A UNIFIED STREAMING AND PROCESSING ARCHITECTURE FOR ULTRASOUND SYSTEMS

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TÜV NORD Polska PN-EN ISO 13485

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INNOVATIVE ECONOMY NATIONAL COHESION STRATEGY

EUROPEAN UNION EUROPEAN REGIONAL DEVELOPMENT FUND

Agenda

- A few words about my Institute and my Team

- Ultrasound signal processing and device architecture
- Unified Streaming and Processing Architecture
- Our Ultrasound Platforms
- Applications
- Summary

IPPT PAN new building (2009)

About IPPT PAN:
The Institute of Fundamental Technological Research

- Established in 1953 under the auspices of Polish Academy of Sciences.

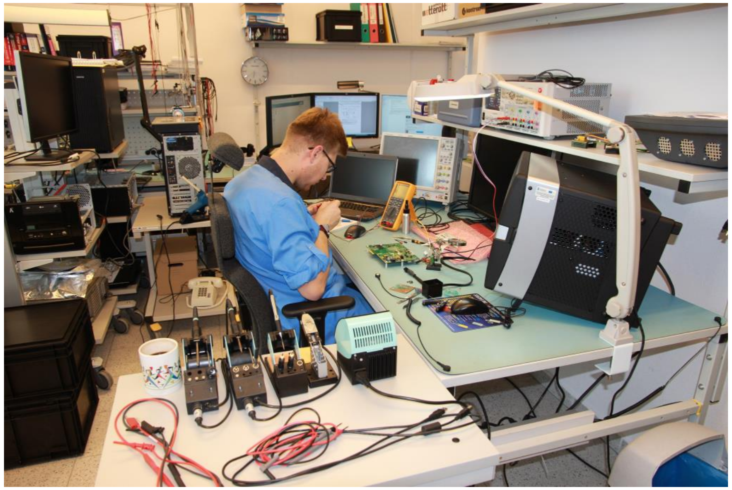
- Departments:
  - Department of Mechanics and Physics of Fluids
  - Department of Mechanics of Materials
  - Department of Computational Science
  - Department of Intelligent Technologies
  - Department of Theory of Continuous Media
  - Department of Ultrasound
  - Department for Strength of Materials
  - Joint Laboratory of Multifunctional Materials

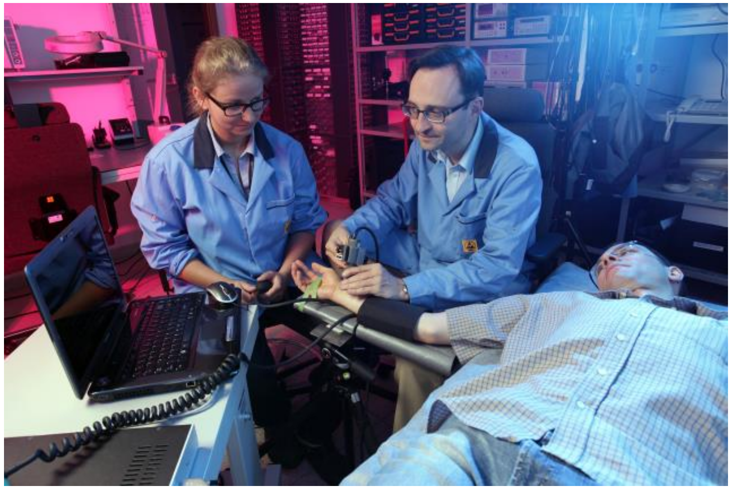
Mechanics of Materials (nano, micro, macro), Smart Systems, Biomed, Electronics, Ultrasound

Our Lab

1965
The first ultrasound apparatus UG-1

2014

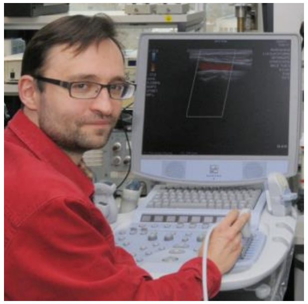




My Team: Design of Electronic Systems and Digital Signal Processing

In 2014 we implemented Quality Assurance Systems:

- **ISO-13485**: Design and development, manufacture and service of medical devices, training for users of medical ultrasonic devices.
- **ISO-9001**: Design and development, manufacture, service and trainings in the scope of electronics systems and software.



Marcin Lewandowski

Development

Mateusz Walczak

Beata Witek

Jakub Rozbicki

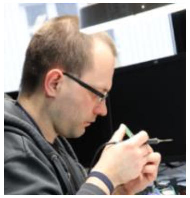
Bogusław Zienkiewicz

Research

Norbert Żołek

Tomasz Steifer

Piotrek Karwat



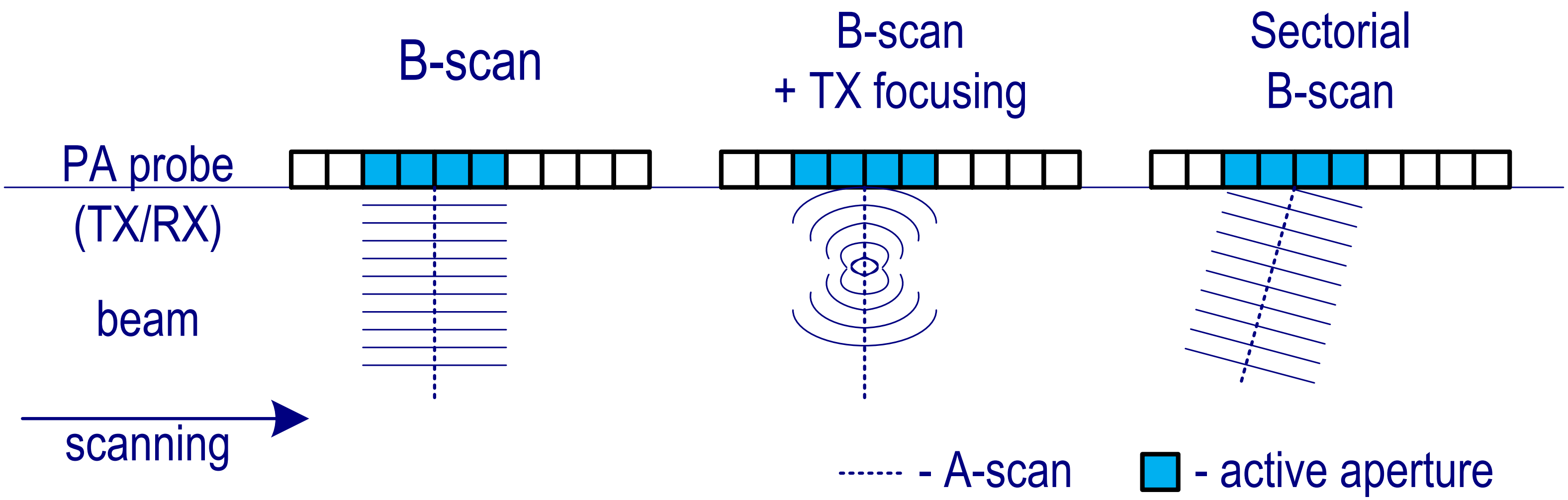
Ziemowit Klimonda

Jurij Tasinkiewicz

Janusz Wójcik

MULTICHANNEL ULTRASOUND SYSTEMS

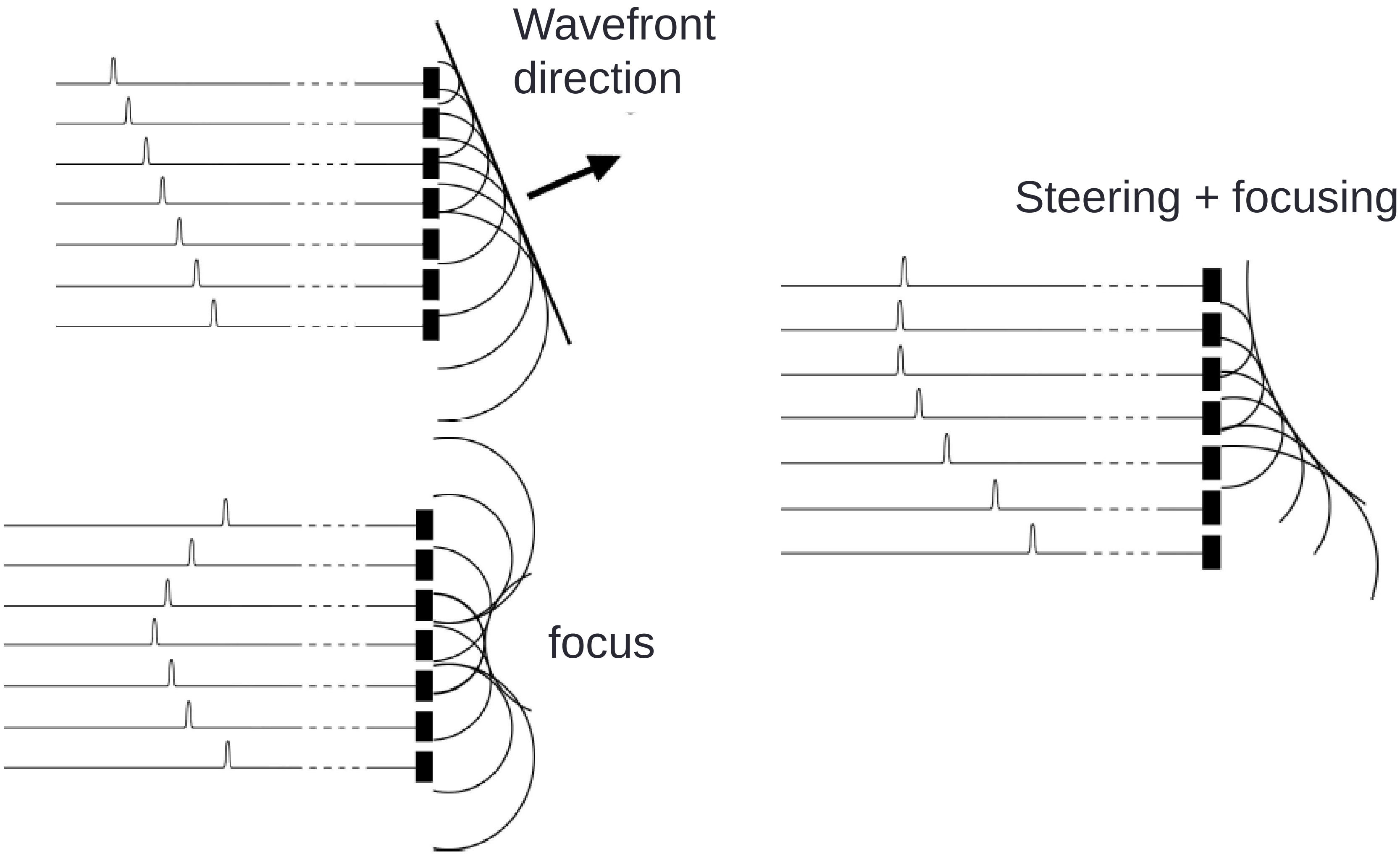
Phased-Array B-scan



B-scan / Beamforming method:

- Standard image reconstruction method (MED & NDT)
- The equivalent of a „universal" single element probe

Transmit beam steering and focusing

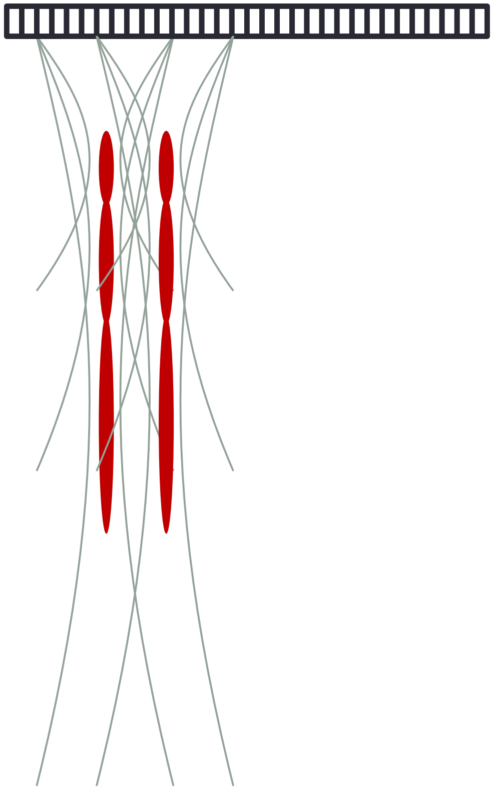


Classical beamforming

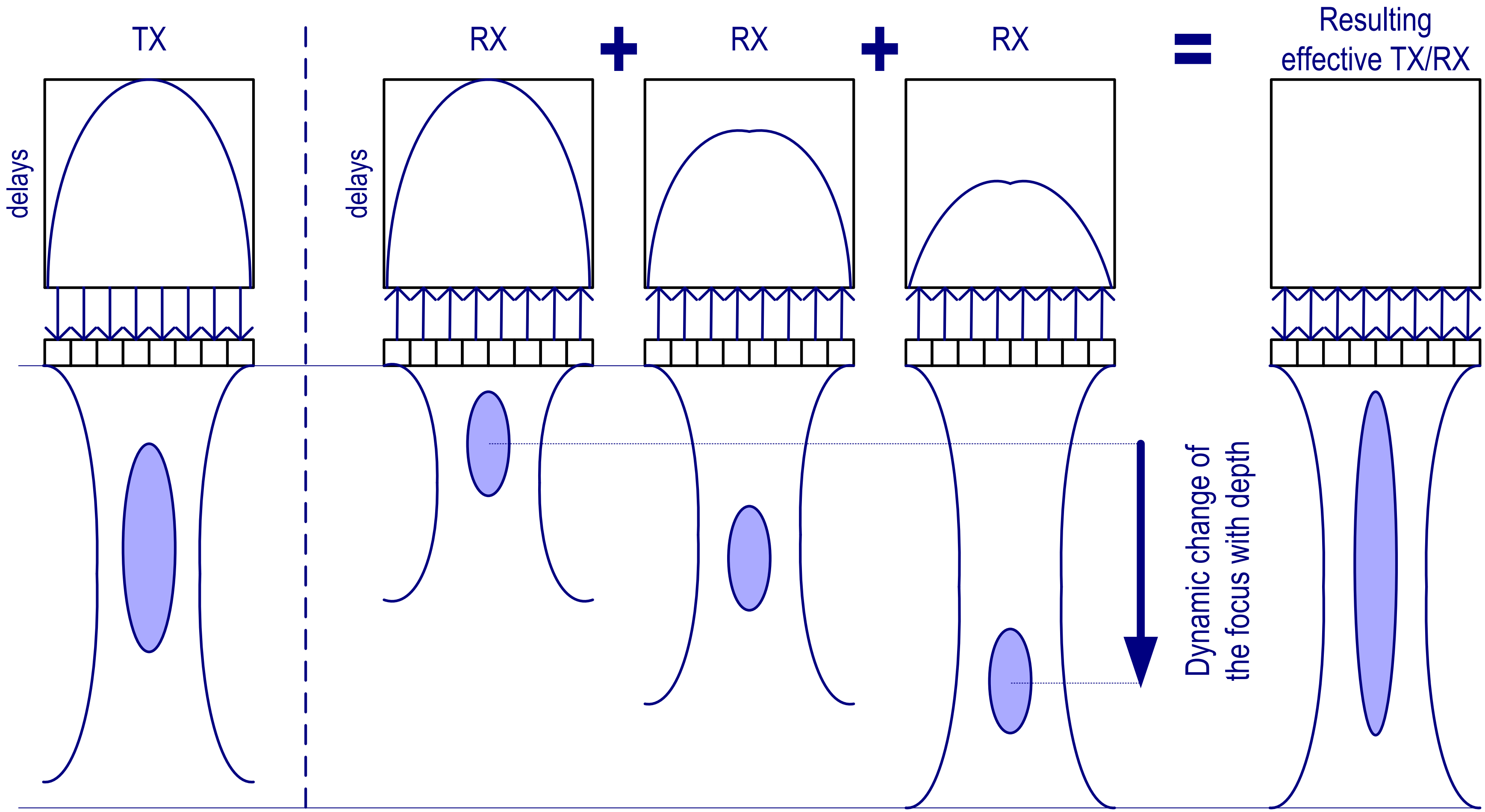
Beamforming:

- Gives good resolution in the focal region
- Requires many transmissions to build an image:

$$N_{TRANSMIT} = N_{FOCUS} \cdot N_{LINE}$$



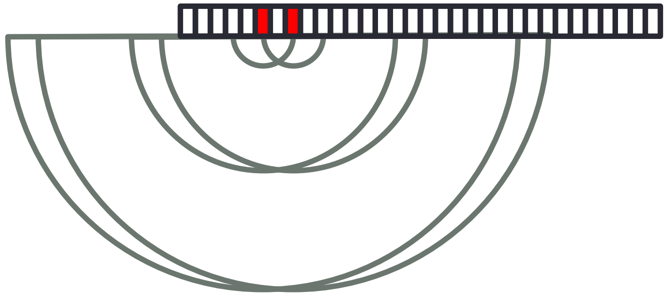
DDF (Dynamic Depth Focusing)



SAFT – Synthetic Aperture Focusing Technique

- Focusing in full ROI by signal processing
- Requires:

  $N_{TRANSMIT} = N_{TRANSDUCERS}$



SAFT, MSAF, STA, SRA

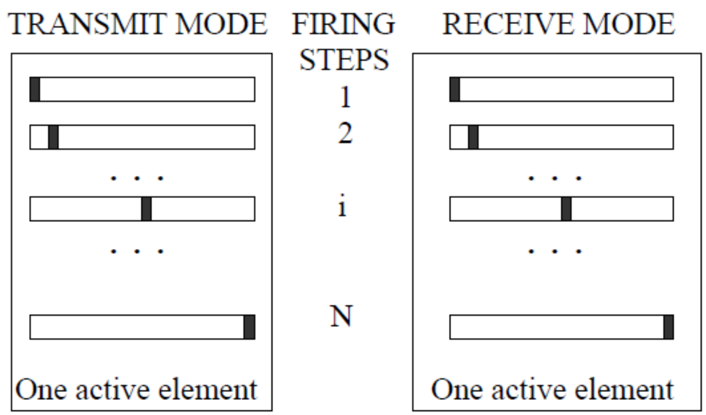


Fig.1: SAFT imaging method

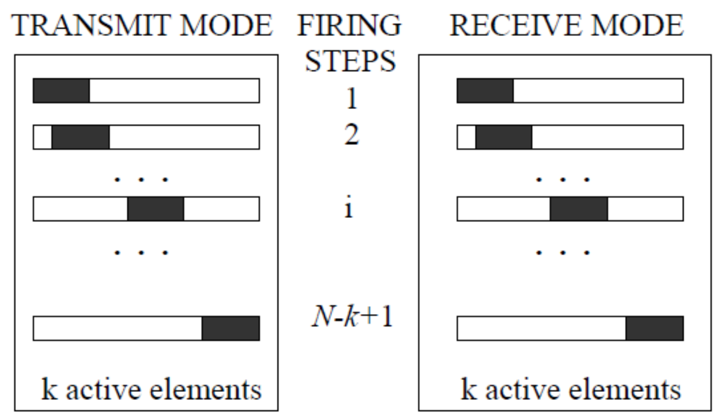


Fig.2: MSAF imaging method

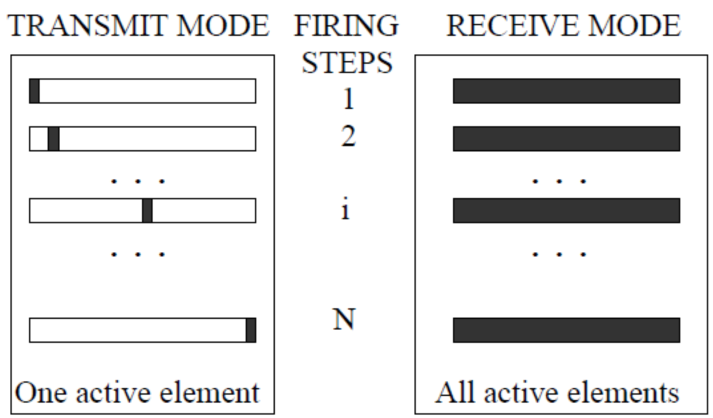


Fig.3: STA imaging method

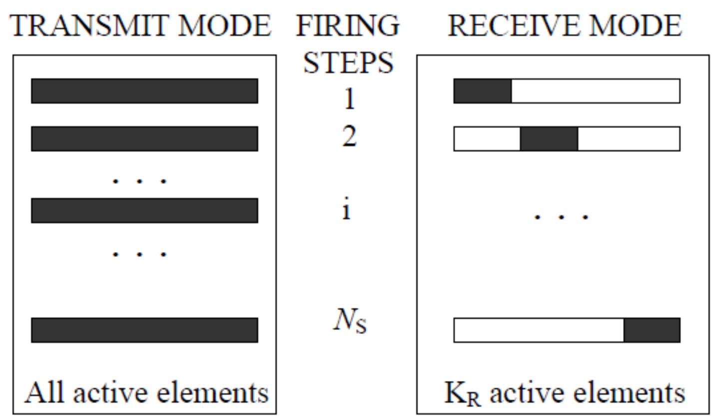
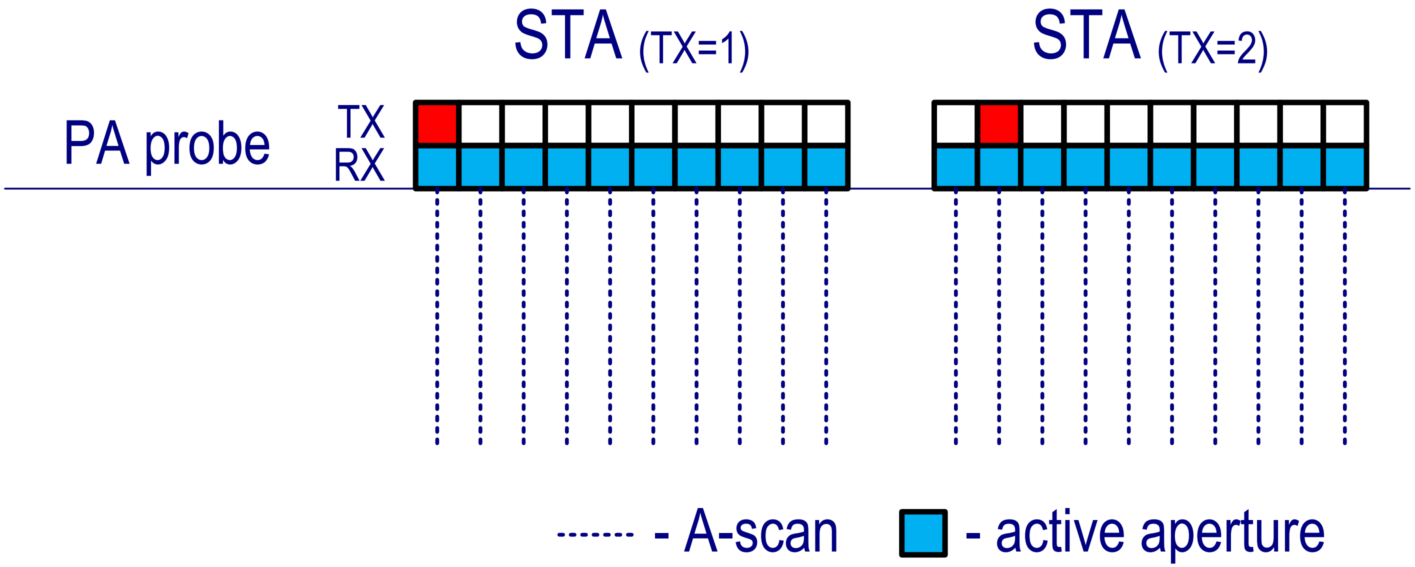


Fig.4: SRA imaging method

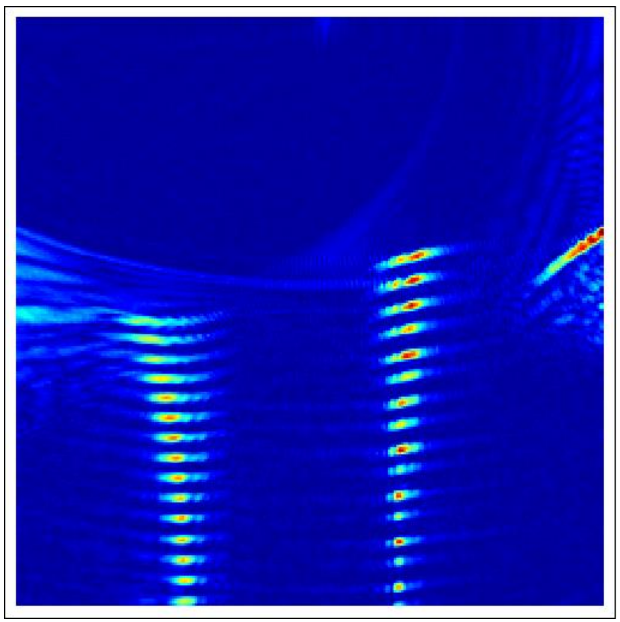
FMC – Full Matrix Capture



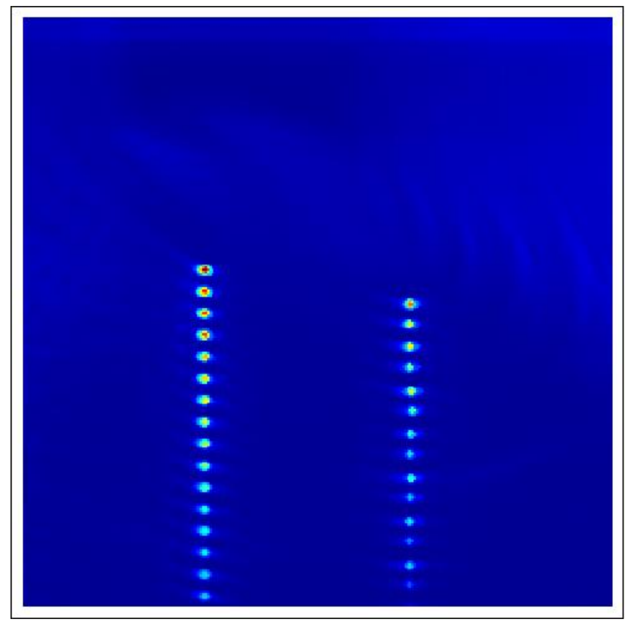
We acquire signals from ALL elements
– a lot of data!!!

STA – Synthetic Transmit Aperture

Image reconstruction of a wire phantom.
STA method with 128 elements TX/RX.

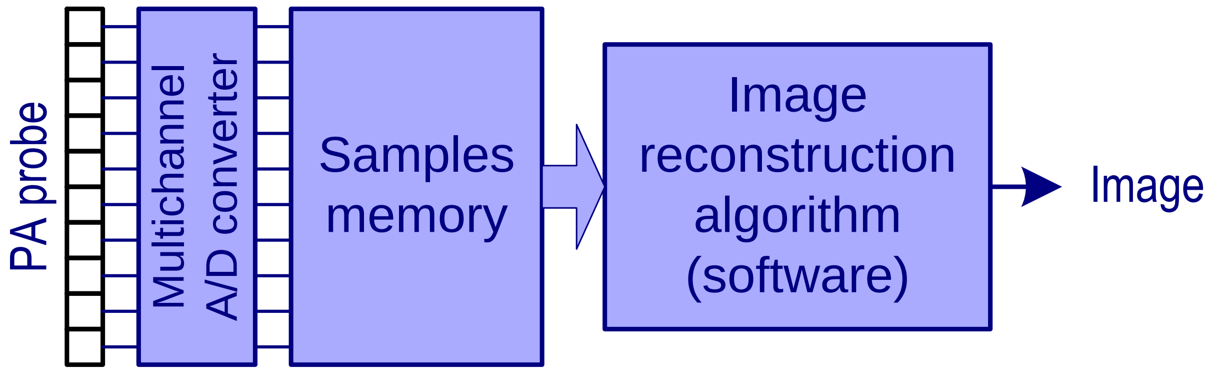


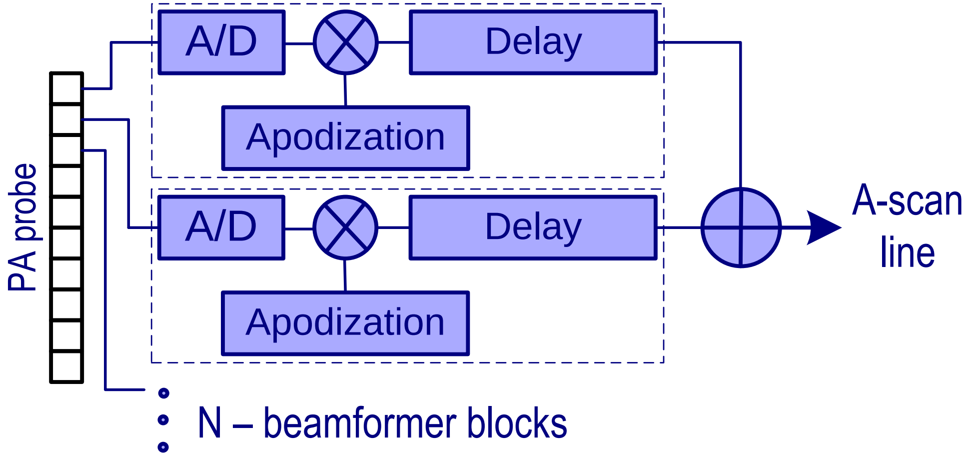
LRI – Low resolution image



HRI – High resolution image

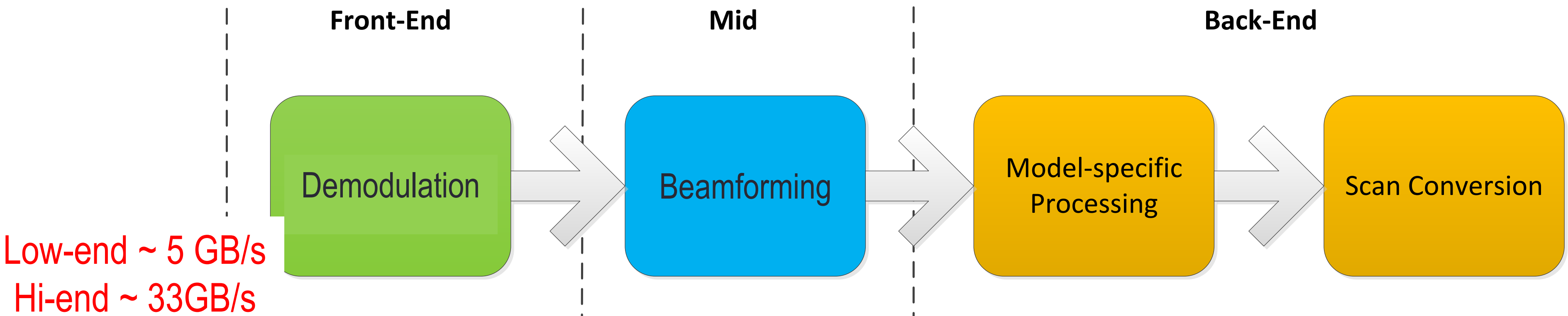
Processing in: Beamforming and FMC



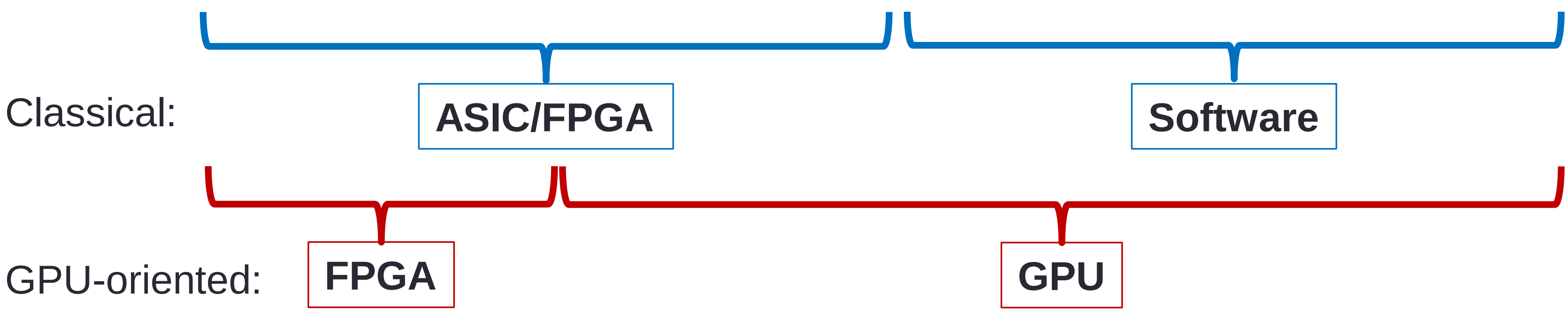


UNIFIED STREAMING AND PROCESSING ARCHITECTURE

Ultrasound processing flow



	Front-End	Mid	Back-End
Data transfer	High	Middle	Low
Computation	High	Middle	High



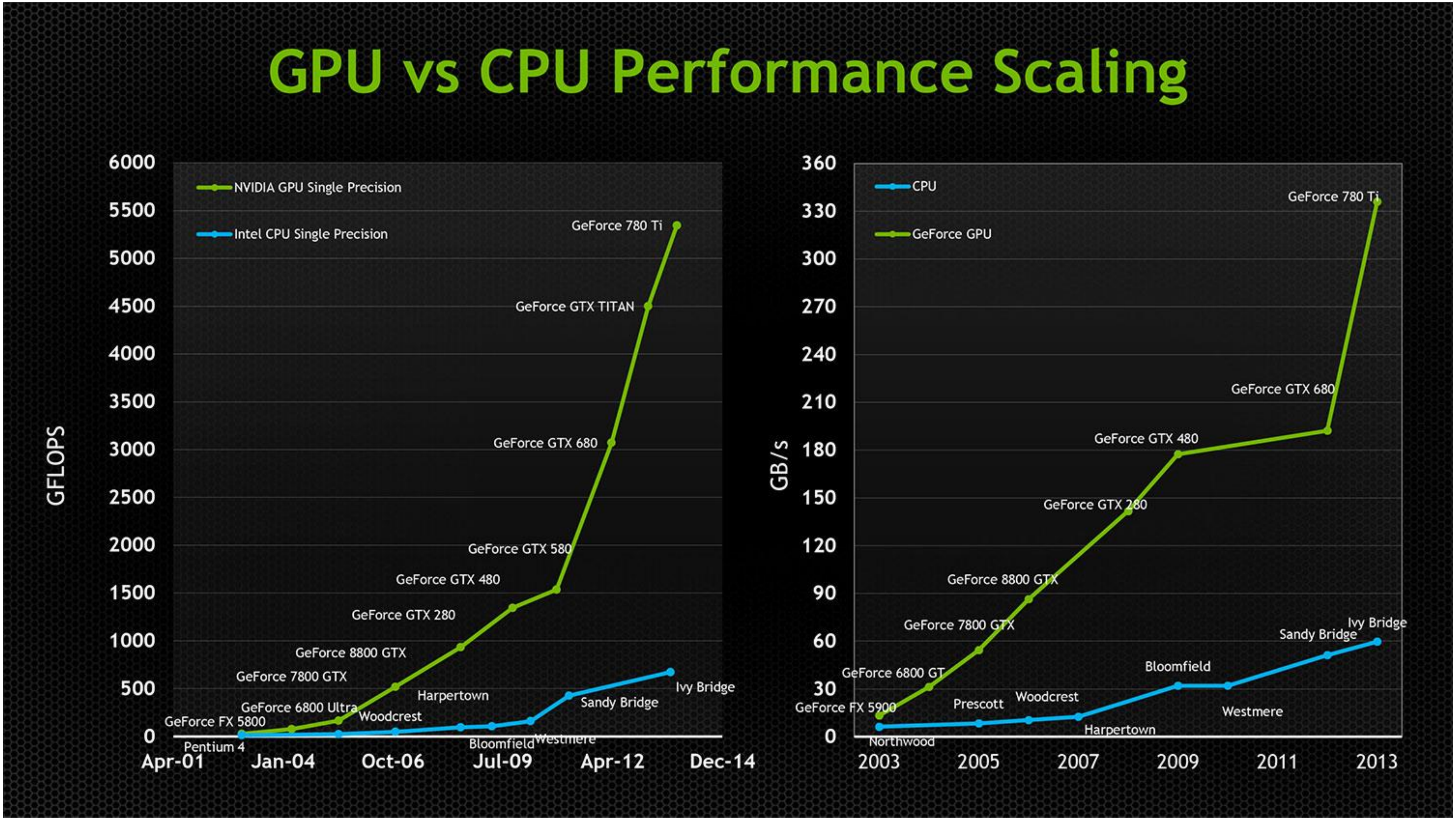
Data bandwidth for 1 channel is ~100MB/s
systems have 64-256 channels

Ultrasound data and processing

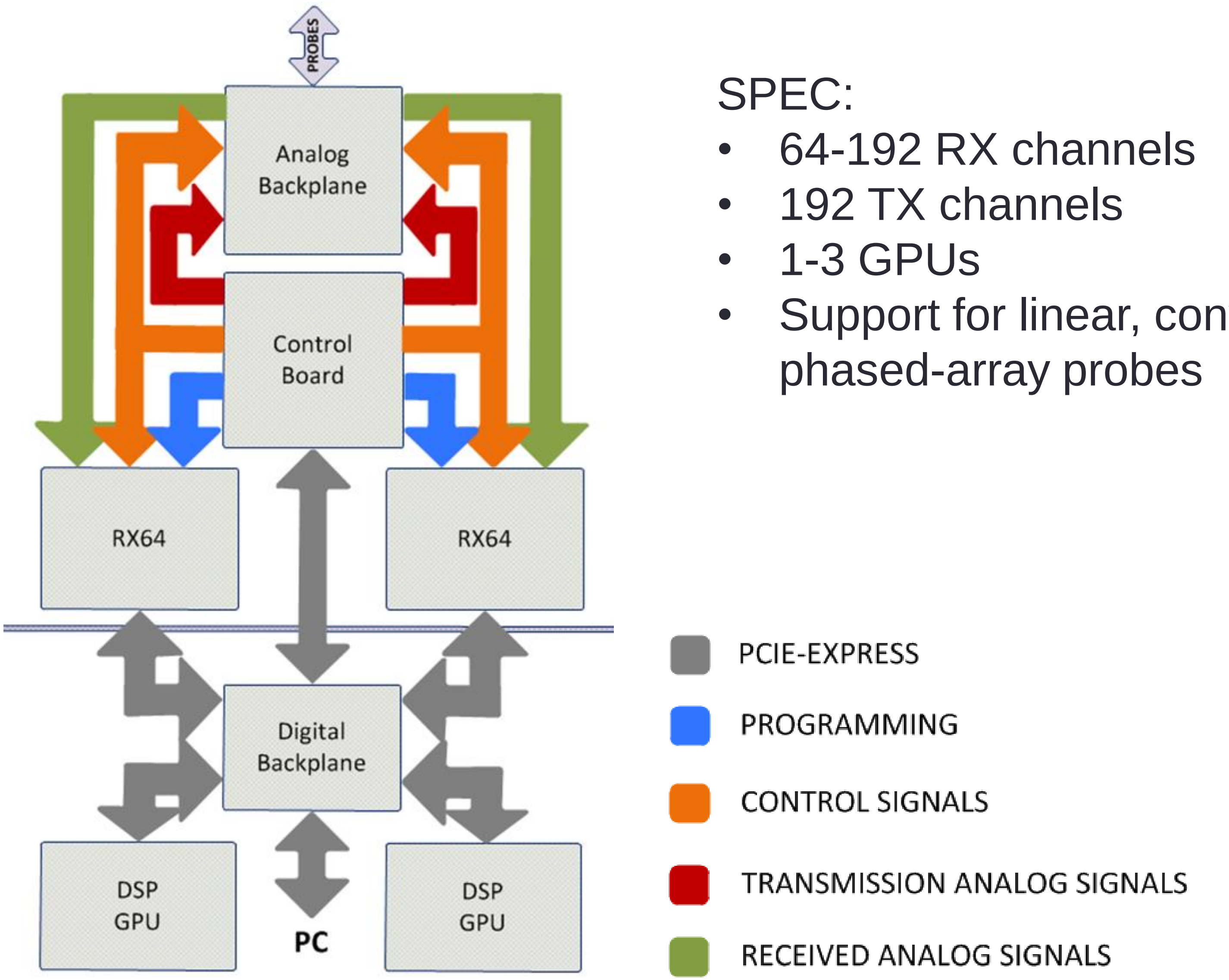
- Ultrasound beamforming algorithms are implemented in hardware, thus:
  - the input data is processed and reduced (not stored),
  - helping to limit data bandwidth to manageable limits.

- PROBLEMS:
  - no direct access to raw RF data,
  - hardware implementation limits what you can do
    - works for one-pass algorithms, troublesome for more advanced multi-pass/adaptive processing

Rationale – GPU exponential performance growth



A Versatile Ultrasound Platform



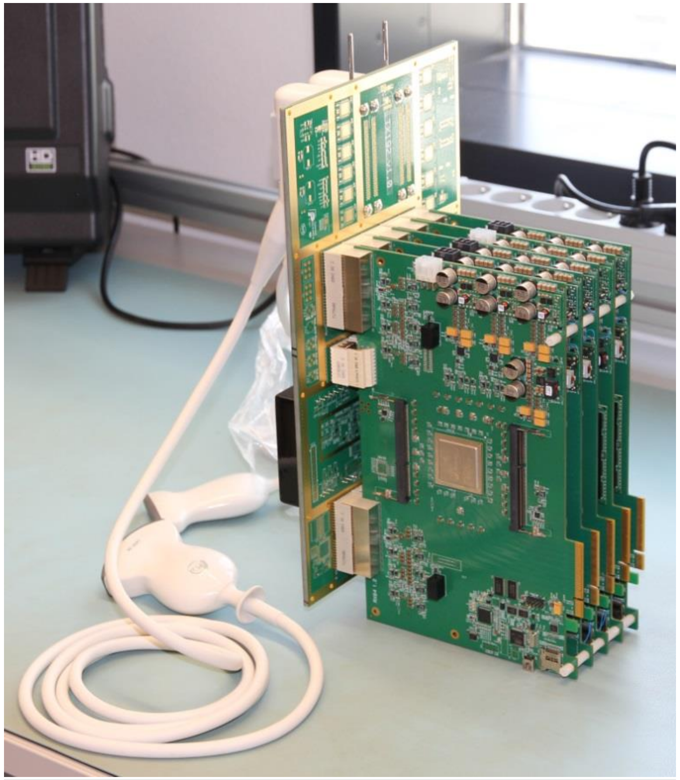
SPEC:

- 64-192 RX channels
- 192 TX channels
- 1-3 GPUs
- Support for linear, convex and phased-array probes

A Versatile Ultrasound Platform

FEATURES:

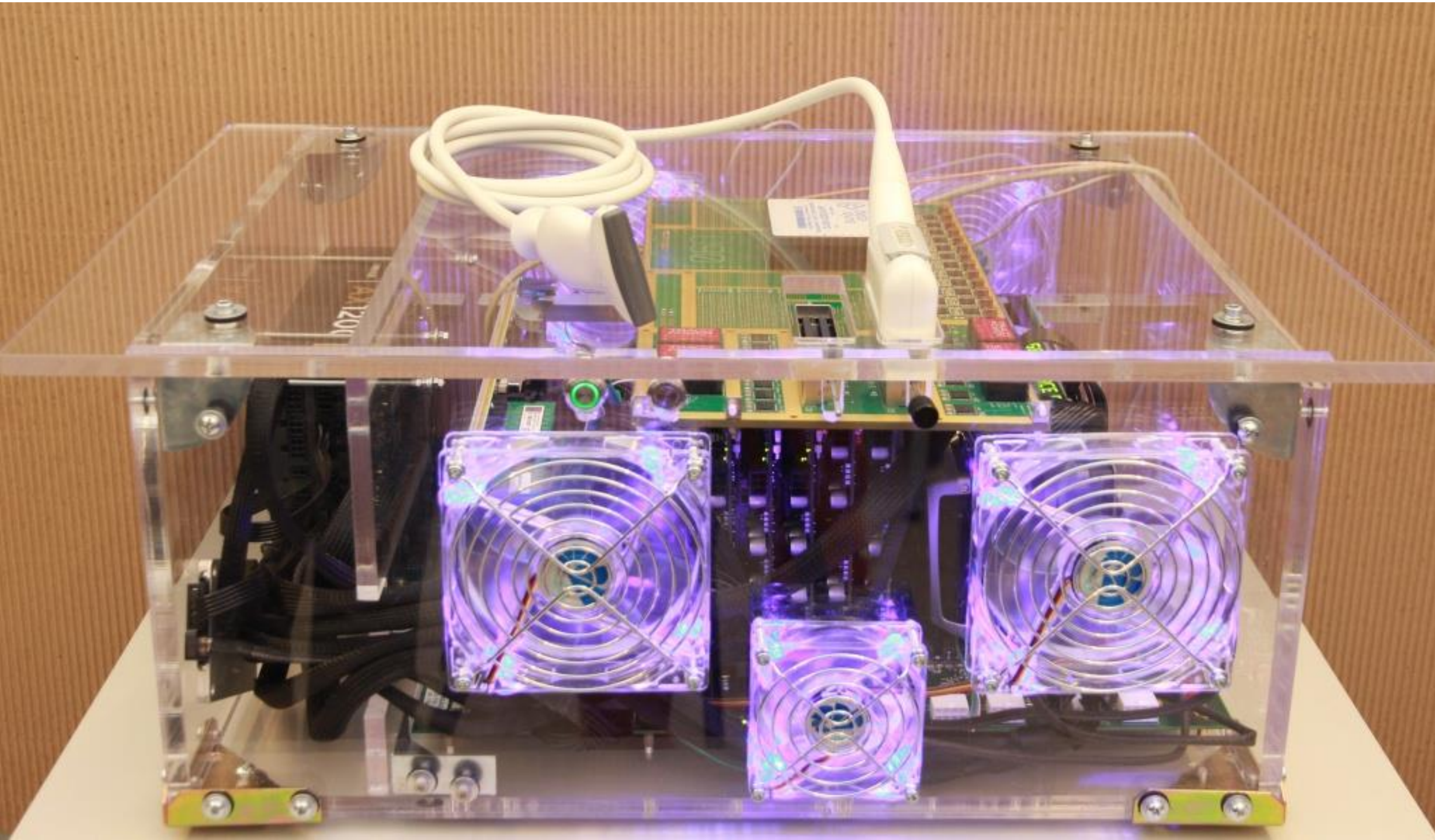
- Fully programmable 64-192 channels
- High-speed communication and processing architecture
- Advanced real-time processing on GPUs
- Software frameworks for Python/Matlab integrated with CUDA/OpenCL
- Implemented classical and novel imaging methods (beamforming, synthetic aperture)



APPLICATIONS:

- Ultrasound R&D labs
- Medical and Non-destructive testing applications
- Test & Measurement equipment

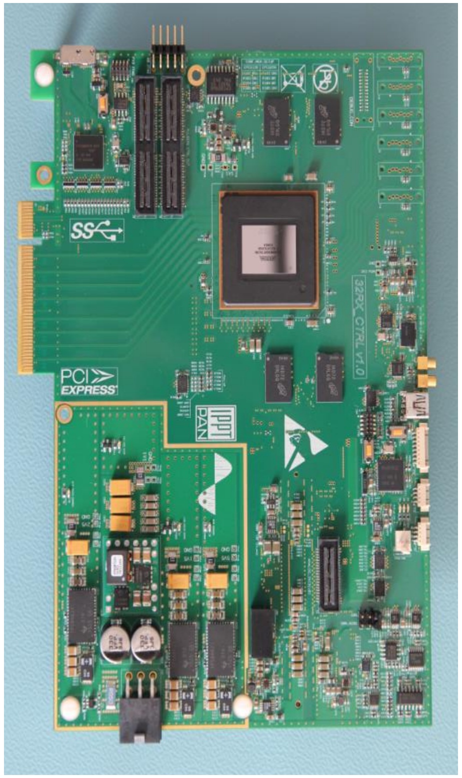
The Platform



A low-cost Portable Ultrasound Platform

FEATURES:

- Fully programmable 32 channels
- High-speed communication and processing architecture
- Advanced real-time processing on the embedded GPU
- Full access to raw RF echo data – enabling the implementation of any imaging algorithms
- A low-cost, low-power solution optimized for portable applications



APPLICATIONS:

- Ultrasound R&D labs
- Medical and Non-destructive testing applications

RX-DAQ – a Parallel Acquisition Module for the *Ultrasonix SonixTouch*

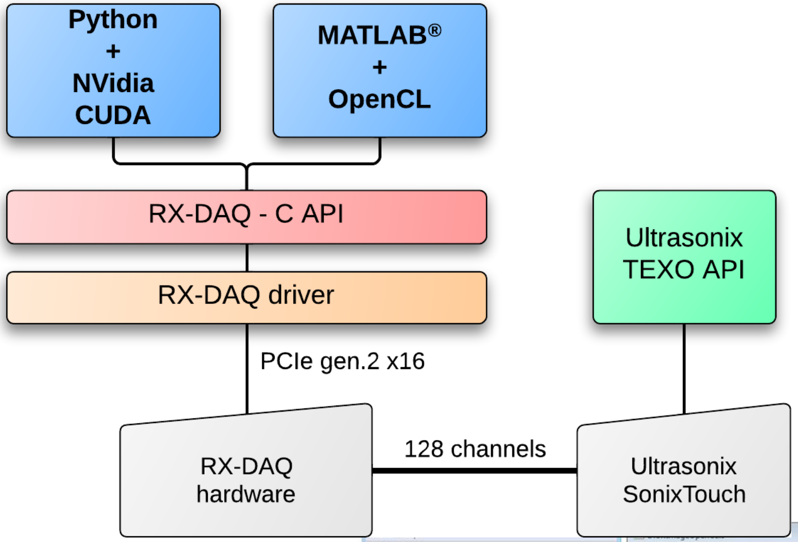
FEATURES:

- 128 channels of parallel acquisition – 12-bit @ 65MHz
- High-speed PCIe x16 data streaming
  - **200x** faster than the original *Sonix DAQ*
- Software for data acquisition and real-time processing
  - Easy integration of custom GPU algorithms

APPLICATIONS:

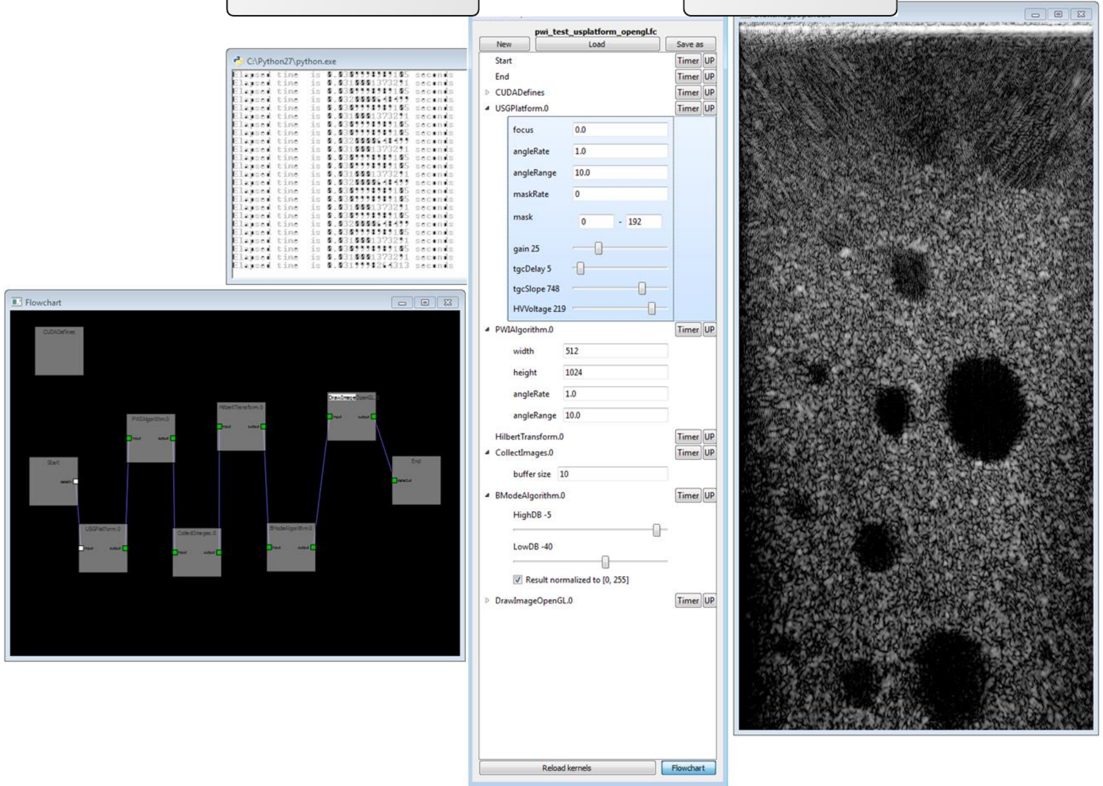
- Ultrasound R&D labs
- Quality control of ultrasound probes
- Test & Measurement equipment

SOFTWARE



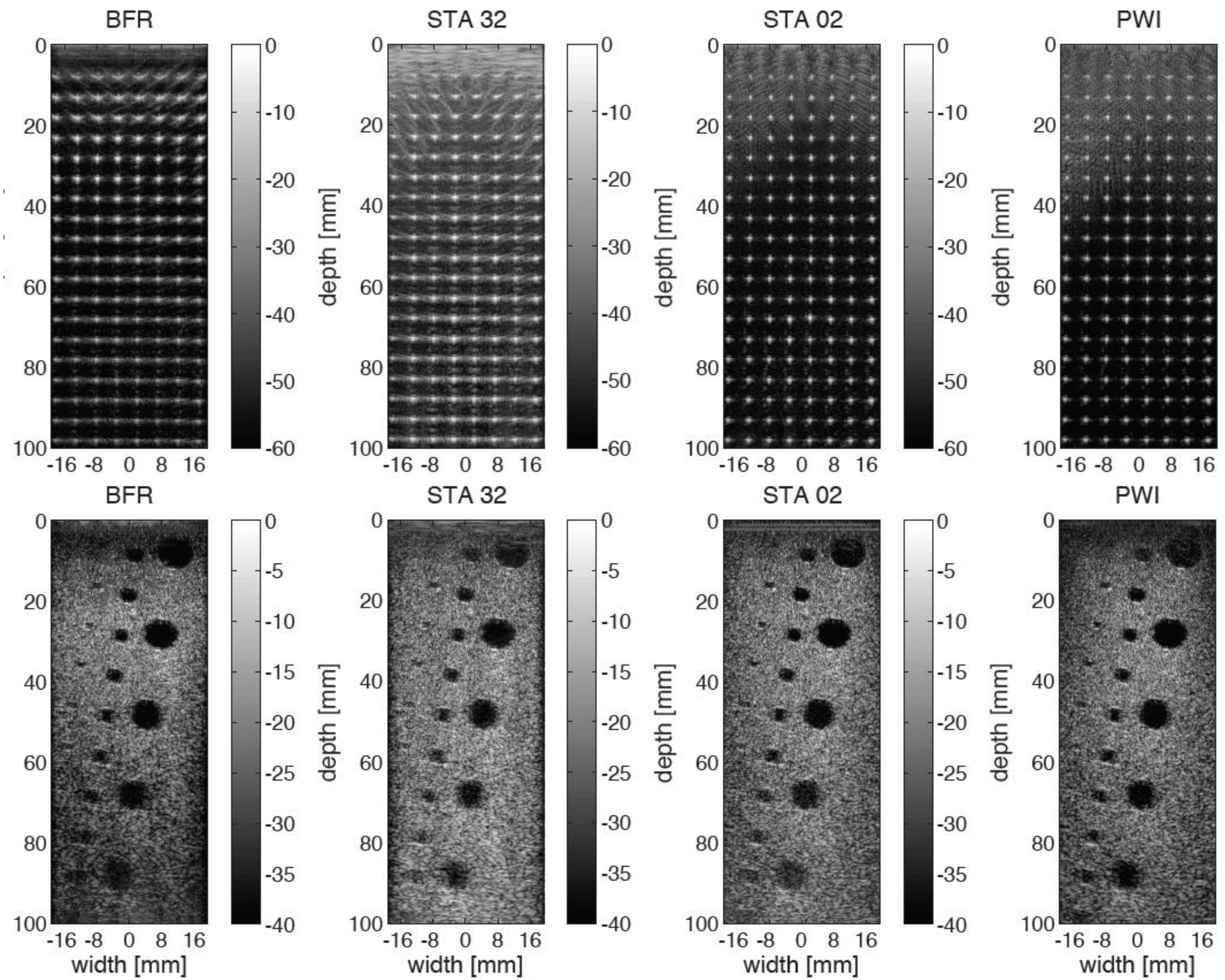
Unified software:

- A low-level API (device control, data acquisition and streaming)
- A high-level API/Framework
  - Python/CUDA
  - Matlab/OpenCL
- Algorithms implemented on GPU:
  - Beamforming
  - SAFT
  - Diverging wave
  - PWI
  - SLSC
  - Doppler methods

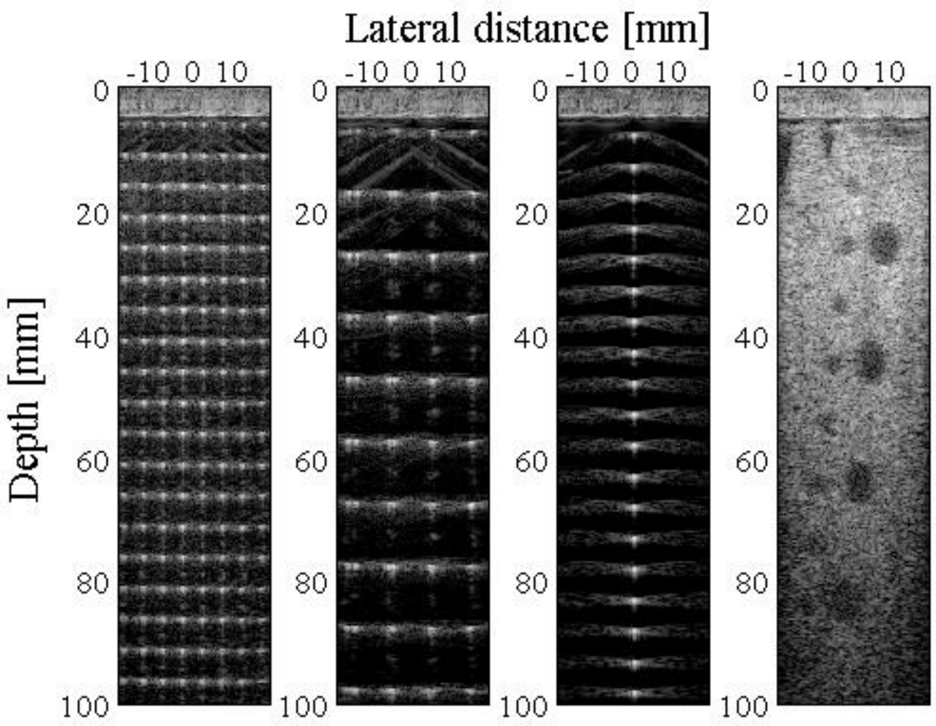


APPLICATIONS

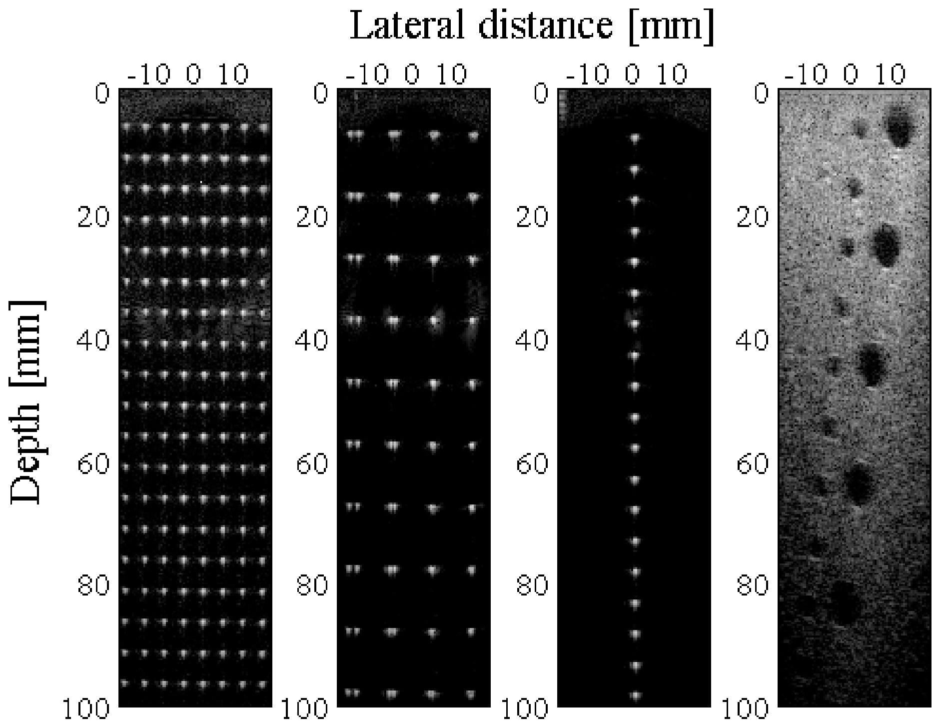
Various US imaging methods and algorithms



Compounded PWI

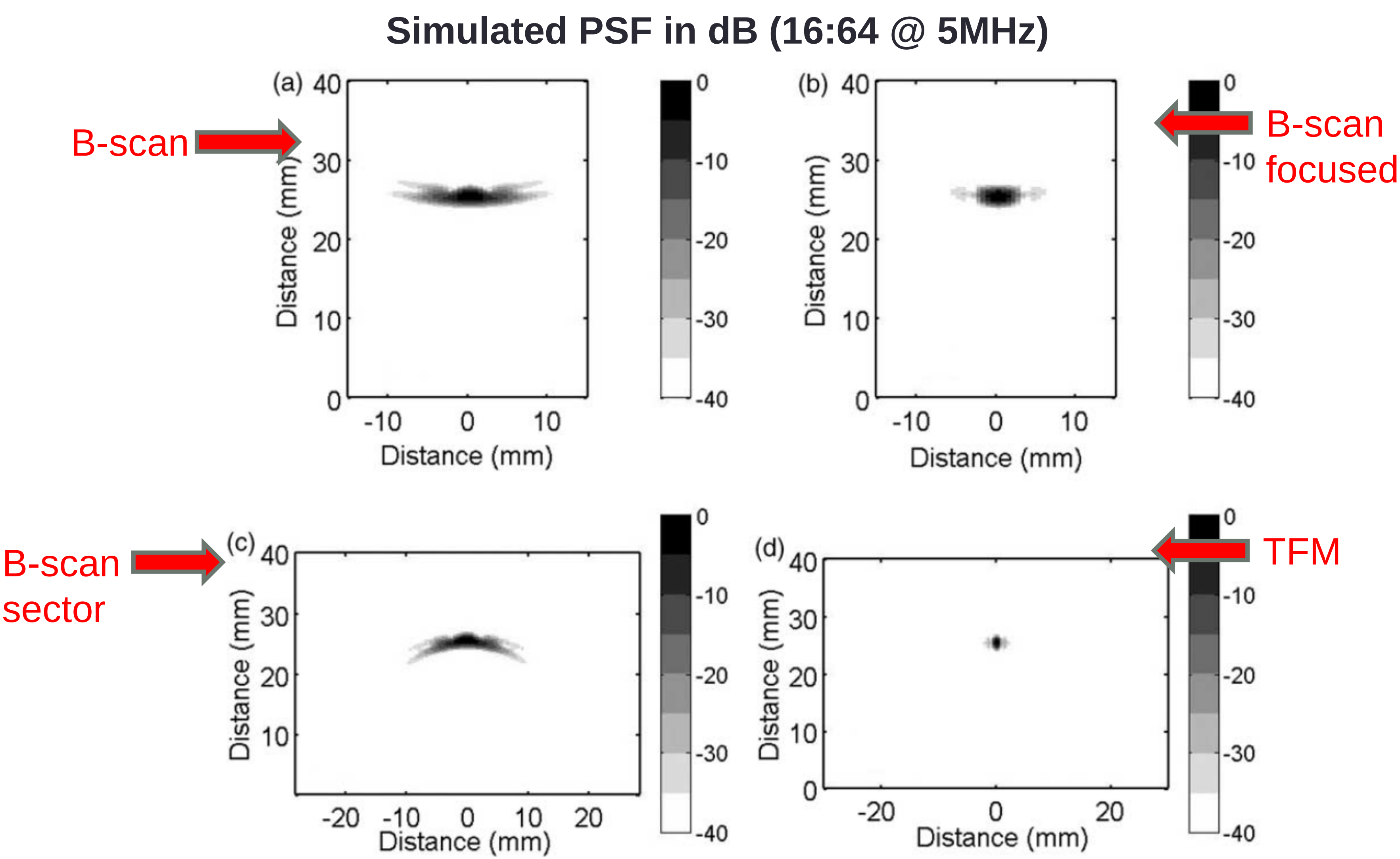


PWI – LR image



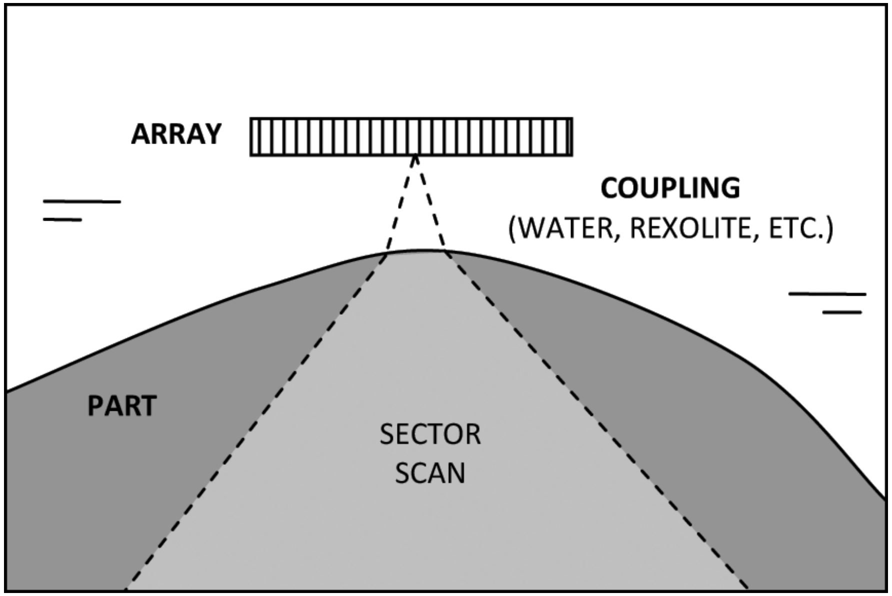
CPWI – HR image
121 emissions, ±30°, step 0.5°

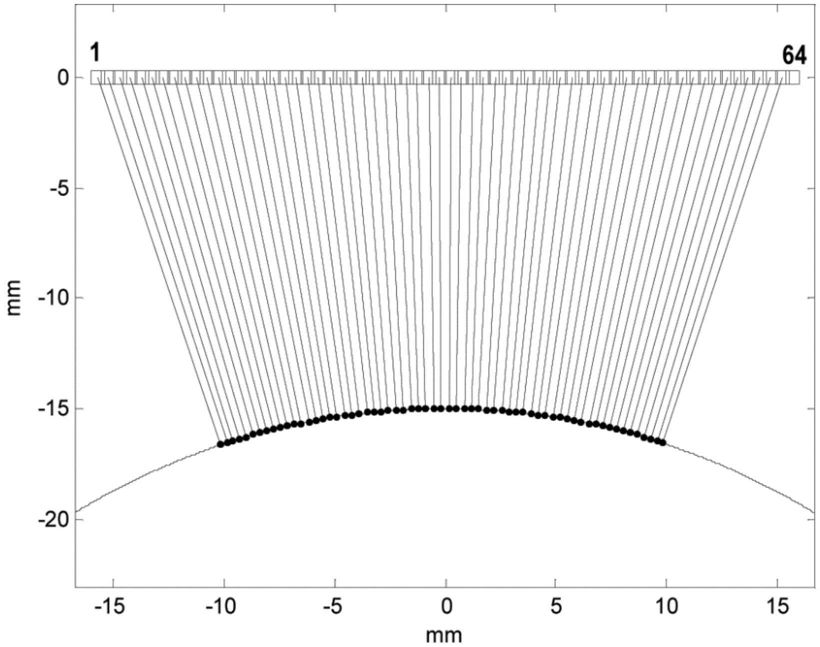
B-scan vs. TFM



Source: C.Holmes, B.W. Drinkwater, P.D. Wilcox, Post-processing of the full matrix of ultrasonic transmit-receive array data for non-destructive evaluation, NDT&E International 38(2005):701–711.

Focusing and imaging in layered media



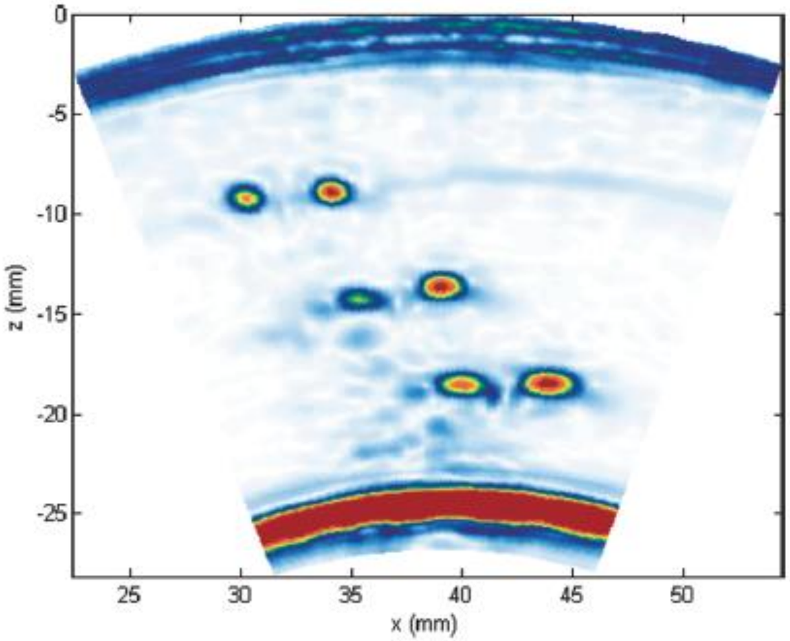


Two media with different speed of sound and non-planar boundary

Detection of media boundary using ultrasound echo method

Source: J. Camacho, J.F. Cruza, J. Brizuela, C. Fritsch, Automatic Dynamic Depth Focusing for NDT, IEEE Trans. Ultrason. Ferroelectr. Freq. Control, 61(4):673-684, 2014,

Focusing and imaging in layered media



Aluminum ring with 3 pairs of SDH

Source: J. Camacho, J.F. Cruza, J. Brizuela, C. Fritsch, Automatic Dynamic Depth Focusing for NDT, IEEE Trans. Ultrason. Ferroelectr. Freq. Control, 61(4):673-684, 2014,

SUMMARY

- We have developed a Versatile Ultrasound Platform featuring:
  - full access to raw RF data
  - real-time streaming and processing on GPUs
  - ready to use Beamforming and SAFT implementation
  - new algorithm implementation using standard CUDA/OpenCL tools
  - applications: medical, NDT/NDE

- New advanced signal processing algorithms (FMC) give new insight in difficult materials and objects

We are open to collaboration and mutual projects!