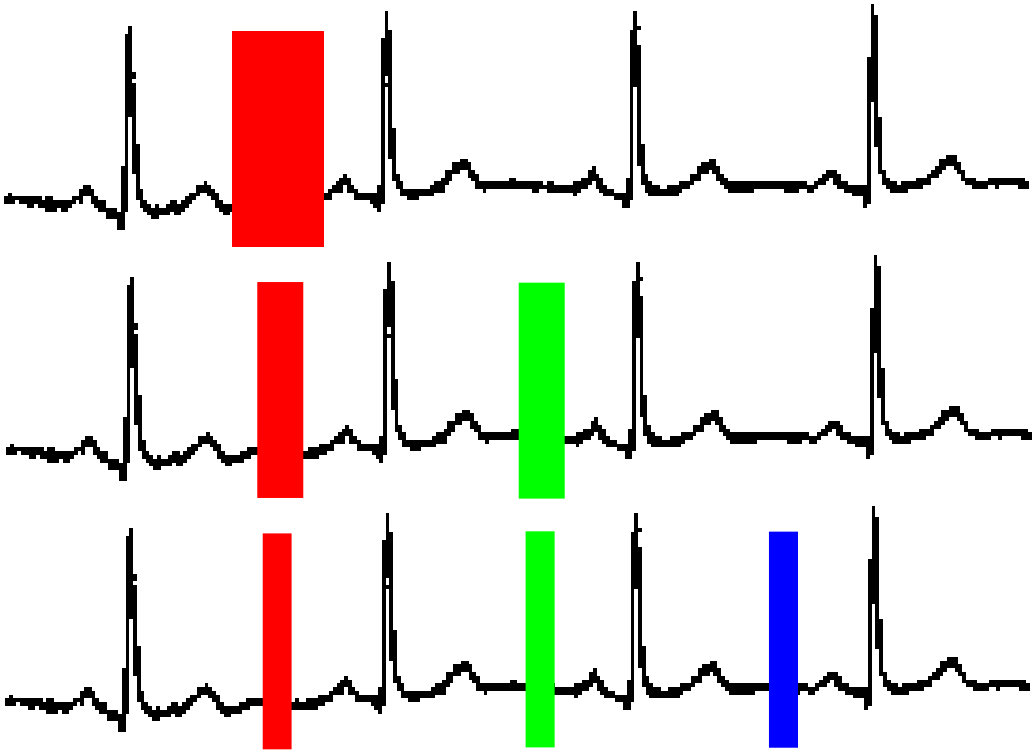
- @ 60bpm → 1 beat/s.
- Need 100ms shot at least to resolve 1mm in diastole (when heart is more still)
- Faster shot for other phases of the heart or better resolution (for plaque, smaller arteries…)
- 12cm long.
- Image the heart in one breath hold.
- Varying beats: % case with stable heart beat (courtesy of GE):
  - 4 beat: 97%
  - 5 beat: 92%
  - 8 beat: 39%
  - 10 beat: 10%

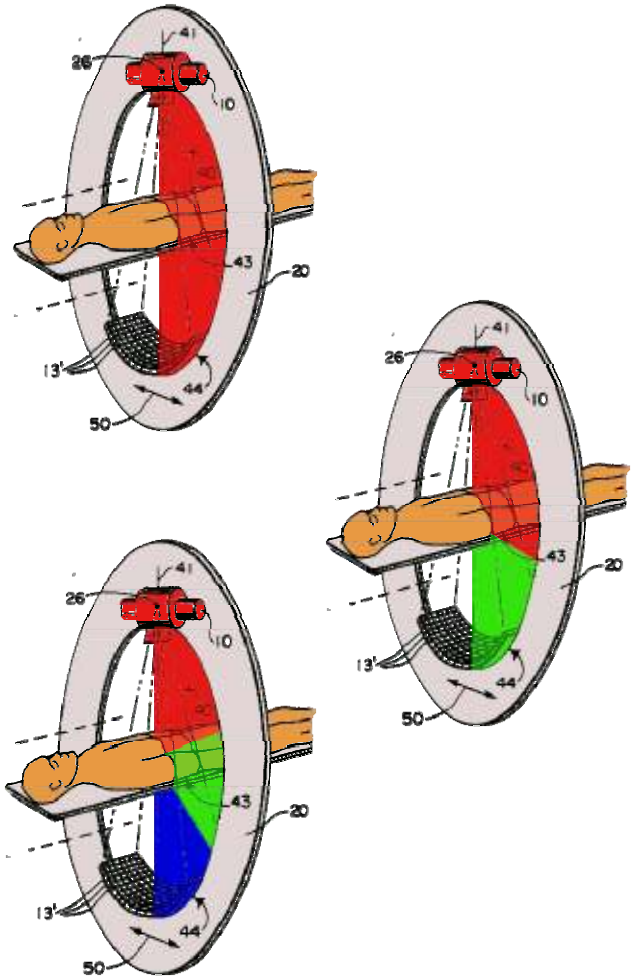




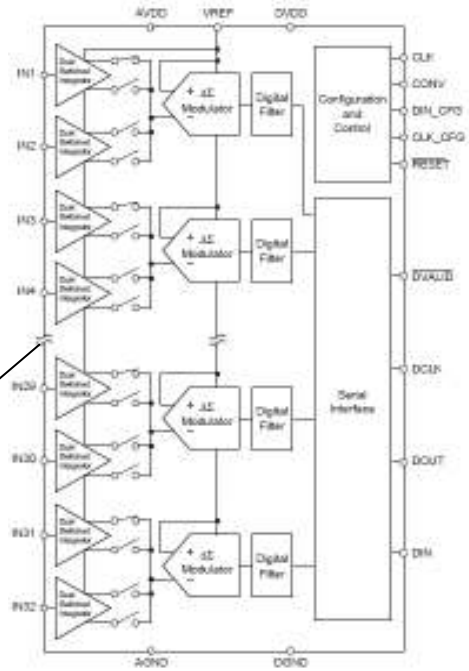
Imaging the heart - Technique

ECG synchronization





Switched Integrator



Photodiode Current

C_{INT}

A

B

FS ≅ 100's pC

ADC

20bits
≅ 6KSPS (x2)
≅ 7mW/channel

C_{INT}

DDC232

Medical Imaging Safety

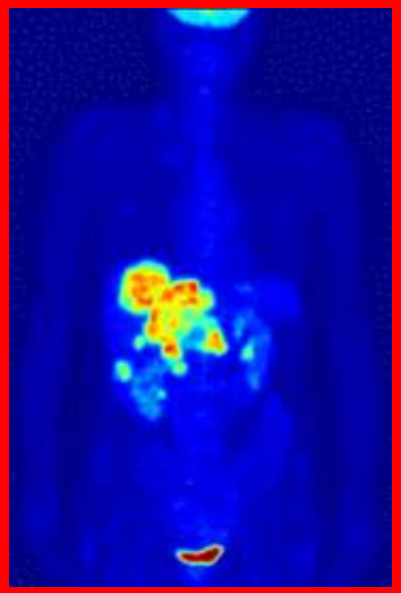
Radiation

Natural background: 2.4mSv/year
Air travel crew: 3mSv/year
Radiation worker federal limit: 50mSv/year
Dental radiography: 0.01mSv
Chest radiography: 0.1mSv
Mammography: 0.7mSv
PET/SPECT : 7mSv
Chess CT: 8mSv
Pelvic/abdomen CT: 10mSv
CT Angiography: 15mSv
50% of cases die in 30 days: 3Sv

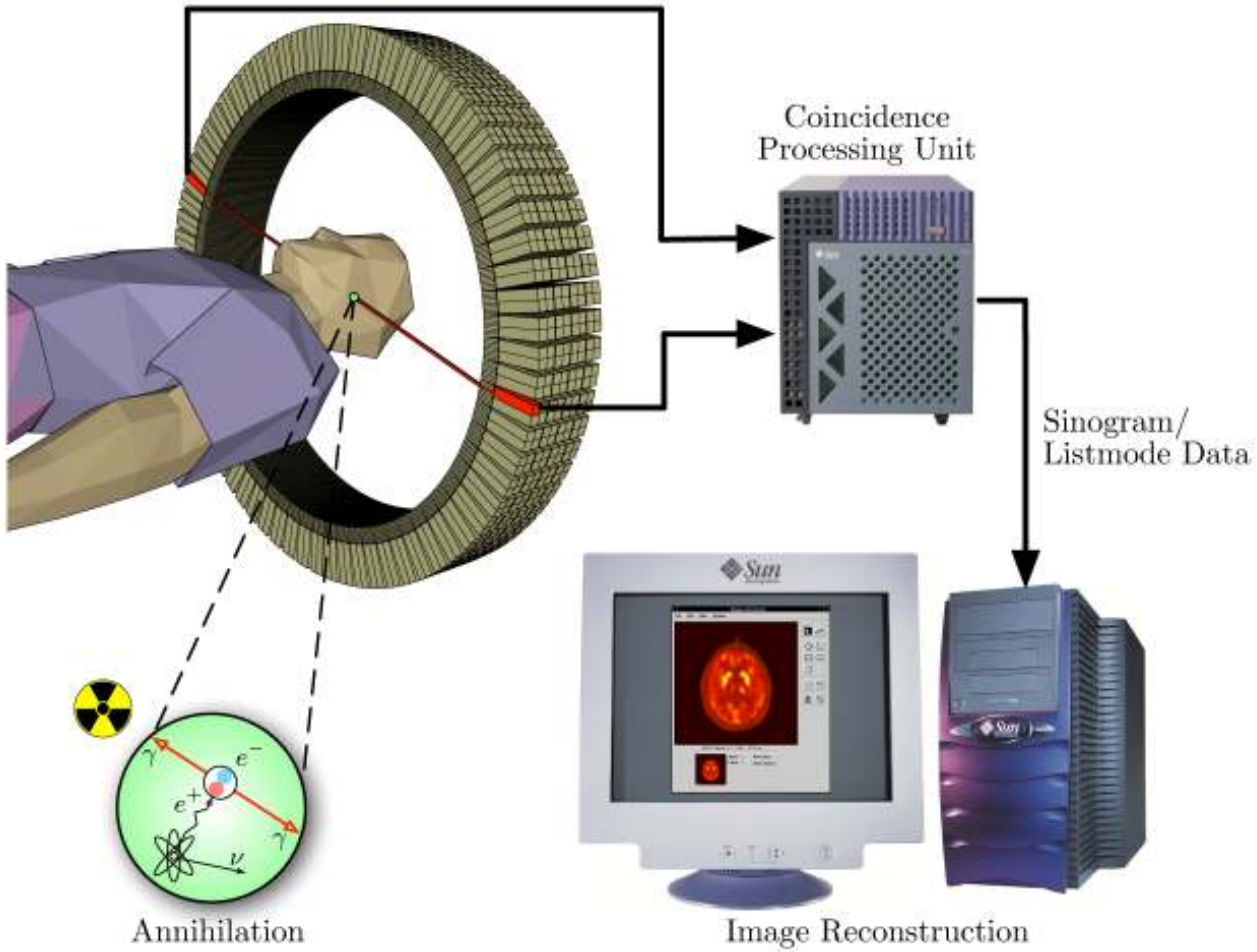
Thank You!!!
Comments & Questions☺

Backup: PET

Introduction to Medical Imaging

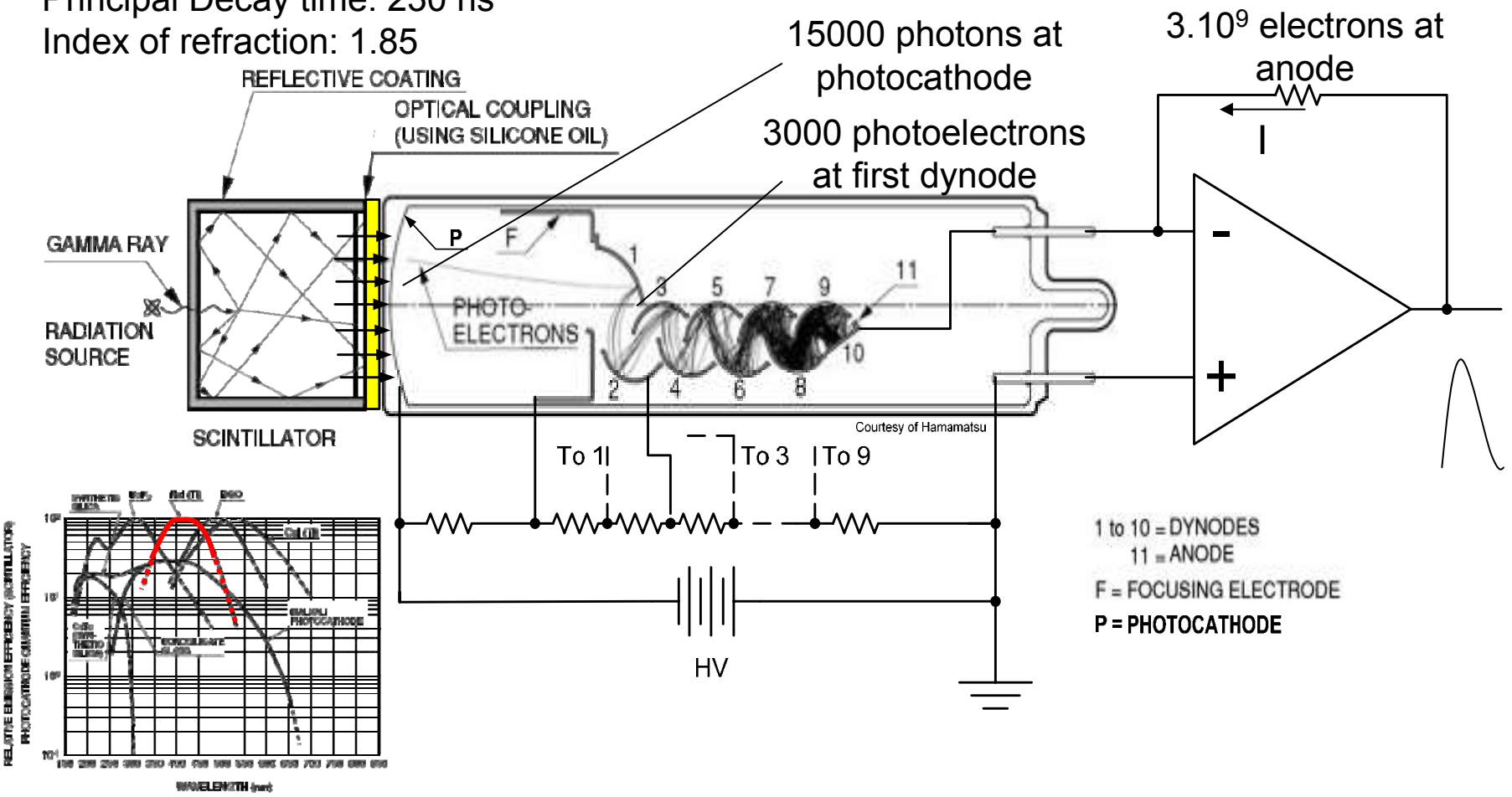


The machine

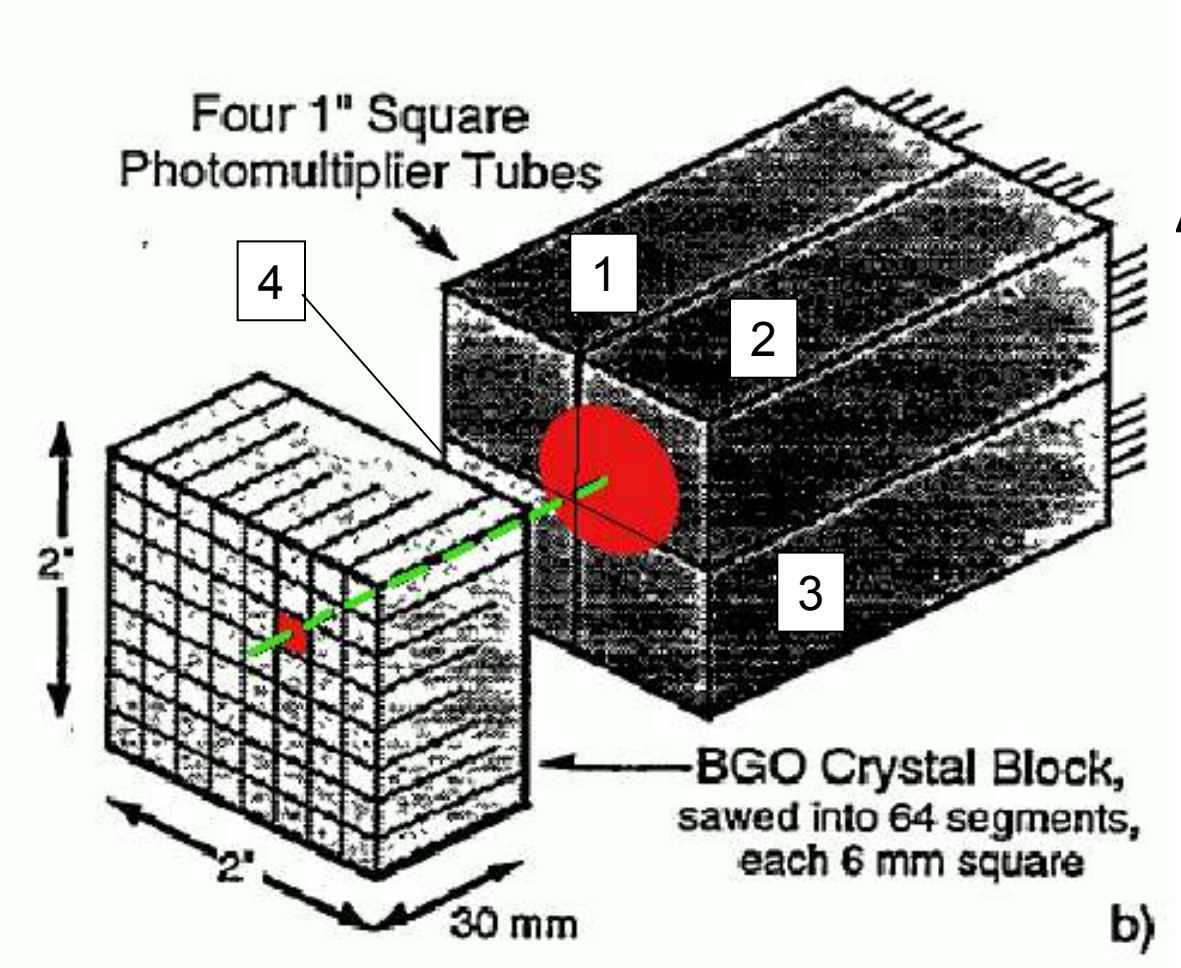

Coincidence
Processing Unit
Sinogram/
Listmode Data
Annihilation
Image Reconstruction

The detector

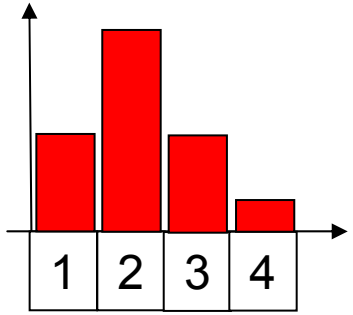
Example (from Derenzo): NaI(Tl) - 3.3 cm
Light output: 50k (38k?) photons/MeV
Principal Decay time: 230 ns
Index of refraction: 1.85



Centroid

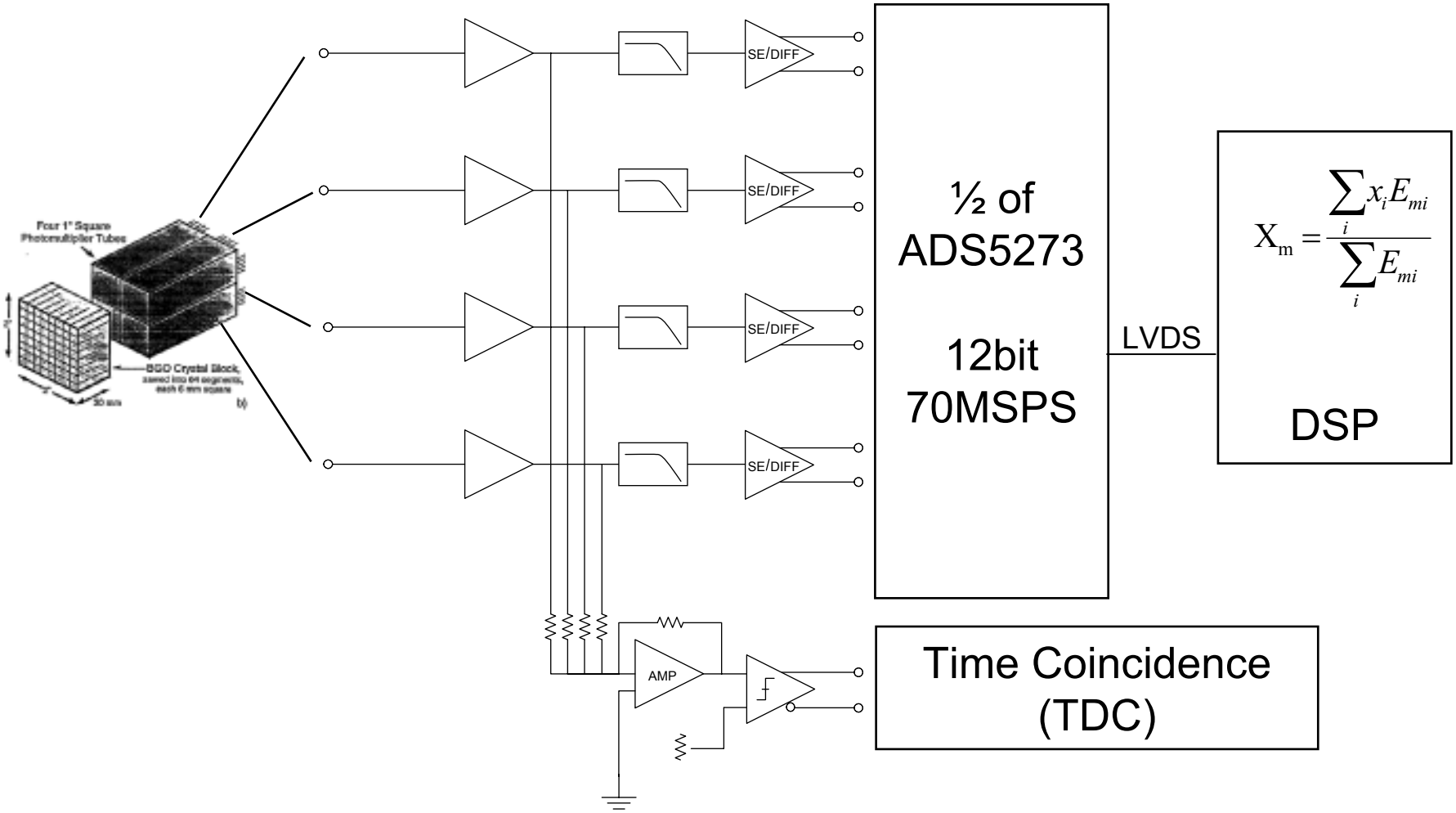


To ADCs
Position
Anger logic



$$X_m = \frac{\sum_i x_i E_{mi}}{\sum_i E_{mi}}$$

Front-end


SE/DIFF
SE/DIFF
SE/DIFF
SE/DIFF
½ of
ADS5273
12bit
70MSPS
LVDS
DSP
$X_m = \frac{\sum_i x_i E_{mi}}{\sum_i E_{mi}}$
AMP
Time Coincidence
(TDC)