Exploration of Ultrasound Imaging Techniques

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Ultrasound Imaging

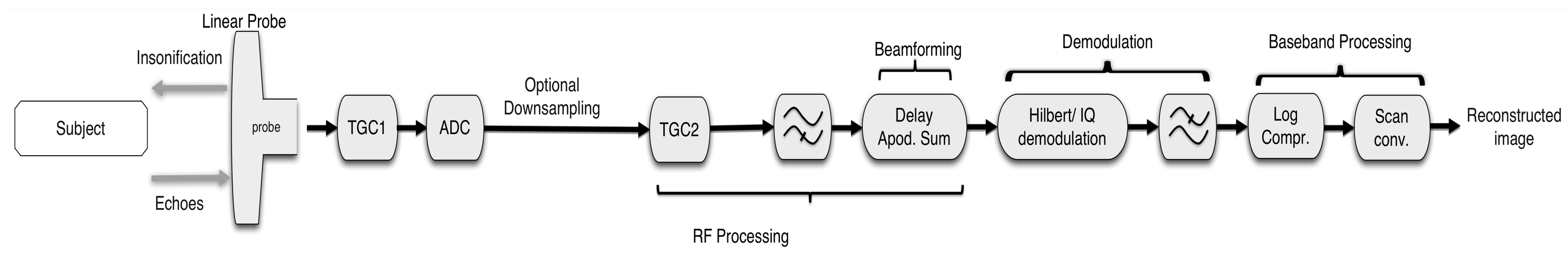
- Ultrasound imaging is one of the most common medical imaging techniques.
- Ultrasound imaging is noninvasive, completely safe compared to X-ray imaging, and it has much lower infrastructural complexity compared to other techniques like Magnetic Resonance Imaging (MRI).
- Ultrasound imaging is based on:
  - Using a probe of vibrating elements that emits short bursts of acoustic waves (frequency range of 1MHz to tens of MHz).
  - After each burst, the probe switches to receive mode and captures echoes reflected by the patient's tissues according to different acoustic impedances (i.e. densities) at the tissue boundaries .
  - Depending on the imaging mode, the received echoes either come with arrival times proportional to the depth of the reflecting scatterers (in imaging stationary objects) or Doppler-shifted in frequency by moving scatterers (in imaging moving scatterers and knowing their speed).
  - The delay, intensity and spatial distribution of the echoes is a function of the patient's body structure at different depths.

Conventional 2D Ultrasound Image

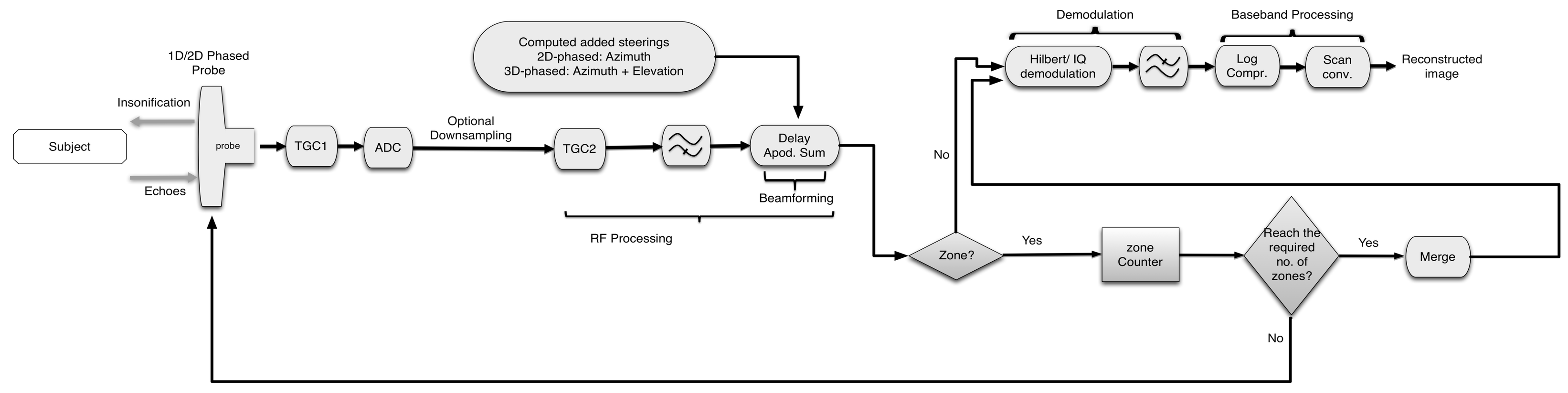
Advanced 3D Ultrasound Imaging

In ultrasound imaging, the echoes received by the probe are converted into electrical signals, amplified, sampled and then processed digitally to reconstruct images

2D linear ultrasound imaging pipeline using 1D linear array transducer



2D/3D phased ultrasound imaging pipeline using 1D/2D phased array transducer



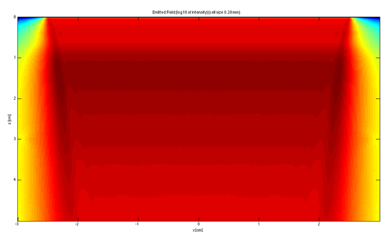
The *UltrasoundToGo* Project

- The ***UltrasoundToGo*** project aims to develop a high-performance, low-power signal processing platform for ultrasound imaging applications. The ideal goal is portable 3D ultrasound imaging.
- **Integrated Systems Laboratory (LSI)** role:
  - An FPGA embodiment of the project is planned.
  - Project development is performed in Matlab as a testing and investigation phase before the implementation and deployment of algorithms on FPGA.

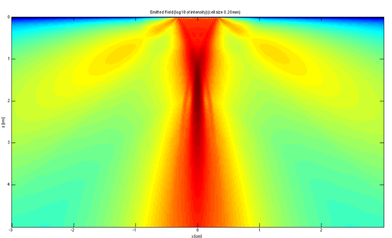
Exploring Image Quality and Computation Cost Alternatives [1]

- This work leverages the Field II simulator [2], running in Matlab.
- Field II is a simulator for ultrasound transducer fields (i.e. emitted field and pulse-echo fields).
- Multiple types of transducers can be defined, including research-oriented models of probes for 3D imaging that are otherwise too expensive to acquire or unavailable for research.
- Arbitrary synthetic phantoms can be defined for testing that allows for objective comparisons between the reconstructed image and the ideal one, yielding beamforming quality metrics.

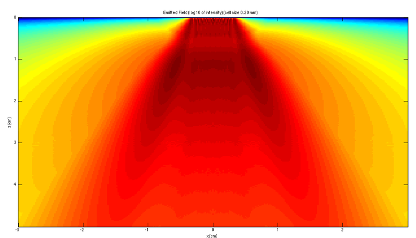
Different Transmit Focus



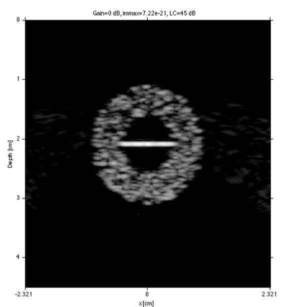
96-element linear array (plane wave)

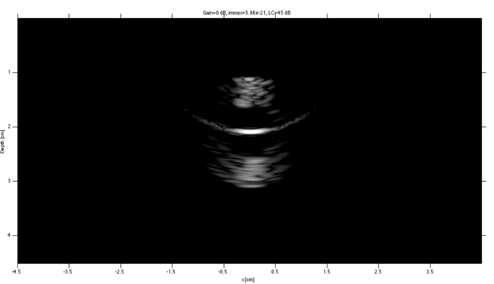


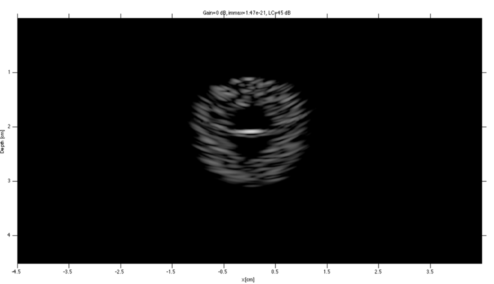
32-element phased array (converging wave)



32-element phased array (diverging wave)

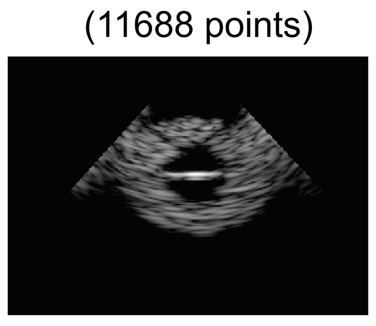






Parameterize the Axial Resolution

Full resolution (11688 points)

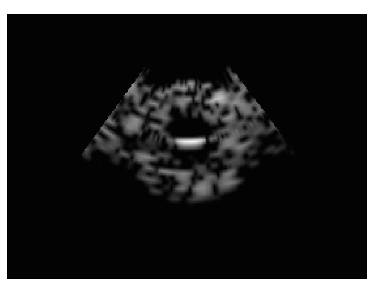


Matlab runtime: ~ an hour

500 points

~ 15 mins

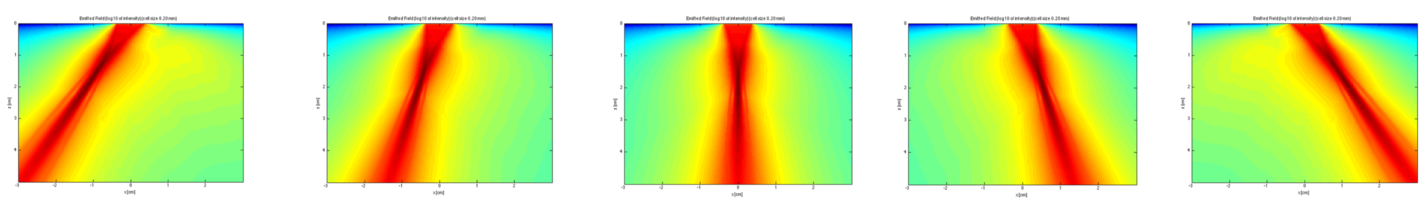
50 points



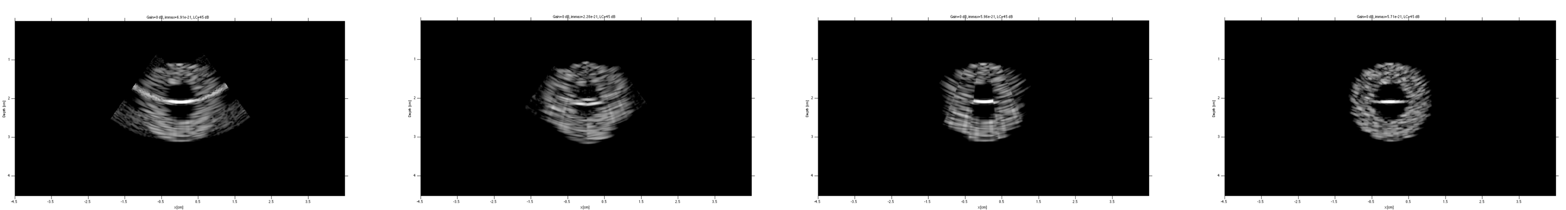
~ 13 mins

Zone Imaging with Different Number of Zones

- Zone sonography divides the region of interest into zones.
- Each zone is insonified and reconstructed separately.
- Then they are combined to form the whole region of interest.



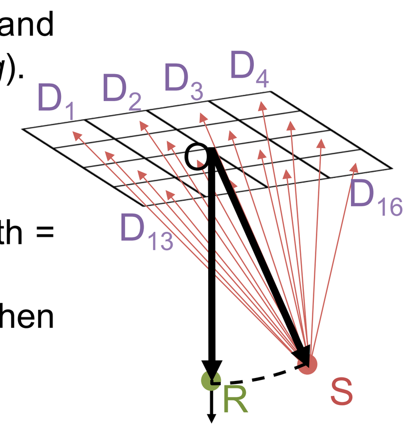
Zone imaging insonifications (5 zones)



Single Zone | Two Zones | Five Zones | 50 Zones

Bottleneck of Delay Tables in 3D Ultrasound Imaging [3]

- Objective:
  - Full 3D beamforming with 100×100 channels.
  - Accurate delay values (unlike available commercial and scientific systems that based on *pre-beamforming* or *muxing*).
  - Ideally, single-chip implementation.
  - Feasible memory access or no external memory.
- Our approach of delay calculation is based on the following:
  - Pre-calculate a delay table for points R along axis of azimuth = 0 and elevation =0.
  - Drive delays for any *S* for the *R* at equal distance from *O*, then "steer" the delay.



$R = (0,0,r)$
$D = (x_D, y_D, 0)$
$S = (r\cos\phi\sin\theta,\ r\sin\phi,\ r\cos\phi\cos\theta)$
θ: azimuth; ϕ: elevation

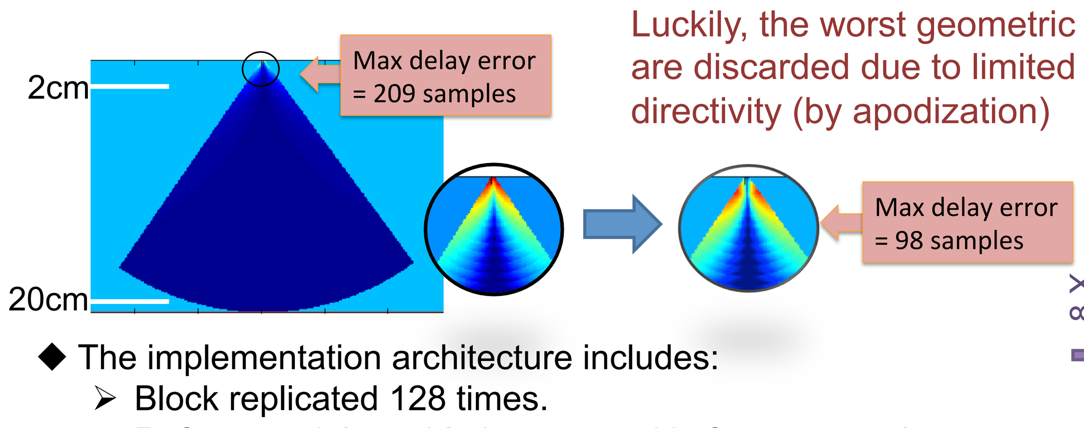
$$t_p(O,S,D) = t_p(O,R,D) + \underbrace{\frac{|\overrightarrow{SD}| - |\overrightarrow{RD}|}{c}}_{\text{1st order Taylor expansion}}$$

$$\boxed{-}\frac{x_D}{c}\cos\varphi\sin\theta\boxed{-}\frac{y_D}{c}\sin\varphi$$

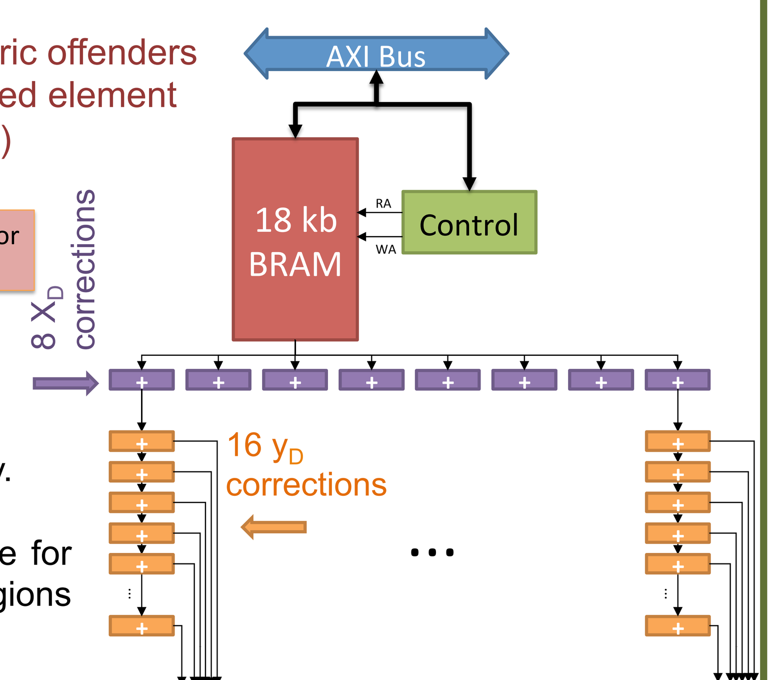
Precalculated

Critical calculation: 2ADDs

- This approximation causes inaccuracy close to the probe, at broad angles *but* excellent in far field and close to the imaging axis.



Luckily, the worst geometric offenders are discarded due to limited element directivity (by apodization)



- The implementation architecture includes:
  - Block replicated 128 times.
  - Reference delay table is streamed in from external memory.
- **Conclusion**: The delay "steering" approach is highly accurate for the whole volume, although there is inaccuracy in small regions (i.e. in edge areas).

	LUTs	Registers	BRAM	Clock	Offchip DRAM BW	Throughput	Frame Rate	Supported channels
Delay Steering 14bit	91%	25%	25%	200 MHz	4.1 GB/s	3.3 Tdelays/s	19.7 fps	100×100
Delay Steering 18bit	100%	30%	25%	200 MHz	5.3 GB/s	3.3 Tdelays/s	19.7 fps	100×100

	Average inaccuracy (|off samples|)	Maximum inaccuracy (|off samples|)
Delay Steering 14bit	1.55	100
Delay Steering 18bit	1.44	100

References

[1] A. Ibrahim, Alena Simalatsar, S. Skalistis, F. Angiolini, P. Thiran, G. De Micheli. "*Assessment of Image Quality vs. Computation Cost for Different Parameterizations for Ultrasound Imaging Pipelines*". Medical Cyber Physical Systems Workshop (CPS workshop 2015), Seattle, Washington, USA, 2015

[2] Field II website, http://field-ii.dk/ .

[3] A. Ibrahim, P. Hager, F. Angiolini, M. Arditi and L. Benini, G. De Micheli. "*Tackling the Bottleneck of Delay Tables in 3D Ultrasound Imaging*". Design, Automation & Test in Europe (DATE 2015), Grenoble, France, 2015